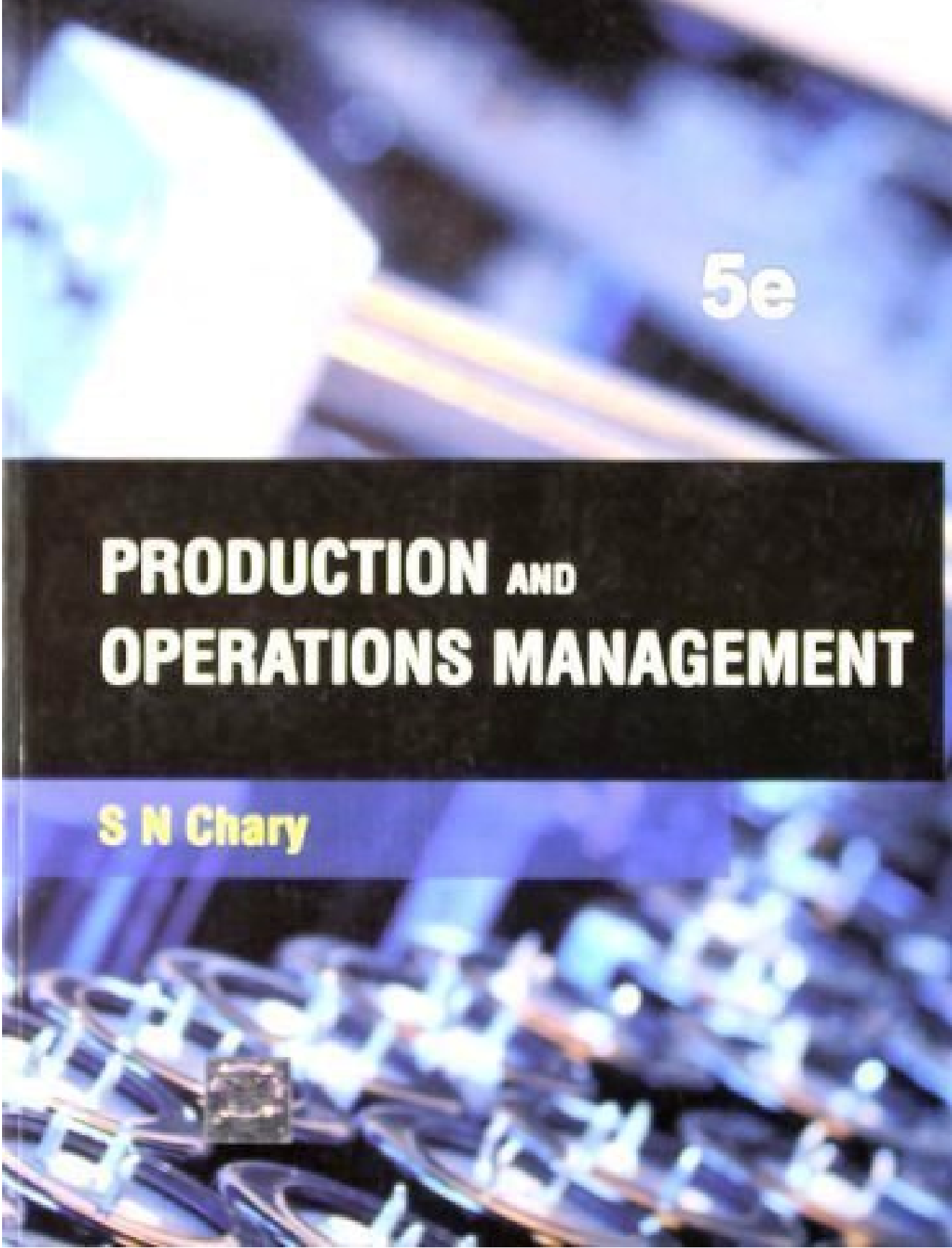

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PRODUCTION AND
OPERATIONS MANAGEMENT
S N Chary

Production and Operations Management

Fifth Edition

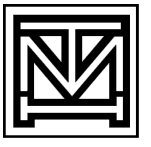
About the Author

S.N. Chary has formerly been a Professor with Indian Institute of Management Bangalore where he taught for over a quarter of a century. A prolific management analyst and thinker, he has written several books, papers and articles. He has been the Director, Kirloskar Institute of Advanced Management Studies, Karnataka and is a well known management and educational consultant. He is working on social change through people empowerment.

Production and Operations Management

Fifth Edition

S N Chary
Former Professor
Indian Institute of Management
Bangalore



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This book
is
dedicated to

Gurudev

Preface

This latest edition incorporates the changes desired by the readers over the past editions, in view of the changing global management culture. This book is primarily addressed to the students studying production and operations management for the first time like those pursuing an MBA, PGDM, MMS or PGDBA programme. The book would, however, be equally useful for a practicing executive.

Production and operations management is a part of the course curricula of a large number of professional engineering and other technical courses. The students of these courses would find this book very useful as a text.

The treatment of the topics and the language in this book has been kept simple to make students easily grasp the concepts. This book is valuable as a primer for undergraduate students such as the BBA or BBM students. This edition has additional solved problems at the end of several relevant chapters to enhance the understanding of the chapter and the various shades of the topic. Each solved problem highlights a significant aspect of the basic concept described in the chapter.

A chapter on 'Lean Operations' has been added since the philosophy underlying 'lean' is going to be the essence of operations and other disciplines of management. 'Lean' is not just about cutting out the flab in the organisation but about the tenet of 'service' to the customer and to the society. That is the direction of the future.

This book has a universal appeal. It contains globally important topics and has numerous examples drawn from India and abroad. Hence, it can certainly be handy for readers across all the continents.

While writing this book I have referred to several papers, articles and books. I take this opportunity to thank the authors and publishers of all the publications I have referred to and some of whom I have quoted in this edition. Likewise, I have provided the examples and case studies from many organisations. I thank all these organisations.

My family Geetha, Sathya, Kartik and Manjula have always been a great source of encouragement. Several thanks to them.

Above all, I thank my Gurudev and the Creator of all to whom this book is dedicated.

S.N. Chary

Preface to the First Edition

In the course of my teaching in the postgraduate programme, I have acutely felt the need for a textbook on production and operations management which does justice to the stipulated curriculum for the basic course in this field. The curricula of the MBA programme offered by the Indian universities are similar in many ways and a similar need would be felt there too. There are very few books on production operations management by Indian authors. The dependence has been, to a large extent, on books by foreign authors written primarily for their curricular requirements and student audience, and based on their work environment.

There are five major reasons why a book tailored to meet the Indian situation is required. First, the basic courses in this discipline in India are more detailed and involve more analysis than those in most American universities. Available foreign books are generally of two kinds: (a) elementary, and (b) very detailed on a special topic. Neither of them are suitable for our teaching purposes.

Second, there are certain topics which are relatively more important in the Indian environment. For instance, project management, incentive schemes, job evaluation, logistics management, regulatory framework, etc. One may find these topics either underplayed or glossed over in the various available foreign books as these pertain to a different economic environment.

Third, there are special Indian topics such as Tandon Committee recommendations or location of facilities. These obviously have to be covered in a book meant for an Indian target audience.

Fourth, there are Indian concerns, such as management of sectors and services, problem of inflation, concern about closing the gap in technology and matching it with the available resources, etc. These have to be reflected upon in the discussions of various topics which may appear universal.

Finally, the book should also appeal to those practising executives who wish to undertake a refresher course in this discipline. The treatment of each topic should, therefore, be practical and simple, yet comprehensive. The book should have sufficient material to offer on individual topics, such as materials management or quality management.

I have made an attempt to fulfil these needs through this book. Readers from other developing countries may also find it useful for the possible reason that we share common concerns and similar objectives. However, the book may have a universal appeal; it may also find interested readership in the developed countries. Perhaps, its comprehensiveness and novel interpretation of the topics could be the attractive features for foreign readers.

This book is my maiden venture. In the course of writing it, I have received much encouragement from my colleagues Prof. Prasanna Chandra, B K Chandrasekhar, Ronald W Haughton, T S Nagabhushana, S Subba Rao, V K Tewari, G K Valecha and Vinod Vyasulu. I express my sincere gratitude to them. My other colleagues, V Vilasini, Anna Robinson and S Murali have helped me by way of secretarial assistance. My thanks are also due to them. In the course of writing this book I have referred to many publications. Wherever possible, I have taken permission and given credits for the sources and I thank them all very much. If some of the sources have been left out inadvertently, I seek their pardon. Any mistakes/errors in the book are, however, fully my responsibility.

I have drawn inspiration from the encouragement of the former Chairman of IIM Bangalore, Mr V Krishnamurthy, now Chairman of Steel Authority of India. My heartfelt thanks to him for writing the Foreword to this book.

Above all, I thank my Gurudev and Creator of all to whom this book is dedicated.

S N Chary

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Role of Production and Operations Management in a Changing Business World

Chapter 1 Production and Operations Management Function
Chapter 2 Operations Strategy
Chapter 3 Services

The last century, particularly the latter half of it, has seen an upsurge in industrial activity. Industries are producing a variety of products. Consumerism has been on a steep rise. People, all over the world, have been demanding more and better products and devices. The developments in technology, particularly in the areas of telecommunications, Internet, mass media and transport have made it possible for products and ideas to travel across the globe with minimal effort. A Chinese girl sitting in Shanghai can see on the television what girls of her age wear in distant USA or Europe. A housewife from Delhi, while visiting her son in San Jose in the Silicon Valley, is able to check out on the interiors and furniture available in that part of the world. A middle class newly married couple from Bangalore thinks of Malaysia or Mauritius as a honeymoon destination. The world has shrunk. Despite the political boundaries, nations are getting closer in trade and commerce. Products are aplenty. A variety of devices are available Communications are quicker. Consumers are the kings.

It is obvious that a lot is being demanded of the production and operations management function. The responsibility of that function is to see that the required products and devices are of a good quality, with an acceptable price and delivered at a time and place the customer desires. Quality, productivity (and hence price) and delivery have become the basic minimums that a firm must offer in order to stay

in competition. There is competition amongst firms even at the level of these basic offerings. In order to have differentiation and a unique selling proposition (USP), a firm and its production or operations function have to make continuous efforts. The USP that exists today may be copied by another firm tomorrow, thus nullifying the competitive advantage. New products or variants of products and devices have to be continuously designed, produced and delivered—all profitably. Production/operations function has to very actively support the marketing function. Engineering has to listen to customer needs. Materials and Logistics people have to react swiftly to the needs of the manufacturing system. The human resources (HR) function has to ensure that people within the firm not only have the needed skills but also the essential attitudes. The production operations function has to interact with the HR function on this count. Each function needs to be attuned to the other function within the firm. The modern business world has necessitated a high level of integration within organisations. It is not that integration was not needed earlier and it is needed now. It is not that quality of products was not a concern earlier and it is so only now. The basic roles and requirements remain, but the intensity of application has increased. The role of production and operations—which is central to the industrial organisation—has become much more intense.

In the competition to seek differentiation, manufacturing firms are finding ways of attaching 'service' components to the physical product. Services are no longer 'frills' that some firms offered earlier. Services have become intertwined with the output of the production process. It is the combination that the customer buys today. No manufacturing company is purely into manufacturing. It is also, in part, a service-providing company. Therefore, the special characteristics of services are getting incorporated into the design of the production system. For one, there is a lot more interaction and interfacing of the production function with the customers today than it was earlier. Customer, so to say, has come closer to, and sometimes within, the company. This has ramifications for the production function. It is no longer an aloof outfit.

The service sector is increasing at a tremendous rate. For instance, there are more banks in one town now than they were in an entire district earlier. More and more banks from the developed world are doing business in the developing countries. Money is more easily available to the consumers. Hence, more leisure activities are being pursued. The number of hotels is, therefore, increasing rapidly. In the places where there were only government-run hospitals, now there are corporate hospitals and lifestyle clinics providing health care combined with comfort. There are thus primary, secondary and tertiary hospitals. A bank also has several back-office operations. A corporate hospital offering comprehensive 'executive health check-ups' needs to streamline its operations right from the minute a 'customer' arrives at the reception counter to her undergoing a series of medical tests and check-ups to her receiving a complete report and personal advice from the physician. Besides, this series of 'check-up' operations has to be a great 'experience' for the customer. Operations management is being called upon to deliver these varied outputs. Since the services sector is as large as (in some economies it is larger than) the manufacturing sector, managing operations in non-manufacturing businesses has assumed as much significance as managing production in a manufacturing set-up.

The fundamentals of this new production-cum-service economy are the same as the earlier manufacturing dominated economy. However, the orientation has changed. For instance, in a bank the customer is right at the place where the operations are taking place. In a hotel, she gets the various 'utilities'. In a way, she is the input that is being transformed. Same is true of a hospital and an educational institution. Thus, 'customer focus' is built into the system. This attitude is rubbing

into the manufacturing firms too. The criteria for performance of an operations system today strongly emphasise customer satisfaction. Production and operations management is becoming less about machines and materials and more about service to the customer. The focus has shifted. All that is done with regard to the machines and materials, spatial and timing or scheduling decisions is with the customer in view.

This has made a huge difference. It has brought relationships to the fore. Since a customer is now an individual or individual entity, the requirements on the production and operations system tend to be multitudinous (number), multifarious (variety) and multi-temporal (time). The tolerance for mistakes is low for a system that is subjected to several variations in demand. This requires real leadership on the part of the firms so as to align the firm's interests with that of its people inside the firm and with that of its suppliers and others outside who provide inputs into the production and operations system. The joint family concept may have gone from the society today, but it has found a new place in the corporate world. A 'supply chain' is one such manifestation. Outsourcing is increasingly being used to gain maximum advantage from the 'core competence' of other firms in the 'family'. Such relationships could spread over several continents; distance or political boundary is not necessarily a constraint. Production and operations have become globalised. A bank in UK or USA can send its several accounting and other operations to be performed in Mumbai by an India-based firm—just as an auto-part producing firm in Chennai provides supplies to an auto manufacturer in Detroit. Long distance business relationships are possible because of the progress in the fields of telecommunication, computers and the Internet. These technologies have made the integration (which means extensive and intensive interconnections) of various business organisations feasible. One may call the present times as the world of inter-relationships.

Due to the inter-relationships, certain things have become easier. For instance, a firm could truly depend on its business associates. Thus the market undulations, i.e., the changing needs of the customers can be met more easily. However, it would behove on the firm to be equally reliable or be better. A relationship comes with its accompanying responsibilities. The modern day production and operations management is expected to provide that kind of leadership.

If 'efficiency' was the all important factor yesterday, and if today 'service' and 'relationships' are the buzz words of production and operations management, what will be in store for tomorrow? The concept of a 'product' has changed over the past few decades to include 'service' in it Environmental and larger social concerns are getting to increasingly occupy the decision space of the management. The production and operations function will remain in the future, even in a 'post-industrial' society. Utilities—of form, state, possession and place—have to be provided and operations cannot be wished away. What may perhaps change would be the nature of the product and the service.

1 Production and Operations Management Function

DEFINITION

Production and operations management concerns itself with the conversion of inputs into outputs, using physical resources, so as to provide the desired utility/utilities—of form, place, possession or state or a combination thereof—to the customer while meeting the other organisational objectives of effectiveness, efficiency and adaptability. It distinguishes itself from the other functions such as personnel, marketing, etc. by its primary concern for 'conversion by using physical resources'. Of course, there may be and would be a number of situations in either marketing or personnel or other functions which can be classified or sub-classified under production and operations management. For example, **(i)** the physical distribution of items to the customers, **(ii)** the arrangement of collection of marketing information, **(iii)** the actual selection and recruitment process, **(iv)** the paper flow and conversion of the accounting information in an accounts office, **(v)** the paper flow and conversion of data into information usable by the judge in a court of law, etc. can all be put under the banner of production and operations management. The 'conversion' here is subtle, unlike manufacturing which is obvious. While in case (i) and (ii) it is the conversion of 'place' and 'possession' characteristics of the product, in (iv) and (v) it is the conversion of the 'state' characteristics. And this 'conversion' is effected by using physical resources. This is not to deny the use of other resources such as 'information' in production and operations management. The input and/or output could also be non-physical such as 'information', but the conversion process uses physical resources in addition to other non-physical resources. The management of the use of physical resources for the conversion process is what distinguishes production and operations management from other functional disciplines. Table 1.1 illustrates the many facets of the production and operations management function.

Often, production and operations management systems are described as providing physical goods or services. Perhaps, a sharper distinction such as the four customer utilities and physical/non-physical nature of inputs and/or outputs would be more appropriate. When we say that the Central Government Health Service provides 'service' and the Indian Railways provide 'service', these are two entirely different classes of utilities, therefore criteria for reference will have to be entirely different for these two cases. To take another example the postal service and the telephones

Table 1.1 Production and Operations Management—Some Cases

	Case	*Input*	*Physical Resource/s Used*	*Output*	*Type of Input/ Output*	*Type of Utility Provided to the Customers*
1.	Inorganic chemicals production	Ores	Chemical plant and equipment, other chemicals, use of labour, etc.	Inorganic chemical	Physical input and physical output	Form
2.	Outpatient ward of a general hospital	Unhealthy patients	Doctors, nurses, other staff, equipment, other facilities	Healthier patients	Physical input and physical output	State
3.	Educational institution	'Raw' minds	Teachers, books, teaching aids, etc.	'Enlightened' minds	Physical (?) input and physical (?) output	State
4.	Sales office	Data from market	Personnel, office equipment and facilities, etc.	Processed 'information'	Non-physical input and non-physical output	State
5.	Petrol pump	Petrol (in possession of the petrol pump owner)	Operators, err- and boys, equipment, etc	Petrol (in possession of the car owner)	Physical input and physical output	Possession
6.	Taxi service	Customer (at railway station)	Driver, taxi itself petrol	Customer (at his residence)	Physical input and physical output	Place
7.	Astrologer/ palmist	Customer (mind full of questions)	Astrologer, Panchanga, other books, etc.	Customer (mind with less questions) (hopefully)	Physical input and physical output	State
8.	Maintenance workshop	Equipment gone 'bad'	Mechanics, Engineers, repairs equipment, etc.	'Good' Equipment	Physical input and physical output	State and form
9.	Income tax office	'Information'	Officers and other staff, office facility	Raid	Non-physical input and physical output	State (possession?)

service are different because the major inputs and major outputs are totally different with different criteria for their efficiency and effectiveness.

Also, a clear demarcation is not always possible between operations systems that provide 'physical goods' and those that provide 'service', as an activity deemed to be providing 'physical

goods' may also be providing 'service', and vice versa. For example, one might say that 'the food in the Southern Railways is quite good' however, food is not the main business of the Railways. To take another example: A manufacturing firm can provide good 'service' by delivering goods on time. Or, XYZ Refrigerator Company not only makes good refrigerators, but also provides good 'after sales service'. The concepts of 'physical goods production' and 'service provision' are not mutually exclusive; in fact, in most cases these are mixed, one being more predominant than the other.

Similarly we may also say that the actual production and operations management systems are quite complex involving multiple utilities to be provided to the customer, with a mix of physical and non-physical inputs and outputs and perhaps with a multiplicity of customers. Today, our 'customers' need not only be outsiders but also our own 'inside staff'. In spite of these variations in **(i)** input type **(ii)** output type, **(iii)** customers serviced, and **(iv)** type of utility provided to the customers, production and operations management distinguishes itself in terms of 'conversion effected by the use of physical resources such as men, materials, and machinery.'

CRITERIA OF PERFORMANCE FOR THE PRODUCTION AND OPERATIONS MANAGEMENT SYSTEM

Three objectives or criteria of performance of the production and operations management system are

(a) Customer satisfaction.
(b) Effectiveness
(c) Efficiency

The case for 'efficiency' or 'productive' utilisation of resources is clear. Whether, the organisation is in the private sector or in the public sector, is a 'manufacturing' or a 'service' organisation, or a 'profit-making' or a 'non-profit' organisation, the productive or optimal utilisation of resource inputs is always a desired objective. However, effectiveness has more dimensions to it. It involves an optimality in the fulfillment of multiple objectives, with a possible prioritisation within the objectives. This is not difficult to imagine because modern production and operations management has to serve the so-called target customers, the people working within, as also the region, country or society at large. In order to survive, the production/operations management system, has not only to be 'profitable' and/or 'efficient', but, must necessarily satisfy many more 'customers'. This effectiveness has to be again viewed in terms of the short- and long-time horizons (depending upon the operations system's need to remain active for short or long time horizons)—because, what may seem now like an 'effective' solution may not be 'all that effective in the future'. In fact, the effectiveness of the operations system may depend not only upon a multi-objectives satisfaction but also on its flexibility or adaptability to changed situations in the future so that it continues to fulfil the desirable objectives set while maintaining optimal efficiency.

JOBS/DECISIONS OF PRODUCTION/OPERATIONS MANAGEMENT

Typically, what are the different decisions taken in production and operations management? As a discipline of 'management' which involves basically planning, implementation, monitoring, and control, some of the jobs/decisions involved in the production and operations management function are as mentioned in Table 1.2.

Table 1.2 Jobs of Production and Operations Management

Long Time Horizon	*Intermediate Time Horizon*	*Short Time Horizon*
• Product design • Quality policy • Technology to be employed • Process selection • Site selection • Machinery and plant / facility selection • Plant / facility size selection—phased addition • Manpower training and development—phased programme • Long-gestation period raw material supply projects—phased development • Warehousing arrangements • Insurance spares • Design of jobs • Setting up work standards • Effluent and waste disposal systems • Safety and maintenance systems • Supply chain and outsourcing	• Product variations • Methods selection • Quality implementation, inspection and control methods • Machinery and plant facility loading decisions • Forecasting • Output per unit period decision • Deployment of manpower • Overtime decisions • Shift-working decisions • Temporary hiring or lay-off of manpower • Purchasing policy • Purchasing source selection, development and evaluation • Make or buy decision • Inventory policy for raw material, work-in-progress, and finished goods • Transport and delivery arrangements • Preventive maintenance scheduling • Implementation of safety decisions • Industrial relations • Checking/setting up work standards and incentive rates	• Production/operations scheduling • Available materials allocation and handling • Scheduling of manpower • Breakdown maintenance • Progress check and change in priorities in production / operations scheduling • Temporary manpower • Supervision and immediate attention to problem areas in labour, materials, machines, etc.

CLASSIFICATION OF DECISION AREAS

The production and operations management function can be broadly divided into the following four areas:

1. Technology selection and management
2. Capacity management
3. Scheduling/Timing/Time allocation
4. System maintenance

Technology Selection and Management

This is primarily an aspect pertaining to the long-term decision with some spillover into the intermediate region. Although it is not immediately connected with the day-to-day short-term decisions handled in the facility plant, it is an important problem to be addressed particularly in a manufacturing situation in an age of spectacular technological advances, so that an appropriate choice is made by a particular organisation to suit its objectives, organisational preparedness and its micro-economic perspectives. It is a decision that will have a significant bearing on the management of manpower, machinery, and materials capacity of the operations system and System maintenance acreas. Some or similar product/service can be produced with a different process/technology selection. For instance, sight seings for tourists can be arranged by bus mono-rail or or cable car. To give an example from the manufacturing industry the technology in a foundry could be manual or automated.

Capacity Management

The capacity management aspect once framed in a long-term perspective, revolves around matching of available capacity to demand or making certain capacity available to meet the demand variation. This is done on both the intermediate and short time horizons. Capacity management is very important for achieving the organisational objectives of efficiency, customer service and overall effectiveness. While lower than needed capacity results in non-fulfillment of some of the customer services and other objectives of the production/operations system, a higher than necessary capacity results in lowered utilisation of the resources. There could be a 'flexibility' built into the capacity availability, but this depends upon the 'technology' decision to some extent and also on the nature of the production/operations system. While some operations systems can 'flex' significantly, some have to use inventories of material's and /or people as the flexible joint between the rigidities of a system. The degree of flexibility required depends upon the customers demand fluctuations and thus the demand characteristics of the operations system. Figure 1.1 illustrates the size, and variability of demand and the corresponding suitable operating system structure. While figure 1.1 is easy to understand in a manufacturing context, it is also applicable to service operations.

As the product variety increases, the systems of production/operations change. In a system characterised by large volume-low variety, one can have capacities of machinery and men which are inflexible while taking advantage of the repetitive nature of activities involved in the system; whereas in a high variety (and low volume) demand situation, the need is for a flexible operations system even at some cost to the efficiency. It may be noted that the relationship between the flexibility, capacity and the desired system-type holds good even for the manufacturing and the service industry.

Scheduling

Scheduling is another decision area of operations management which deals with the timing of various activities—time phasing of the filling of the demands or rather, the time phasing of the capacities to meet the demand as it keeps fluctuating. It is evident that as the span of fluctuations

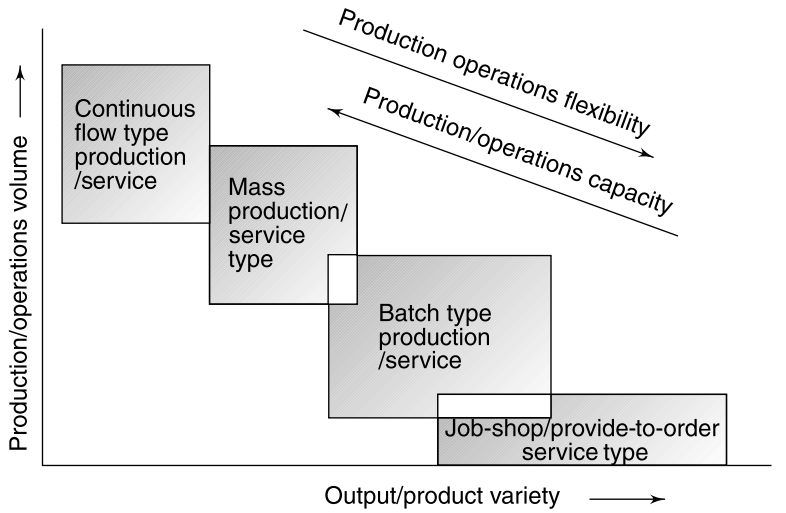


Figure 1.1 Production and Operations Systems

in variety and volume gets wider, the scheduling problem assumes greater importance. Thus, in job-shop (i.e. tailor-made physical output or service) type operations systems, the scheduling decisions are very important which determine the system effectiveness (e.g. customer delivery) as well as the system efficiency (i.e. the productive use of the machinery and labour). Similarly, we can also say that the need for system effectiveness coupled with system efficiencies determine the system structure and the importance of scheduling. When 'time' is viewed by the customers as an important attribute of the output from a production/operations system, then whatever may be the 'needs of variety and flexibility', the need for 'scheduling' is greater and the operations system choice is also accordingly influenced. Thus, when a mass production of output is envisaged, but with a 'quick response' characteristic to the limited mild variation, the conventional mass production assembly line needs be modified to bring in the 'scheduling' element, so that the distinctive time element is not lost in the mass of output. This necessitates significant modifications in the mass-production system and what emerges is a new hybrid system particularly and eminently suited to meet the operations system objectives.

The capacity management and scheduling cannot be viewed in isolation as each affects the other.

System Maintenance

The fourth area of operations management is regarding safeguards—that only desired outputs will be produced in the 'normal' condition of the physical resources, and that the condition will be maintained normal. This is an important area whereby 'vigilance' is maintained so that all the good work of capacity creation, scheduling, etc. is not negated. Technology and / or process selection and management has much to contribute towards this problem. A proper selection and management procedure would give rise to few problems. Further, the checks (e.g. quality checks on physical/non-physical output) on the system performance and the corrective action (e.g. repair of an equipment) would reduce the chances of the dsired outputs being sullied. In a manufacturing industry these may be the physical defects. In service operations, it could be each of confidence of

the customers like the stealing of credit card accounts of customers.

NEW WAYS OF LOOKING AT THE DECISION AREAS

The classification presented earlier has been the traditional classification which is quite valid even in the present times. However, the nature of production and operations management function is changing to an increasing service orientation and therefore it has become necessary to relook at the classification of the decision areas.

Traditionally, the focus of production and operations management discipline has been the product and the process producing the product. Hence its earlier orientation towards technology, capacity, scheduling and system maintenance. The focus has been internal i.e., on the operations of the company. Thus, the traditional view may be termed as having been 'product-centric' or self-centric ('self' meaning company).

Transition from Product-centric to People-centric

However, with the changes in the customers' requirements and with the changes occurring in the social set-up worldwide, the production and operations discipline is placing increasing emphasis on relationships with the people that interact with the firm such as customers, employees and suppliers or business associates. The latter are important for the company to have its supplies of materials and services flowing in as desired. The firm interfaces with its associates while taking these 'supply' decisions.

It is ess ential to maintain the desired quality of the produce from the firm. However, it is being increasingly realised now that the imperatives quality and productivity are intimately related to the human input, i.e., the employees of the company, more than anything else. Therefore, another area of decisions is that of HR decisions. The most important of all the human interactions of a firm is that with its customers. In addition to quality and productivity the customer is interested in the timeliness of the delivery of the desired goods/services. Thus, another area of decisions is that of 'timing'. These decision areas are, thus, focused on people—on 'others' (i.e., other than the company as represented by the capital). There is one more area, that of spatial decisions – decisions regarding the locations and layouts. The former is related predominantly to the 'supply' and 'timing' problems. The latter is related to the 'timing' and 'productivity' issues. Thus the production management decisions may be classified as those pertaining to: People, Supply, Time and Space. This view is reflected in Table 1.3.

Table 1.3 Classification of Production and Operations Management Decisions: People-centric View

Target People	*Decision Type*	*Affected Aspect*
Employees	HR decisions	Quality and productivity; Safety/security
Business associates	Supply decisions	Supplies and capacity
Customers	Timing decisions	Production/operations planning and scheduling; Technology/process
All the above	Spatial decisions	Location of plants/facilities, location of business associates; Layouts

Changes in the Long-term/Short-term Decisions

The recent philosophy is that the technology is subordinate to the customer as customer requirements dictate the technology generation and use. One may note that a distinction needs to be made between scientific research and technology. Capacity of the operations system is related to the technology employed. It is also much dependent upon the business associates who provide capacity in terms of outsourced products, supplies and services. Scheduling, the timing decision, is related to the customer. Technology, capacity and system maintenance are in some ways related to it.

In consonance with this view, Table 1.2 listing the 'jobs of production and operations management' needs to be modified. For instance, it is not the technology which is a long-term decision, but the company's manpower and its suppliers. Product design is better fitted in the intermediate term as the technology and the designs keep changing (or are required to be changed) often enough these days. Plant selection, manpower training and setting up work standards would rather belong to the intermediate term decisions. Outsourcing (not exactly 'make or buy') is a long-term decision as it involves selecting business partners who would be partners for a long time. Such classification based upon the long, intermediate, or short-term bases is useful in knowing the firm's areas or decisions that will have impacts for a long time. It also highlights the needs that have to be attended to now (short-term decisions).

It may be interesting, at this juncture, to trace the history of production and operations management.

BRIEF HISTORY OF THE PRODUCTION AND OPERATIONS MANAGEMENT FUNCTION

At the turn of the 20th century, the economic structure in most of the developed countries of today was fast changing from a feudalistic economy to that of an industrial or capitalistic economy. The nature of the industrial workers was changing and methods of exercising control over the workers, to get the desired output, had also to be changed. This changed economic climate produced the new techniques and concepts.

Individual Efficiency

Fredric W. Taylor studied the simple output-to-time relationship for manual labour such as bricklaying. This formed the precursor of the present day 'time-study'. Around the same time, Frank Gilbreth and his learned wife Lillian Gilbreth examined the motions of the limbs of the workers (such as the hands, legs, eyes, etc.) in performing the jobs, and tried to standardise these motions into certain categories and utilise the classification to arrive at standards for time required to perform a given job. This was the precursor to the present day 'motion study'. Although, to this day Gilbreth's classification of movements is used extensively, there have been various modifications and newer classifications.

Collective Efficiency

So far the focus was on controlling the work-output of the manual labourer or the machine operator. The primary objective of production management was that of efficiency—efficiency

of the individual operator. The aspects of collective efficiency came into being later, expressed through the efforts of scientists such as Gantt who shifted the attention to scheduling of the operations. (Even now, we use the Gantt Charts in operations scheduling.) The considerations of efficiency in the use of materials followed later. It was almost 1930, before a basic inventory model was presented by F.W. Harris.

Quality

After the progress of application of scientific principles to the manufacturing aspects, thought progressed to control over the quality of the finished material itself. Till then, the focus was on the quantitative aspects; later on it shifted to the quality aspects. 'Quality', which is an important customer service objective, came to be recognised for scientific analysis. The analysis of productive systems, therefore, now also included the 'effectiveness' criterion in addition to efficiency. In 1931, Walter Shewart came up with his theory regarding Control Charts for quality or what is known as 'process control'. These charts suggested a simple graphical methodology to monitor the quality characteristics of the output and how to control it. In 1935, H.F. Dodge and H.G. Romig came up with the application of statistical principles to the acceptance and/or rejection of the consignments supplied by the suppliers to exercise control over the quality. This field, which has developed over the years, is now known as 'acceptance sampling'.

Effectiveness as a Function of Internal Climate

In addition to effectiveness for the customer, the concept of effectiveness as a function of internal climate dawned on management scientists through the Hawthorne experiments which actually had the purpose of increasing the efficiency of the individual worker. These experiments showed that worker efficiency went up when the intensity of illumination was gradually increased, and even when it was gradually decreased, the worker efficiency still kept rising. This puzzle could be explained only through the angle of human psychology; the very fact that somebody cared, mattered much to the workers who gave increased output. Till now, it was Taylor's theory of elementalisation of task and thus the specialisation in one task which found much use in Henry Ford's Assembly Line.

Advent of Operations Research Techniques

The birth of Operations Research (OR) during the World War II period saw a big boost in the application of scientific techniques in management. During this war, the Allied Force took the help of statisticians, scientists, engineers, etc. to analyse and answer questions such as: What is the optimum way of mining the harbours of the areas occupied by the Japanese? What should be the optimum size of the fleet of the supply ships, taking into account the costs of loss due to enemy attack and the costs of employing the defence fleet? Such studies about the military operations was termed as OR. After World War II, this field was further investigated and developed by academic institutions. Various techniques such as linear programming, mathematical programming, game theory, queueing theory, and the like developed by people such as George Dantzig, A. Charnes, and W.W. Cooper, have become indispensible tools for management decision-making today.

The Computer Era

After the breakthrough made by OR, another marvel came into being—the computer. Around 1955, IBM developed digital computers. This made possible the complex and repeated computations involved in various OR and other management science techniques. In effect, it helped to spread the use of management science concepts and techniques in all fields of decision making.

Service and Relationships Era

The advances in computing technology, associated software, electronics and communication facilitated the manufacture of a variety of goods and its reach to the consumer. In parallel, the demand for services such as transport, telecommunications and leisure activities also grew at a rapid pace. Worldwide, the service economy became as important as that of physical goods. In fact, manufacturing started emulating some of the practices and principles of services. The far-eastern countries, particularly Japan seemed specialised in providing manufactured products with various services/service elements accompanying it. During the last quarter of a century, service has become an important factor in customer satisfaction. Likewise, many production management principles have been finding their way into services in order to improve the efficiencies and effectiveness.

The very word 'service' signifies some kind of a 'special bond' or 'human touch'. It is, therefore, natural that production and operations management is now getting to be increasingly 'relationship oriented'. There is a web of relationships between the company, its customers and its business associates and its social surroundings. The production / operations strategy, systems and procedures have begun to transform accordingly.

LESSONS FROM HISTORY

Economic history and the history are of operations management both important in the sense that these would suggest some lessons that can be learnt for the future. History helps us to know the trends and to take a peek at the future. If the 21st century organisations have to manage their operations well, they will have to try to understand the 'what and how' of the productivity improvements in the past and what led to the various other developments in the field of production and operations management. The past could tell us a thing or two about the future if not everything. Looking at the speed with which technology, economies, production and service systems, and the society's values and framework seem to be changing, one may tend to think that 'unprecedented' things have been happening at the dawn of this millennium. However, there seems to be a common thread running all through.

Limiting ourselves to history of production or manufacturing, we see that the effort has always been on increasing productivity through swift and even flow of materials through the production system. During the Taylor era, the production activities centered on an individual. Hence, methods had to be found to standardise the work and to get the most out of the individual thus making the manufacturing flows even and fast. Ford's assembly line was an attempt at further improving the speed and the evenness of the flows. Thereafter, quality improvements reduced the bottlenecks and the variability in the processes considerably, thus further facilitating the even and rapid flow of goods through the production system.

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The attempt has always been to reduce the 'variability', because variability could impede the pace and the steadiness of the flow. Earlier, variability came mostly through the variability in the work of the workers. However, in the later decades the variability came from the market. Customers started expecting a variety of products. Manufacturers, therefore, started grouping like products together. The flows of materials for those products were, therefore, exposed more easily; this helped in quickly attending to bottlenecks, if any, and in ensuring a speedy and even flow through the manufacturing system. Cellular manufacturing or Group Technology was thus born. Materials Requirement Planning (MRP) and Enterprise Resource Planning (ERP) were other efforts at reducing the variability by integrating various functions within the operations system and the enterprise as a whole, respectively.

The customer expectations from the manufacturing system increased further. They started asking for a variety in the products that had to be supplied 'just in time'. In order to realise this, the manufacturing company had to eliminate the 'unevenness' or variations within its own plant as also limit the variations (unevenness) in the inputs that came from outside. This required the 'outside system' to be controlled for evenness in flow despite the requirements of varied items in varied quantities at varied times. This could not be done effectively unless the 'outsider' became an 'insider'. Therefore, the entire perspective of looking at suppliers and other outside associates in business changed.

As we notice, the scope of production and operations management has been expanding and the discipline in getting more inclusive—from employees to business associates in supply chains to external physical environment to the society at large. Its concerns are widening from a focus

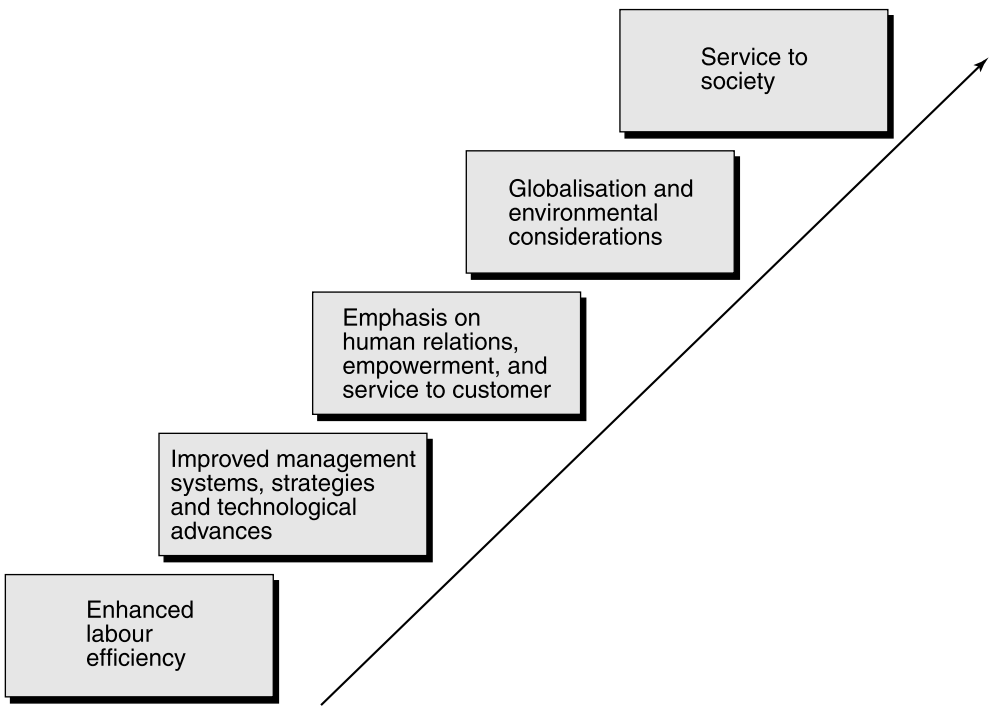


Figure 1.2 The Journey of Production and Operations Management

on employee's efficiency to improvement in management systems and technological advances to human relationship to social issues. Figure 1.2 depicts this progression.

The inroads made by the 'service' element have been subtle and the impacts have been profound. It unfolded an overwhelming human and social perspective. Organisations are realising that what is advantageous to the larger society, is advantageous to the organisation. This does not mean that individual employee efficiencies, operations planning -and-control techniques, systems and strategies are less relevant; in fact, they are as relevant or more so today in the larger social context. Materials and supply management was important in yesteryears; it is even more important in the light of environmental and other social concerns which production and operations management discipline has to address today.

It is also extremely important to take adequate cognisance of further developments in science and technology, the changes in value systems and in the social structures that are taking place worldwide. Developments in science and technology give rise to certain social mores, like, for instance, the mobile phones are doing today. Similarly, the changed social interactions and value systems give rise to changed expectations from the people. The type of products and services that need to be produced would, therefore, keep changing. Today a 'product' represents a certain group of characteristics; a 'service' represents certain other utility and group of characteristics. These may undergo changes, perhaps fundamental changes, in the days to come. We may see rapid shifts in the lifestyles. So, whether it is for consumption or for the changed lifestyle, the type of products demanded and the character of services desired may be quite different. Production and operations management as a discipline has to respond to these requirements. That is the challenge.

QUESTIONS FOR DISCUSSION

1. How does the production and operations management function distinguish itself from the other functions of management?
2. The historical development of production and operations management thought has been briefly mentioned in this chapter. Can you project the future for the same?
3. Mention situations in (a) banking, (b) advertising, (c) agriculture, and (d) hoteliering where production and operations management is involved. Describe the inputs, outputs, processes, utilities.
4. What are the different types of production/operations systems? Where would each one of them be applicable? Give practical examples.
5. How is production management related to operations research and quantitative methods?
6. How has and how will the computer influence production and operations management? Discuss.
7. Is there a difference between the terms "production management" and "operations management"? If so, what is it?
8. What is the concept of "division of labour"? How is it applied to the assembly lines?
9. Can the above concept be applied to other "service" situations? Mention two such examples and elaborate.
10. How do long-term, intermediate and short-term decision vary? Discuss the differences in terms of their characteristics. Also discuss the increasing overlaps between these decisions.

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11. Is the production and operations management function getting to be increasingly people-centric? If so, what may be the reasons?
12. Will 'time' be an important area of decision-making in the future? Reply in the context of the production and operations management function. Explain your response.
13. 'Historically, much of the developments in production and operations management discipline have centered on reduction of variability.' Do you agree with this statement? Explain.
14. Looking at the economic history of nations, one may observe that those nations that emphasised 'time', such as England and Japan, industrialised rapidly. Others like India who did not much emphasise time, did not industrialise as rapidly. Do you agree with this statement? Explain your response.
15. What may be your prognosis for the future of the production and operations management discipline in general? Discuss.
16. In your opinion, where is India on the trajectory of the changing production and operations management function? Discuss.

ASSIGNMENT QUESTIONS

1. Study any organisation(manufacturing or service, profit or non-profit, government or private) of your choice regarding the impact of technology in its operations. Study the past trends and the probable future and present a report.
2. Read books/articles on the history of Indian textile industry and its operations. What are your significant observations ?

2 Operations Strategy

STRATEGIC MANAGEMENT PROCESS

Alfred Chandler* defined strategy as, "the determination of the basic long-term goals and objectives of an enterprise, and the adoption of courses of action and the allocation of resources necessary for carrying out these goals". William F. Glueck** defined strategy as, "a unified, comprehensive, and integrated plan designed to ensure that the basic objectives of the enterprise are achieved." These definitions view strategy as a rational planning process.

Henry Mintzberg,*** however, believes that strategies can emerge from within an organisation without any formal plan. According to him, it is more than what a company plans to do; it is also what it actually does. He defines strategy as a pattern in a stream of decisions or actions. So, there are deliberate (planned) and emergent (unplanned) strategies.

In support of Mintzberg's viewpoint, the case of the entry of Honda motorcycles into the American market may be mentioned. Honda Motor Company's intended strategy was to market the 250 cc and 305 cc motorbicycles to the market segment of mobike enthusiasts, rather than selling the 50 cc Honda Cubs which they thought were not suitable for the American market where everything was big and luxurious. However, the sales of 250 cc and 305 cc mobikes did not pick up. Incidentally, the Japanese executives of Honda used to move about on their 50 cc Cubs, which attracted the attention of Sears Roebuck who thought they could sell the Cubs to a broad market of Americans who were not motorcycle enthusiasts. Honda Motor Company was initially very reluctant to sell the 50 cc (small) bikes and, that too, through a retail chain. 'What will happen to Honda image in the US?', they thought. Expediency of the situation (failure in the sales of bigger motorcycles) made them give a nod to Sears Roebuck. The rest is history. Within a span of next five years, one out of every two motorcycles sold in the US was a Honda. Thus,

* Chandler, Alfred, *Strategy and Structure: Chapters in the History of the American Enterprise*, MIT Press, Cambridge, Mass., USA, 1962.

** Gluek, William F., *Business Policy and Strategic Management*, McGraw-Hill, NY, USA, 1980.

*** Mintzberg, Henry, 'The Design School: Reconsidering the Basic Premises of Strategic Management', *Strategic Management Journal*, Vol. 11, No. 6, 1990, pp. 171–95.

successful strategy involves more than just planning a course of action. How an organisation deals with miscalculation, mistakes, and serendipitous events outside its field of vision is often crucial to success over time.* Managers must be able to judge the worth of emergent strategies and nurture the potentially good ones and abandon the unsuitable, although planned, ones.

Strategic planning can be of two types: 'usual' and 'serendipitous'. What the Honda Company had thought of doing earlier was the usual approach of a business strategy of deciding 'who' the customer is going to be, what to provide him/her and 'how' to provide. Thus, being in the US market for 250 cc and 305 cc motorbikes for the bike-enthusiasts was a defining feature of Honda's usual business strategy. It was planned based on the normal modes of understanding a market. This business strategy, in its turn, was to drive the functional strategies like the operations strategy, marketing channels and distribution and logistics strategy in the firm. However, the actual experience in the field (in USA) gave Honda a new, previously unthought-of perspective on the market – that of the dormant demand for a cheap transport vehicle that could be supplied through a never before imagined channel of Sears Roebuck stores. This new perspective that 'emerged' made Honda to change its business strategy radically. The new perspective now became a dominant factor in strategic planning. The company sold 50 cc Honda 'cubs' instead of the highly powered motorbikes through an altogether new marketing channel with new logistics needs. This is an 'emergent strategy' aspect of strategy formulation. Serendipity also has a role in deciding a company's business strategy in addition to planning based upon regularly available data on the market. Figure 2.1 depicts these aspects of strategic planning.

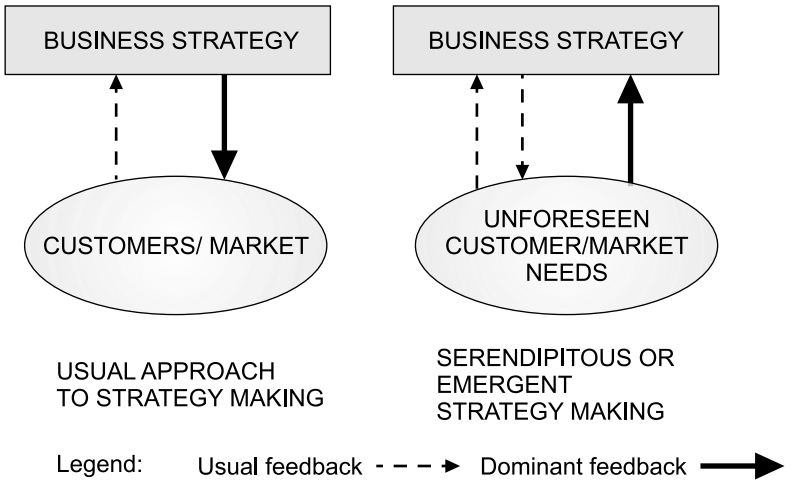


Figure 2.1 Usual and Serendipitous Strategy Making

Another example of a 'serendipitous strategy' or, in other words, 'seizing the unexpected opportunity' is that of the 3M Company, which was a small firm during the 1920s, attempting to get over the problems with its wet-and-dry sandpaper used in automobile companies. While trying to develop a strong adhesive to solve the specific problem of the grit of the sandpaper getting detached and ruining the painting job, the R & D man at 3M happened to develop a weak adhesive

* Richard T. Pascale, 'Perspectives on Strategy: The Real Story Behind Honda's Success', *California Management Review*, Vol. 26, No. 3, Spring 1984, pp. 47–72.

instead of a strong adhesive. However, a paper coated with it could be peeled off easily without leaving any residue. This serendipitous discovery was seized by 3M to develop a 'masking tape' to cover the parts of the auto body that were not to be painted. It became a huge success. From this time on, 3M devoted its business to 'sticky tape'. The rest is history.

Thus, while strategy making is mostly a planned activity, an organisation has to be alert about any chance opportunities that may emerge. Strategies can be 'emergent' also.

The major components of the strategic management process are: **(a)** Defining the mission and objectives of the organisation, **(b)** Scanning the environment (external and internal), **(c)** Deciding on an organisational strategy appropriate to the strengths and weaknesses of the organisation after taking cognisance of the emerging opportunities and possible threats to the organisation, and **(d)** Implementing the chosen strategy.

WHAT IS OPERATIONS/MANUFACTURING STRATEGY?

From the earlier discussion on strategy, it is clear that operations/manufacturing strategy has to be an integral part of the overall organisational strategy. Without defining the mission and objectives of the organisation, checking up on the external and internal environment, performing the SWOT analysis for the organisation and then deciding on the basis for competing and/or key factors for success, no operations/manufacturing strategy can be formulated. The latter presupposes an in-depth knowledge/understanding about the organisation: its past direction, its strengths and weaknesses, the forces affecting it and what it must become.

This means, there are two-way feedbacks in any process to arrive at the strategies of the organisation and of its functional disciplines such as the operations function. It is understandable that a functional strategy such as the operations strategy is derived from the overall organisational and business strategies. Operations have to be congruent with the strategic stance of the business. However, the business strategy may be derived based on the 'strengths' of the operations function in that organisation. The 'core competence' of the firm is a very important consideration, because that special competence can be exploited by the firm while competing in the market. For instance, if the quality/reliability of products/services is a special strength of a firm, then that firm's business strategy is mainly based on its ability to supply quality products and reliable service to the customer. Strategy making is not a one-way street. Strategy formulation is an iterative process where there are feedbacks between business strategy and the functional strategy like the operations strategy.

It is true that since the customer should be the focus of a business, the customer and the environment in which s/he is situated are of paramount importance in deciding upon a business strategy and the functional strategies. While the core competencies and the exceptional strengths of the functions like operations can be and should be leveraged in the market to provide improved services/products to the customer, a firm cannot always design its strategies based upon its own perceived strengths. Yesterday's core competence may not be today's competence. One has to guard against such self-delusions. Knowing the pulse of the market, i.e. knowing the customer and providing her/him the desired serivce/product through appropriate business and operations strategies, is the prime *raison-de-etre* of the organisation. Figure 2.2 depicts these concepts.

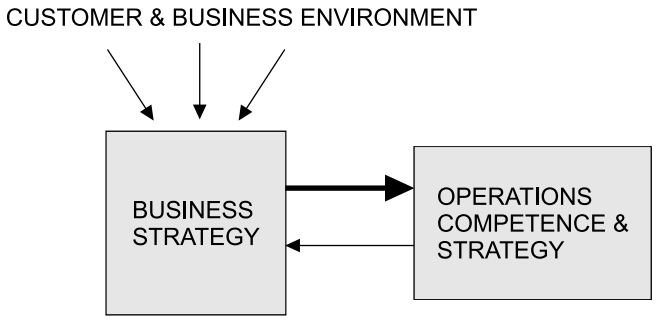


Figure 2.2 Two-Way Process of Strategy Making

Chapter 1 contains a table listing various long-term decisions. Some of the long-term decisions could be strategic decisions. But, strictly speaking, not all long-term decisions are strategic decisions. These could be decisions supportive to the strategy decided upon. In the earlier decades, when the competition was not as intense as it is today at a global level, it was apt to speak only in terms of technology strategy, market strategy and resources strategy in isolation. A company could develop and produce a technologically superior product and could expect the customers to fall head over heels to buy the product. For, the process of technology diffusion was significantly slower than that during the present days. The technology leadership remained with the innovating company for a substantial period of time. The companies could afford to stay glum in the belief that 'our designs are superior', and not do anything else. After a passage of time, whether the customers needed the 'superior' design features offered in full or partially or did not need at all, the company would not change it stance. It would keep banking on its 'strategy' of design competence. However, it is now very much realised that all these 'superiorities' are for the customer. If a company sources its inputs efficiently or even uniquely, it is so done keeping in view the interests of the customer. All strategies originate from the need to satisfy the customer without who there is no business. Strategic planning is not a static and compartmentalised process, but it is an on-going and integrated exercise.

After having decided upon the mission, objectives and (as a part of it) the targeted market segment in which the company will compete, the company has to choose between the fundamental strategic competitive options of **(a)** Meaningful differentiation and **(b)** Cost leadership.

MEANINGFUL DIFFERENTIATION

It means being different and superior in some aspect of the business that has value to the customer. For instance, a wider product range or a functionally superior product or a superior after-sales-service. The underlying fundamental objective is to serve the customer better through various means. A company may make a product with a superior design, but, then, that is done with the customer in mind; it is not a design for design's sake and waiting for customers to make a bee-line for the better designed product. The cart should never be put before the horse. Such customer-orientedness will make the objective of the 'differentiation' clear to the decision-makers. Differentiation is a strategy to win customers and to keep retaining them for a long time. The requirement, therefore,

is to keep retaining the advantage of 'differentiation' by continual improvement in the specifically chosen area of differentiation. One could even diversify into other areas of differentiation.

FLEXIBILITY

In fact, today's market requires that while a company differentiates itself (from the competitors), on one aspect, it should perform adequately on other aspects of service too. Concentrating exclusively on one aspect at the expense/neglect of other aspects is just not done. The company, therefore, does an adequate or satisfactory job on various fronts, such as providing flexibility in terms of:

(i) Product design
(ii) Product range or product mix
(iii) Volumes
(iv) Quick deliveries
(v) Quick introduction of new product/design
(vi) Responding quickly to the changed needs of the customer or quickly attending to the problems of the customer.

While *flexibility* is one of the *differentiation strategies*, the former is fast becoming a vital prerequisite for providing meaningful service to the customer. This is because the competitive conditions are changing rapidly and a company cannot hold on to the advantage of a particular kind of differentiation for a long time unless it is flexible enough to respond quickly to the changed needs to the customer. Future is not viewed as a static extrapolation of the past trends and the present; it is seen more as a dynamic phenomenon, although a few basic or floor-level issues might remain the same.

Flexibility is a part of being responsive, responsible, reliable, accessible, communicative and empathetic to the customer. These are all service quality characteristics. Flexibility involves not only operations (manufacturing, supplies) but also the design and development, the project execution, the marketing and the servicing functions. The manufacturing/operations part consists of being flexible enough (flexibility in machines, process and in manpower) to process the altered designs, the variety, in small batches with minimal wastage of time, of the desired quality, in a shortest process-time possible and deliver on time for the logistics function to take over the next part of the responsibility. Flexibility in operations should provide alternative potential platforms to compete if the business so desires or if the market so requires it. It should provide the company with a capability to be resilient to threats of new/improved competition, of substitute products availability, of local government's or international policies getting changed, of resource crunches suddenly popping up. An operations system should offer market flexibilities through flexibilities in machinery, processes, technology implementation, men, systems and arrangements and time utilisation. The flexibility should improve the capacity (rather, the capability) for self-renewal and adaptation to the changing external and internal environment. Competing for tomorrow should be as much on the agenda as that for today.

COMPARISON: TRADITIONAL vs NEW APPROACHES

It may be interesting to compare the traditional and new approaches even while the basis for competition is the same. The comparison has been given in Table 2.1.

Table 2.1 Approaches to Meaningful Differentiation through Product Availability

Basis for Competition: Product is available when needed by the customer.	
Old Approach	*New Approach*
• Keep/increase buffer stocks of the finished goods and other materials. • Invest in more machinery, hire more people, get more materials and thus increase the production capacity.	Decrease response time by: • Reduction of operations lead times, delivery times through continuous improvements. • No postponements or cancellations of the scheduled production, thus ensuring the supply on time.
The by-products are: • Increased costs due to higher inventories and higher investments. • Larger inventories (W.I.P. and Finished Goods) require longer internal lead times, defeating the very purpose behind larger inventories. • Stock-outs due to overload of some work-centres. • Urgent orders increased in order to meet the stock-outs. • Increased complexity giving rise to further wastes and costs. • Confusion on the shop floor or in the operations system. • Failure to meet customer's changing needs.	• Improvements in quality; producing right the first time, self-inspection and certification; all of this leading to unnecessary wastage of time and in actual reduction in operations/process times. • Improved machinery maintenance, improved design of the products and processes, so that the expenditure of time due to breakdowns, rejects, reworks is avoided. The by-products are: • Improved reliability in terms of deliveries and performance quality. • Simplicity in the system. • Reduced costs. • Reduced product variability. • Improved flexibilities (time, product-mix, volumes). • Enhanced company/brand image.

Source: Adapted from Greenhalgh, Garry Robert, *Manufacturing Strategy: Formulation & Implementation*, Addison-Wesley, Singapore, 1990.

COST LEADERSHIP

The other fundamental strategic competitive option that a company can choose is 'cost leadership' i.e. offering the product/service at the lowest price in the industry. This has to be achieved by cost reductions. However, the difference between the modern approach and the traditional approach

to cost reduction shows the wide gulf in understanding the customer. The concern for customer (and, therefore, the provision of strategic flexibility), which is an essential ingredient, makes all the difference as shown in the comparison presented in Table 2.2.

Table 2.2 Approaches to Cost Leadership as a Strategy

Basis for Competition: Cost leadership	
Traditional Approach	*Modern Approach*
• Control on costs, especially related to direct labour.	• Eliminate only the non-value adding activities.
• Reduction in the budgetary allocations, particularly easily implementable ones such as on training, human resource development, and on vendor development.	• Improve quality of design and thus reduce costs of input materials and costs of processing and packaging, etc.
• Defer investment in machines, including the necessary replacements.	• Improve the processes and thus increase the yields, reduce the rejections and the rework.
• Reduction of various indirect labour expenses and, therefore, reduction of support activities.	• Reduce the set-up times and save on attendant costs.
• Reduce inventories of raw materials, of bought-out items and of supplies.	• Reduce the need to have inventories, in the first place, by reducing the internal and external lead times and by achieving reduction in the uncertainty through concerted positive management action and monitoring.
This results in:	
• Increase in uncertainties.	
• Depletion of skills of the manpower.	• Use technology to simplify the processes, procedures and to reduce confusion and the resultant wastes.
• Reduction in motivation of the manpower.	
• Vendors feeling alienated and an increase in vendor-related problems.	This results in:
• Machinery getting spoilt at an accelerated pace.	• Lean and flexible operation. • Better product/service quality.
• Support for production—through various indirect activities—getting diminished.	• Better time discipline and enhanced responsiveness to the customer.
• Delivery and quality taking a beating.	• Improved market performance.
• Customer getting increasingly dissatisfied. • Company facing problems in recovery, as dissatisfied customers delay payments on one pretext or another.	• Improved profits to plough back in better technology, improved machines, better training of manpower, better support to vendors and dealers, more service to the customer.
• Problems of cash flow further leading to tightening at unnecessary places.	• A virtuous cycle is set in.
• The above leading to further problems in customer service.	
• A vicious cycle is set in.	

OPERATIONS STRATEGIES

Thus, manufacturing/operations strategies, that one should complement with the fundamental organisational strategies, comprise of the customer oriented strategies of:

Improved Responsiveness in terms of

- minimising time to respond
- timely response
- accessibility through better locations, better geographical proximity, improved logistics, and better systems of communication
- wider product/service choice through flexible operations/manufacturing system, reduced throughput times, reduced cycle times, reduced set-up times, flexible manpower, better trained manpower, flexible machines and improved product designs and processing capabilities
- increased proactivity

Reduced Prices through

- overall improvements in the production-delivery value chain
- better designs of products/services

Improved Quality through

- better skills, better knowledge, and better attitudinal orientation of all production-and-service providers
- improved technology
- reduced complexity and confusion
- reduced problem-generators

A lean or light production, flexible production and enlightened production should be the strategic responses of the operations function to the changing market conditions.

KEY SUCCESS FACTORS

Kenichi Ohmae* mentions the following as the key success factors for any business:

(i) Product performance
(ii) Technology leadership
(iii) New product introduction
(iv) Access to key decision-makers or key influencers
(v) Delivery service

For a given industry, one or more of these factors will be crucial. For instance, in a sunrise industry such as the computers industry, the key success factors will be technology leadership and new product introduction. For a routine household product such as a tube-light or bulb or a ceiling fan, the key factor is the product performance. For an industrial product such as a machine-tool, the key factors are product performance, delivery service and, in some cases, new product introduction. A company manufacturing and selling standard agricultural pumpsets in India found that the key success factor was the locally available village mechanic who was found

* Ohmae, Kenichi, *The Mind of the Strategist: The Art of Japanese Business*, McGraw-Hill, NY, USA, 1982.

to be always consulted by the farmer in making his choice of a pumpset from amongst a group of several competing brands providing almost the same level of performance. Similarly, in project marketing where complete/partial systems or a large complex equipment is to be sold, installed and commissioned, the buyer companies generally go by the opinion of their technical consultants. The village mechanic and the technical consultant are the key influencers.

In governmental projects/contracts or in any bureaucracy the access to key decision-makers is a major success factor for business. Here, the authority is concentrated in one person (or in one department) who may or may not understand all the nuances of technology improvements or of new designs of products. Since the sales are generally in bulk, the delivery also is usually not a problem or a key factor. Access i.e. having open channels of communication with the decision-maker goes a long way as the credibility is already established.

There could be operations/manufacturing related issues with each of these key success factors. If it is product performance, then the concerned operations issues would be, for instance, the quality management system, the attitudinal aspects of the operating personnel, the process variability, etc. if it is 'access to key decision-makers', then only if these happen to be technical/operating people, the relevant manufacturing issue in a small measure could be the other success factor which is product performance; otherwise, there is no manufacturing issue or strategy to go along with that key success factor. The following Table 2.3 is interesting in this context.

Table 2.3 Key Success Factors and Relevant Operations Issues

	Product performance	*Technolgy leadership*	*New product introduction*	*Access to key decision-makers*	*Delivery service*
Relevant operations/manufacturing issues to be addressed by the company	• Process variability • Quality management system • Work culture and attitudes • Product variability • Proper design	• Process technology eplacement policy • Manufacturing management's openness for experimenttion • Skilled manpower	• Flexible production/operations facility/system • Capacities of machines, men, materials • Capabilities of men, machines, materials (and its suppliers)	None	• Lead times: internal and external • Discipline regarding schedules • Flexibility of produs ction/operations facility/system • Proper forecasting of demand and hence the load on the operations system

STRENGTHS, WEAKNESSES, OPPORTUNITIES AND THREATS (SWOT) ANALYSIS

Whatever one may talk about the operations/manufacturing strategic issues, the relevant strategic plans cannot be implemented unless one takes a good look at the company's internal strengths and weaknesses. For instance, a century-old Indian company making fluid handling devices has very old equipments and equally old and less-skilled people manning and managing the production facility. It is pointless to attempt at 'technology leadership' and/or 'new product introduction' as a key success factor for that company. The system is ridden with inertia and the only manufacturing strategy that might work there would be to keep producing a product of consistent quality with some improvement in manufacturing lead times. Sweeping changes in manufacturing are not possible within such a set-up. The company has been attempting a complete change in the organisational structuring through a new set of strategic business units (SBUs). While bringing in focussed profit-orientation through SBUs is a good thought, it fails to address the real problem. Results of such restructuring could only be quite cosmetic and frustrating. Restructuring and therefore trying to bring in enhanced adaptiveness and responsiveness through the profit orientation is possible only if the system had not been rigid in the first place. An organisation does not automatically become more flexible because of an increased profit-orientation. This is a wrong medicine administered, because the diagnosis is not accurate.

Opportunities are those events currently occurring or the potential events where a company may additionally exploit its strengths—strengths being those activities, resources, systems, procedures, technologies, knowledge base and skills which the company has distinctively better as compared to its competitors. For instance, if an engineering company has foundry technology as its strength, the company should chalk out its future strategy in terms of a superior product and perhaps a greater product range in a bullish market. The latter (a bullish market) is an opportunity which can be made use of by the company through its manufacturing strategic response. Similarly, the company can overcome the threat of the entry of multinational competition through a positive strategic manufacturing action of providing quality and variety using the company's own internal strengths. Figure 2.3 depicts some of the typical strengths, weaknesses, opportunities and threats.

The SWOT analysis should indicate a 'fit' between the proposed strategic response of the operations function and the strengths of the company. Also, the strengths and weaknesses need not be taken as static or as constants; a company should always introspect: "What should our strengths be? What weaknesses must be overcomed or converted into strengths?" "What weaknesses must go in order to ward off or win over a potential threat?" Employee age could be a strength or a weakness. It all depends upon how a company exploits it, or on how it does not allow the competitors to exploit that distinctive characteristic of the company. Government policy changes can be viewed either as an opportunity or as a threat depending upon the particular company's strengths and weaknesses. Thus, an opportunity or a threat can also be a matter of perception, or a product of the relative strengths and weaknesses. An operations strategy is a response to this perception.

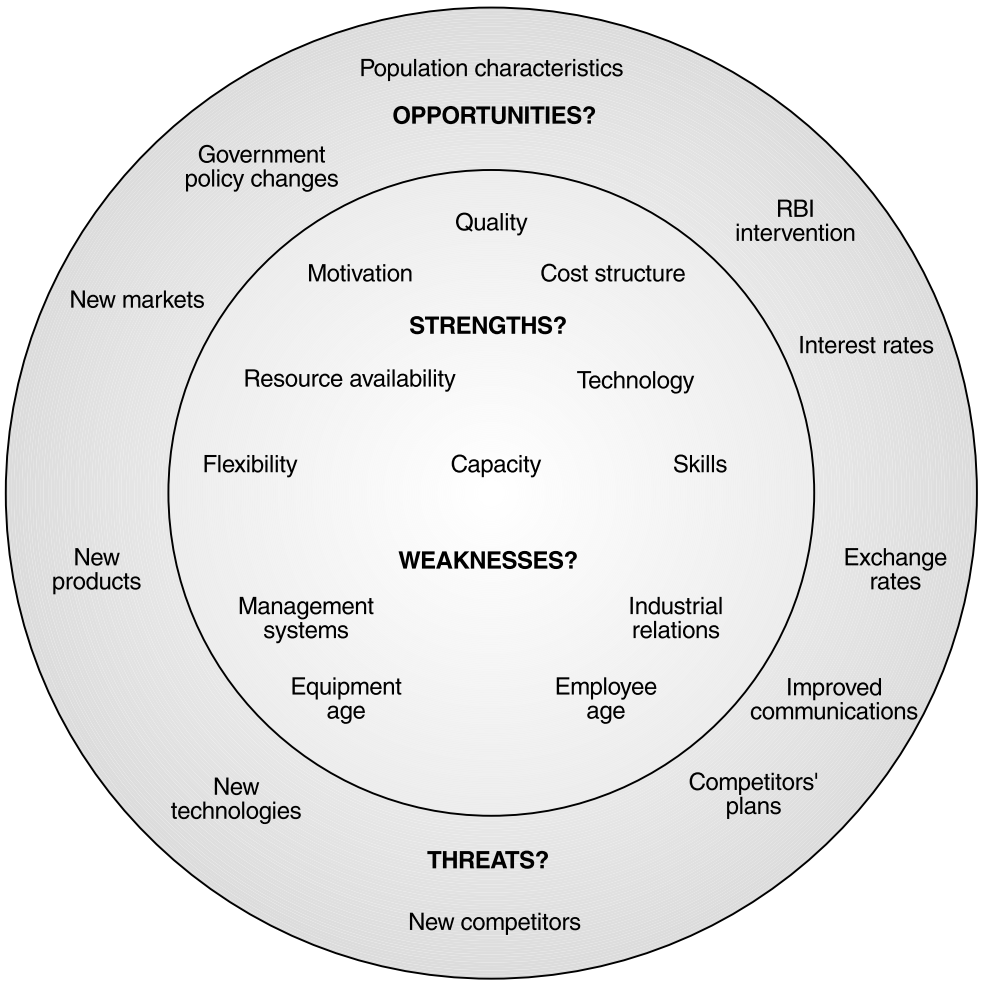


Figure 2.3 SWOT Analysis

FIVE FORCES MODEL

Another analysis that could be useful in devising an appropriate operations strategy is that of *Five Forces Model* as presented by Michael E. Porter (refer Fig. 2.4).

Porter's model is one of the structured ways in which the industry environment is analysed. He says that the stronger each of these five forces is, the more difficult it will be for the company to raise prices and make more profits. A strong force is equivalent to a threat, a weak force is equivalent to an opportunity. It is upto the operations strategy formulators to recognise the opportunities and the threats as they arise and design an appropriate strategic response from the operations function. As it is a dynamic world, the strength of each of the competitive forces can change over time due to factors external to (i.e. beyond the control of) the company. The relative strengths of

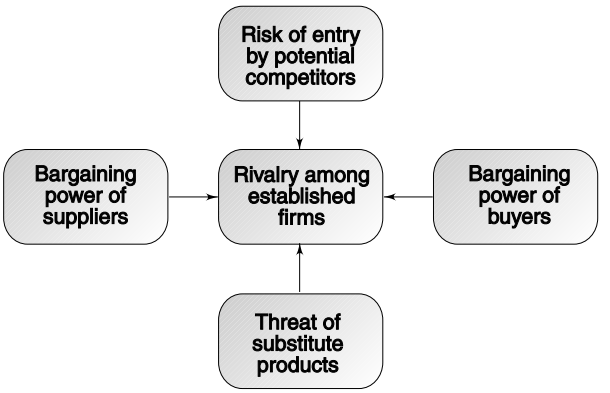


Figure 2.4 Porter's Five Forces Model

Source: Michael E. Porter, 'How Competitive Forces Shape Strategy', *Harvard Business Review*, March–April 1979.

these forces can also be engineered by the company through an appropriate choice of a strategy and thus, tilt the competitive forces to its advantage. For instance, in the Toyota production system, the force of bargaining power of suppliers is lessened by removing the 'bargaining' bit. This is done by means of 'single sourcing' and by placing tremendous emphasis upon vendor relations and vendor development. The threat of substitute products can be minimised by providing a variety in the first place. This requires an appropriate manufacturing strategic response through a cost-conscious yet flexible system of manufacturing. The risk of entry of potential competitors can be reduced through making/providing a quality product/service as the customer desires at an affordable price. Also, a wider range of product variety and timely services could be provided. Bargaining power of buyers can be lessened through building long-standing relationships between the two companies, through an atmosphere of transparency and through a dedicated service orientation. Operations strategy and consequent actions can be built around these organisational necessities.

OPERATIONS STRATEGIC ACTION AND ITS RELATIONSHIP WITH OTHER FUNCTIONAL AREAS OF MANAGEMENT

Operations strategies cannot function in isolation. A synergy is to be sought between operations and other functions. A company's competitive advantage stems from such holistic or complete approach towards its strategic posture. There is no point in manufacturing function adopting a strategy of product differentiation through superior quality, without an adequate supportive strategic action by, say, human resource development function to upgrade the skills of people and enhance motivation through its HRD strategy. Similarly, the operations function needs strategic support from the research and development function in improving the process capabilities, introduction of new/modified technologies, or coming up with better substitutes for inputs. Moreover, for modified new products, it is necessary that marketing function provides insight into the customers' requirements. In this case, marketing, operations and R&D functions have to work in tandem.

Ultimately, whether it is the operations strategy or a marketing strategy, its source can be traced to the organisation's strategic decision and thus, all functional strategies have to serve the organisational interests. For instance, lean production is a manufacturing response to the organisational need for serving the customer efficiently and just in time. Time-based competition as an organisational strategy leads to the manufacturing strategy of building flexibility and adaptability in the production system. This, again, has to have a parallel supportive strategy of the logistics function and appropriate marketing arrangements. It must be noted that marketing under time-based competition is a wholly new ball game. The purpose ("What are we trying to achieve?") must be clear at the organisational level, so that appropriate functional strategic response is generated supporting the organisation's purpose.

When the factors outside of the organisation such as the business environment, competition, available products/services, availability and supply of resources and, of course, the customers are taken into consideration to arrive at the firm's business strategy and when this business strategy decides/suggests certain operations strategy, it is an 'outside-in' approach. But when the operations function has certain core competencies, these might dictate what the firm's stance in the business-world could be, i.e. while facing the business environment. This is a case of 'Inside-out'. The former deals with 'coping' with the environment and making the best under the circumstances.

However, a firm can develop such competencey which would create a demand for certain service from the market. Steve Jobs, co-founder of Apple, was such a trend-setter. He would ideate, develop and produce products that would set a demand for that class of products. His 'Apple' computers and i-Pod were the kind of products that created the demand in the market for those products. Microsoft, too, initially set a trend in the operating stystems. Dhirubhai Ambani's Reliance set a trend of IPOs for generating capital in India. In these cases, the R & D function and the finance function, respectively, exhibited special competencies and the business strategy of the firms was kick-started by these functional capabilities. Toyota Motors, during the 1970s, developed unique capabilities in manufacturing operations through an innovative Just-in-Time system of production. Toyota's special competence in operations influenced its business strategy; it was the game-changer. Dr. Verghese Kurien of Amul conceptualised and successfully implemented the cooperative milk production, collection and distribution strategy for its operations in Gujarat. Amul's core competence in 'social engineering' or generating a 'cooperative movement' in its operations was a dominant factor in deciding its successful business strategy. These are instances where the firm 'faces' the given business environment and the customers are exposed to 'what they did not know they wanted'.

It ought to be stated once again that the latter 'game-changer' or 'inside-out' avatar of an organisation happens once in a way and rest of the time the former 'outside-in' aspect has to take over. Innovation, consolidation, decline and re-innovation are the different stages of a business. Figure 2.5 illustrates the "coping" and "facing" aspects of operations strategy.

It may be reemphasised that strategy formulation is an interactive and iterative process. Business strategy leads to operations strategy and operations core competence may lead to business strategy: the business and operations function's strategies have to be supported by appropriate strategies of other functions. All strategies need each other's support.

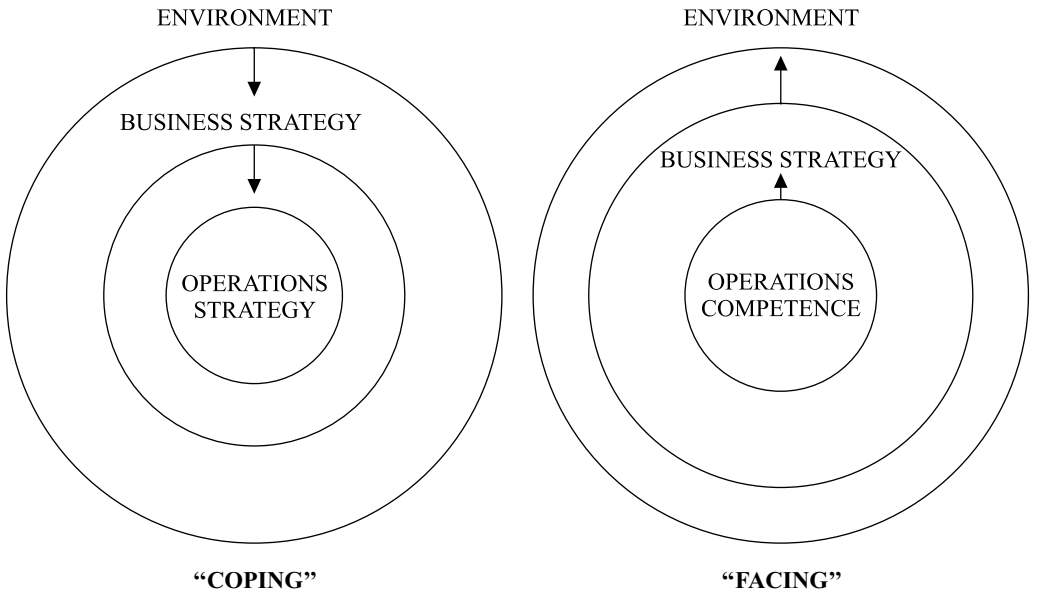


Figure 2.5 Two Aspects of Operations Strategy

Table 2.4 provides some of the relationships between operations and other functions within an organisation.

OPERATION FUNCTION'S ROLE: A NEW CONCEPT

Traditionally, the operations function has been seen as optimally utilising the resources of men, machines and materials (and, hence, money) while producing the designated output. It has been interpreted as ensuring efficiency in the operations function. Thus, production costs should be low; men and machinery should be fully utilised; materials wastage should be curtailed; production/operations should properly plan and control the people and the output. The entire operations management discipline has been built around these basic tenets. Accordingly, inventories are economically ordered and controlled, production runs are scheduled, maintenance programmes are arranged, people assessment and reward systems such as work study, O&M, incentive schemes, merit rating etc are devised, and physical layouts and locations are decided upon.

While efficiency is a virtue, it is being increasingly realised these days that the operations function needs to address some basic issues:

1. 'Optimisation' needs an objective. Optimisation for whom? What is the basic purpose behind optimisation? Should optimisation be limited to minimising costs and/or maximising profits to the company? Shouldn't the customer enter into the calculations regarding optimisation?
2. Is 'profits' the primary objective, or is it the 'customer service' that should be the primary objective guiding the company?
3. How should 'efficiencies' and 'optimisations' help towards fulfilling the organisation's objectives?

Table 2.4 Relationships between Operations and Other Functions

Human Resource Development	➢ Make the company a preferred employer, thus attracting the best talent and keeping it. This would help the manufacturing function in terms of improving productivity, quality and flexibility. ➢ Enhance the capabilities of the people through training and other individual/group activities. These capabilities should be congruent to the manufacturing strategy. ➢ Create coherence between the people's attitudes and the organisation's objectives and strategies. This is true of manufacturing companies. In an industry such as computer software, the span of retention of the employee could be quite low. While the HRD function should try to retain these software professionals as long as possible, the emphasis would be on hiring quality personnel and align their attitudes with the company's objectives in as short a time-span as possible.
Marketing	➢ Marketing strategy based on any of the P's such as Price, Positioning, Place should be congruent to the manufacturing strategy and vice versa. For instance if 'place' is important in the marketing strategy, then the manufacturing function must gear up to the challenge of, say, multi-locational operations or providing the product on time at different (possibly distant) locations. ➢ Marketing strategy may lead to the company's technology strategy. Manufacturing strategy has to be in line with the latter. Its strategic actions involve preparation of people, equipments, process, and systems for the technology upgradation or new product introduction. ➢ Manufacturing strategy should provide perfect back-up for the customer service goals of the marketing function. ➢ Marketing function should provide relevant market feedback to operations.
Research and Development	➢ Operations cannot bring in additional flexibility, beyond a point, unless the R&D function helps in process capability improvements, in the design of new processes, and in the design of new products that can be produced/worked on existing operations facilities.
Logistics	➢ Provide for the quick movement of materials inside and outside the factory. ➢ Arrange for storage, distribution and other support to help manufacturing strategy of 'providing product/service on time'.
Finance/Accounting	➢ If technology leadership or new product introduction is a strategy, appropriate finance must be raised through an aggressive financing strategy. ➢ The accounting, budgeting and control system should be supportive of the manufacturing strategy. For instance, a Just In Time production system requires that the accounting system and control system be different from the traditional system where machinery utilisation and labour utilisation were being emphasised.

4. Resources do not comprise of men, machines and materials (and hence, money) only. Time and technology are equally important (if not more important). In fact, technology also relates to men, machines and materials as its subsets. People, on other consideration, are the 'mother resource' from which technology and the competitiveness/preparedness of the organisation originates.
5. In light of the last point, should management be viewed as doing only planning and controlling activities? The role of management in general and that of operations management in particular has changed more and more to that of providing a vision, strategic direction and leadership to people and managing change.

This means that the operations function can no longer insulate itself from the organisation's perspectives. It cannot consider itself as a 'mechanical' limb or a 'producing machine' for the organisation. It has a strategic leadership role to play. It has to actively help in setting directions, creating focus and building appropriate culture and values into manufacturing so that the changes and challenges of the present and of the foreseeable future are met. Operations have to be a vital participant in the organisation's business strategy. Operations as a system reactive to the environment is a necessity but, equally importantly it has to be proactive and future minded.

Just as the operations function's actions follow from the business strategy, the former can also develop unique capabilities – like novel technology, novel systems, and novel ways of obtaining or developing resources – that would allow aggressive or novel business strategies.

GLOBALISATION

Globalisation unfolds a wide canvas for the business organisation to paint upon. Many Indian companies are planning to go global. How are the issues in management, particularly operations management issues, different when a company decides to globalise as opposed to when it was a regional or at best a national player? The answer is:

1. The organisation now faces a worldwide competition as opposed to the limited regional/national competition it faced.
2. Substantially enhanced competition throws up the issues of 'focus' and 'customer orientation' to the fore with greater force and urgency. The organisation must define 'Who is our customer?' and 'What services does he need and/or expect?'.
3. Depending upon the market segment chosen, the basis for competitive advantage for the organisation has to be chosen.
4. The latter choices lead to the major operations issues of a global organisation, viz.
   - **(a)** *Technology:* Choice, development and/or implementation.
   - **(b)** *Location:* Note that the technology has to be appropriate to the location, and vice versa. Location decision involves answering two basic questions among others: (i) where will the organisation's presence be, and (ii) in what form should that presence be?
   - **(c)** *Orientation:* For instance, if it is product orientation, then only a few operations facilities can produce the entire worldwide requirement (and the products would be distributed the world over from these limited production/operations facilities). If it is region or market orientation, then each region or market has one or more operations facilities. If it is supply chain orientation, then each facility produces specially assigned part/s. All these are finally assembled and distributed. Thus, comparative advantages of nations/regions enter into the strategic framework.

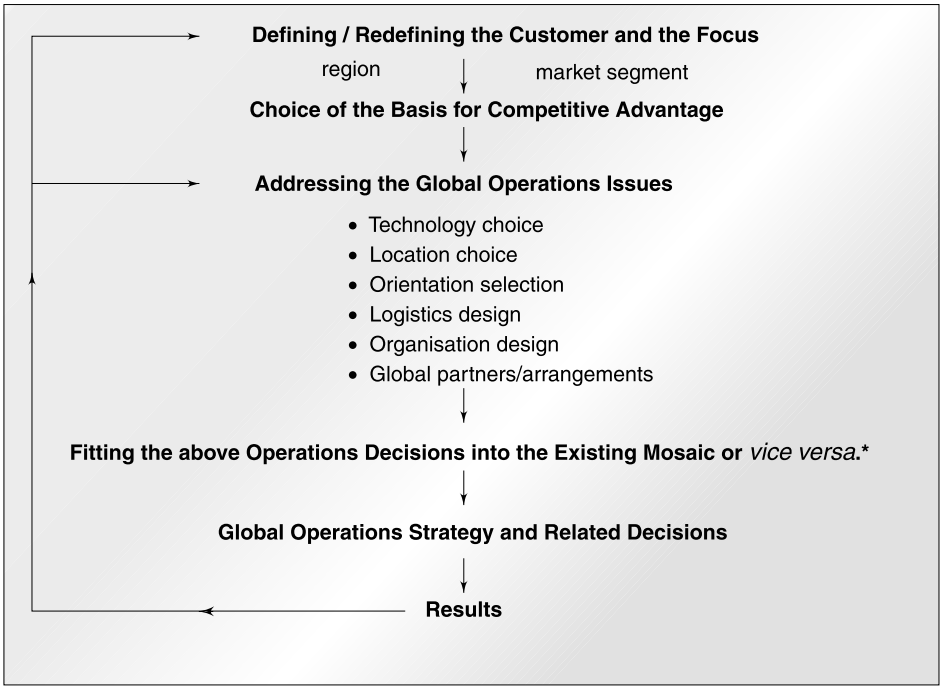
(d) *Logistics:* For a firm that is globalising, logistics is a very vital issue. Logistics involves transport issues, issues of selection and arrangement with vendors, issues of inventory/warehousing and stocks management and of arrangement of marketing/distribution channels. Logistics tries to fulfill the need to bring the operations/production closer to the customer in a globalised set-up irrespective of the geographical, political, economical, social and cultural distance.

(e) *Organisation:* Globalisation also accentuates the issues of organisational structure, management systems, resources (particulary people), and that of management style and culture which have to meet the local requirements and be congruent to the conditions of the global places where the production facilities are located.

(f) *Competitor activity:* As mentioned earlier, this is always an important input in designing a strategic response. Competitors need to be studied for (i) their markets, (ii) their capacities and locations, (iii) their capabilities, and (iv) their future plans.

5. The latter manufacturing issues lead to the arrangement of the operations functions taking into consideration the already existing operations set-up and network of the organisation, and also considering any arrangements possible with the other global players.

The above can be depicted in a diagrammatic fashion as given Fig. 2.6. It may be noted that it is a cyclical process with corrections incorporated whenever the feedback requires so.



**Note: Refer to Chapter 30 (Location of Facilities) of this book, especially Fig. 30.1*

Figure 2.6 Developing a Global Operations Strategy

A consideration of the strategic aspects of operations is necessary before one proceeds towards the details of the design of the production and operations system. In these fast-changing times, organisations must brace themselves for meeting the challenges of the future with appropriate organisational and operational strategic responses.

QUESTIONS FOR DISCUSSION

1. What is corporate strategy? How is operations strategy related to the corporate strategy? Explain.
2. What are the various strategic actions possible from operations function? List them and discuss each of them.
3. How would operations strategy for a service industry be different, if any, from that for a manufacturing industry? Cite an example and explain.
4. Strategy may be the same, but the approaches could differ with differing results. Explain this statement with examples.
5. Explain Kenichi Ohmae's 'key success factors' theory and discuss its relevance to manufacturing strategy.
6. Perform a SWOT analysis for your organisation. What strategic insights did you gain? Discuss.
7. How can you turn a 'threat' faced by your organisation into an 'opportunity' ? How will you overcome the 'weaknesses'?
8. What is Michael Porter's thesis in his Five Forces Model? Explain.
9. What is 'flexibility' in operations function? Can it be one of the strategic weapons? Explain your response.
10. How are people important in an operations strategy? Discuss what needs to be done in your organisation and in India, in general.
11. If a company is a 'technology leader', what strategic support would it require from its operations function? Discuss.
12. What has accounting function got to do with operations strategy? Explain.
13. How could the operations strategies be different for organisations that have different focus:
    (a) Customer focus **(b)** Technology focus **(c)** Product focus
    Explain the operations strategy in each case.
14. Why is 'efficiency' versus 'effectiveness of operations' debate important from the strategic angle?
15. What is competing on time? Explain.
16. What is globalisation? What are the effects of globalisation on strategic aspects of operations? Discuss.
17. Link up environmental management and operations management in a strategic framework. Explain your response.

ASSIGNMENT QUESTION

1. Take any company in the manufacturing or service sector. Study as to how its overall business strategy has impacted its operations strategy. Collect data by means of published papers, articles, books, reports and /or actual visit to the company's establishment and interviews.

3 Services

SERVICES IN INDIAN ECONOMY

The Service sector's contribution to the Indian economy in increasing at a high rate. In terms of GNP, it may not be as dramatic as in USA where it is over 70 per cent or as in Europe where about 75 per cent of the employment is in services. However, there has been a tremendous growth in the demand for services since India's independence. For instance, transport services demand in terms of the goods movement by roads grew from 6 billion tonne-km in the year 1951 to 400 billion tonne-km in the year 1995. During the same years, the passenger traffic by roads increased 65 times. It further doubled by the year 2001. The number of registered vehicles on the Indian roads increased from 1,865,315 during the year 1971 to 60,763,143 during the year 2003—a whopping rise of over 32 times in as many years. This is not to say that the required infrastructure facilities have grown in the same proportion; in fact, as per the available figures, the total road network has expanded by not about 4 times during the period 1971 to 2008.

The railways freight traffic and passenger traffic have grown from 37,565 NTKm (Net Tonne-Km) and 66,517 million passenger-km respectively in 1951 to 282,900 million NTKm and 371,421 million passenger-km in 1997. Between the years 1997 and 2007, these traffic figures have grown to a whopping 479,454 million NTKm and 602,655 million passenger-km. Table 3.1 and Fig. 3.1 present the growth in traffic on the Indian Railways.

Table 3.1 Indian Railways: Freight and Passenger Traffic

Year	*Revenue-Earning Freight Traffic NTKm (Million)*	*Passenger Traffic Passenger-km (Million)*
1971–72	116,894	125,329
1976–77	144,030	163,836
1981–82	164,253	220,787
1986–87	214,096	256,544
1991–92	250,238	314,717
1996–97	277,567	357,574

(Contd.)

Year	*Revenue-Earning Freight Traffic NTKm (Million)*	*Passenger Traffic Passenger-km (Million)*
2001–02	333,228	473,461
2002–03	353,194	498,426
2004–05	407,398	575,608
2005–06	440,883	614,452
2006–07	479,454	682,655

Source: CMIE, Mumbai, "Economic Intelligence Service", *Infrastructure,* May 2006, pg. 31 and 38.

The growth in the number of telephone lines has also been spectacular during the past decade. From 5.8 million lines in 1991–92, it has grown to more than 46.2 million lines in 2004–05, which is an increase of about 700 per cent in just 13 years. The telephone density in India has risen from 0.6 telephones per 100 persons in 1990–91 to about 6.0 in 2003 – 04. The number of cellular telephone subscribers have grown from 1.2 million in 1998-99 to 14 million in 2004–05, which is an increase of about 330 times in just 6 years. Figure 3.2 and Tables 3.2 depict the explosive growth in telephones during the recent past in India. THe survey by the Economic Division. The survey by the Economic Division, Ministry of Finance, Government of India put the figure for the cellular phones at 101 million by the year 2006, while the number of fixed lines stabilized at around 40 million.

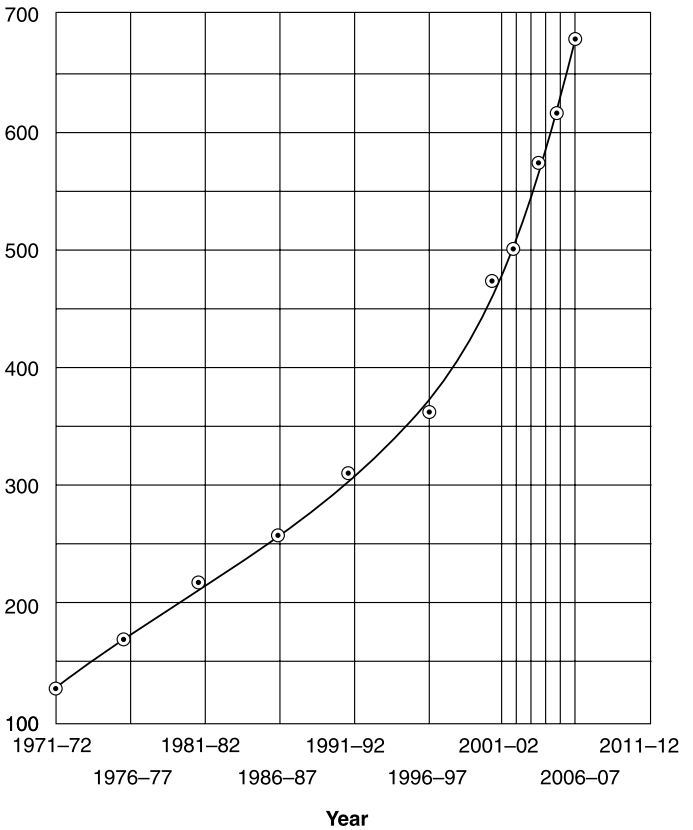


Figure 3.1 Indian Railways Passenger Traffic, Passenger-km (Billion)

Table 3.2 Growth of Telephones in India

(a) Direct Telephone Exchange Lines	
Year	*No. of Lines ('000)*
1985–86	3,166
1990–91	5,075
1995–96	11,978
2000–01	32,436
2202–03	41,930
2004–05	46,198

(b) No. of Cellular Phones Subscribers	
Year	*No. of Subscribes ('000)*
2001–02	6,431
2002–03	12,688
2003–04	26,154
2004–05	41,026

Source: CMIE, Mumbai, "Economic Intelligence Service", *Infrastructure,* May 2006, pg. 252 and 258.

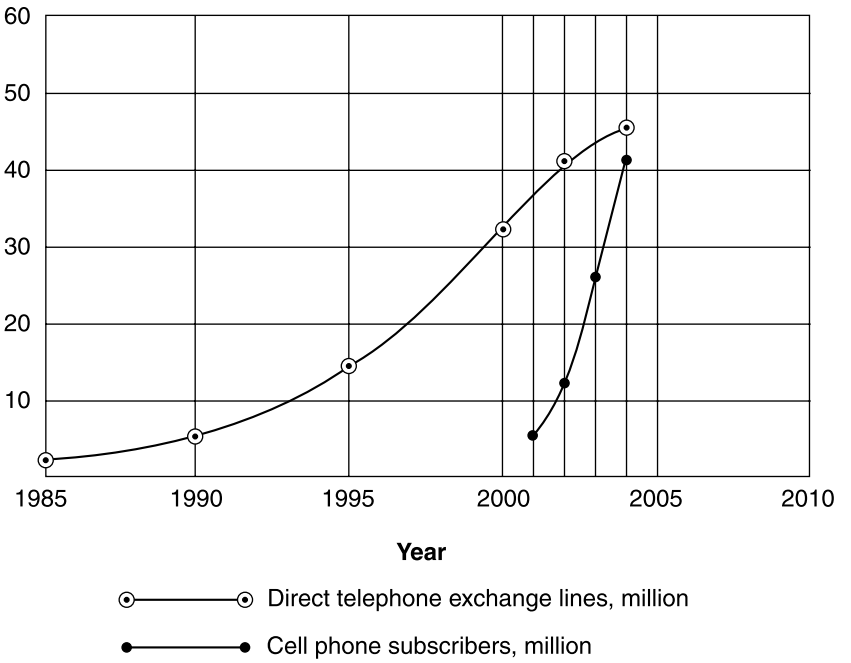


Figure 3.2 Telephone in India

Civil aviation has been growing in India. The growth has been dramatic since the turn of the millennium, i.e., since the year 2000–01. Table 3.3 and Figure 3.3 clearly show this trend.

Table 3.3 Civil Aviation in India

Year	*Passenger-km flown (lakh)*		
	Domestic	*Internationl*	*Total*
1970–71	15,590	19,963	35,553
1975–76	20,173	35,841	56,554
1980–81	39,172	67,632	106,804
1985–86	68,348	79,275	147,623
1990–91	70,281	88,202	158,483
1995–96	92,493	122,568	215,061
2000–01	122,875	139,282	262,157
2002–03	128,480	158,190	286,670
2003–04	145,660	181,070	326,730
2004–05	180,308	222,722	403,030

Source: CMIE, Mumbai, May 2006, "Economic Intelligence Service", Infrastructure, pp 226–227.

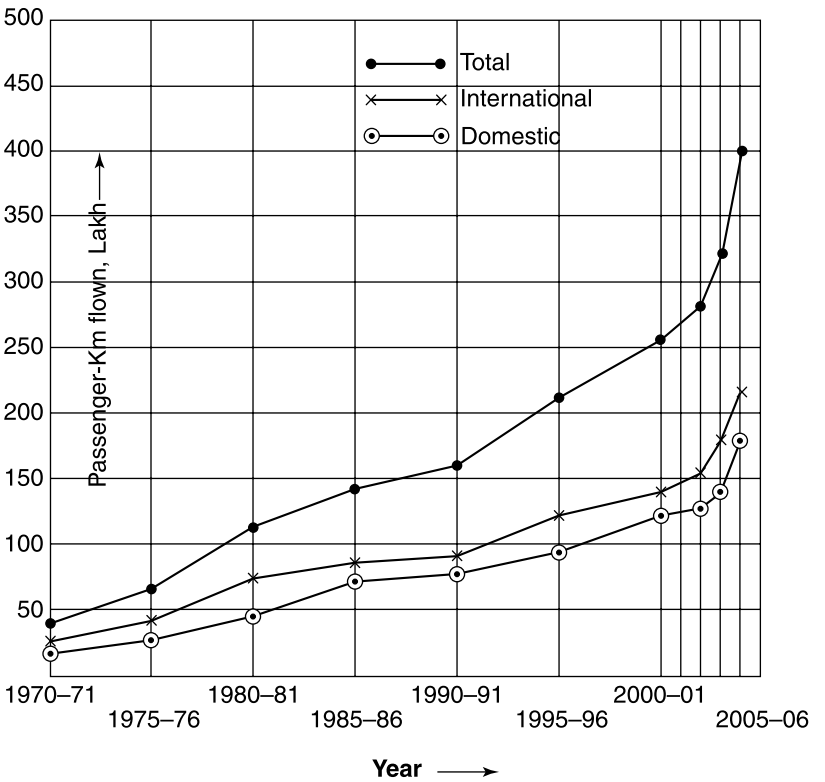


Figure 3.3 Civil Aviation in India

The last two decades have seen a boom in consumerism in India. Services related to consumer goods and consumer services *per se* have seen a significant rise in the country. The social characteristics of India and the lifestyle of Indians are rapidly changing. Indians have become increasingly pleasure seeking. The size of the middle-class has increased along with its purchasing power. More families now go out to eat in restaurants; travel is no longer just for pilgrimage or business, but it is undertaken increasingly for pleasure. The demographic characteristics of India are changing. The average life span has increased. In urban India, the number of cases where the husband and wife both go out to work have increased. Families have become more nuclear. These changes have given rise to an increase in the demand for support services. A tremendous increase in the number of fast-food joints, take-home services, creches, play-homes and pre-nursery schools, beauty parlours, beauty clinics, and schools, activities to reduce mental and physical stress such as Yoga, Reiki, etc. can be felt these days.

The opening up of the Indian economy for the multinationals will further change the social scenario. Open doors for foreign direct investment, open skies i.e. air travel, open media (newspapers, electronic media), open telecommunications policies are going to usher an unprecedented increase in the availability of services. Consequently, the Indian population is now going to get more used to the services. It will, and has already started to, ask for better services from even the physical goods manufacturing companies. For instance, after-sales-service is now gaining prominence. And, no doubt, the Indian businessman/industrialist is realising that without a substantial service component to his product, it is not possible to survive in the globalised market.

WHAT IS SERVICE?

Intangibility of Service

In order to understand as to what difference this increasing orientation to service is going to make in the production/operation decisions, one ought to understand as to what the 'services' are all about. One distinguishing feature about any service is that it is not tangible like the physical goods. This implies that a service is mostly 'felt' i.e. it is mostly a characteristic connected with the mind or psychology of the persons.

This characteristic regarding has tremendous implications regarding the 'quality' aspects of a service. In other words, the service quality cannot be measured wholly by physical specifications alone. In the control of quality of the physical goods, it was assumed that a complete hold over the product specifications was all that was required in order to offer consistent quality to the customer. But now, consumer's/customer's mind comes into the evaluation of the quality of a product, as much as the product's physical characteristics.

Thus, the 'service product'* consists of:

(i) Physical items or facilitating goods,
(ii) Sensual benefits or explicit services, and
(iii) Psychological benefits or implicit services.

For a passenger airline, the physical items consist of the aircraft itself—including its capability to transport the person quickly to the desired destination. Thus, the experienced pilots and engineers also form a part of the physical component of this 'service product'.

* Sasser, W., Olsen R. Paul, and Wyckoff D. Daryl, *Management of Service Operations: Text, Cases and Readings*, Allyn and Bacon, Boston, Mass., USA, 1978.

The sensual benefits consist of good food, good taste of wine, the beautiful polite, friendly and always cheerful air-hostesses. The cushy seats combined with the beautiful sights of pretty/handsome people, melodious music of your choice right at your seat, a good movie if you care to watch (not being disturbed by the sound, in case you desire to sleep), all add up to the sensual benefits.

The psychological benefits consist of a feeling of status (e.g. travelling by Concord—an exclusive experience), a feeling of being looked after and cared for, a feeling of safety and dependability, and a feeling of being acknowledged as an important person (through the behaviour of the air-hostesses, stewards and the captain—who greets you even during the middle of the journey and offers you information on the mountain range below, the city that you have passed, the height and speed at which you are flying, etc. You feel as though you are an overlord of these natural as well as man-made creations).

All the three components are important. Since in most airlines the type of aircraft, the frequency and the destinations covered will be comparable, therefore, the latter two components may make the difference between the service product of one airline from that of another. That is the reason why various airlines keep advertising the sensual and psychological benefits they offer. Singapore Airlines have concretised these benefits into a symbol viz. the 'Singapore Girl'—an embodiment of gentle, courteous service by a gracious, charming, helpful hostess. 'Singapore Girl' became their unique selling proposition. In 1979–80, Singapore Airlines' advertisement presented the Singapore Girl as a mysterious world traveller. The advertisement copy read:

> Through the sheen of a London cab window, I glimpsed you passing. Who are you? Where were you going? In the serenity of a Hong Kong temple you lit sweet incense. What were you thinking? Who are you, Singapore Girl? When will I see you again?

Thus, travelling by Singapore Airlines became a poetic, mysterious, ethereal and romantic venture.

Customer's View

Of course, while designing the package of the service product, one must first try to fathom as to what the customers really expect. For example, for Boston–New York shuttle flights all that the customers expect is that there should be frequent flights to ferry them quickly from Boston to New York or *vice versa*. Thus, frequency, quickness, timeliness, 'no waiting in the line' and reliability to ferry are the important attributes. There is not much point in offering ethereal experiences when the needs and expectations are very earthly or mundane.

Which means that the following may be some of the ways in which customers think about the service attributes:

1. *One overpowering attribute* For example: Dombivli to Mumbai VT fast local train should transport you in 55 minutes flat with just one stop at Kurla. The other attributes of the local train service carry little or no weight.

2. *Single attribute with threshold minimums* For instance: Middle class non-resident Indians visiting India from New York or London, availing of the cheap economy fares offered by one of the airlines of the Middle East region, which saves US $1,000 per trip per person, just have one primary attribute under consideration: the cost of air transport i.e. the price of the ticket. The other attributes such as the comfort and the inflight service are expected to meet just the threshold values.

3. *Weighted average of attributes* In this case, all attributes are important enough. Some may be considered a little more important than the others. So, a 'weighted average' is what the customer evaluates regarding the 'goodness' of the service. Since it is an average, a deficiency in one service attribute can be made up by more service on some other attribute. For instance, the lack of politeness in a restaurant can be made up by the fast service or by the good taste and aroma of the food.

In order to design the service system, one should know what the customer expects and in which of the above three ways he/she evaluates the service product. All the operations decisions related to the service depend upon this assessment. These operations decisions address questions such as: What tasks to include? Where should the operations facility be located? What kind of products need to be prominently presented? What kind of products should be excluded? What type of manpower is necessary? What should be the training given to the staff? What should be the level of mechanisation? Where should the staff be deployed? What should be their tasks? How should the facility be designed? What should be the 'people ambience' of this service product? What should be the customer's involvement in the service delivery?

For example, a department store which caters to the rich or super-rich clientele should be very careful as to the choice of its location. It has to be located in a posh, up-market, snobbish area. Exclusivity is the main attribute needed along with threshold minimums of quality of goods, politeness and comfort. The products which should prominently figure would be the foreign goods or domestic goods which are clones of foreign goods, expensive items, exclusive brands and big names along with a dash of quirky, off beat items for the bold and the rich. Of course, even rich people need 'daal-chaawal' (staple items) and these should be carried by the store in adequate quantity but not displayed bluntly. The store should employ modern-looking, suave young women or men who would look equally stylish and snobbish while appearing to be polite. The pricing should be such that only the rich or super-rich can afford the goods stocked therein. This way, the ambience of the store is controlled. What may appear like an anti-thesis of service, the staff should be snobbish enough to discourage the other than rich people to use the store. To the thus 'selected' customers, the store may now offer various explicit services such as a welcome soft drink or soft tunes of piped in music, air-conditioning, beautiful and courteous attendants, and the like. It may even include a lounge where the customers can sit, socialise and be seen to have shopped at this exclusive store.

Table 3.4 provides a comparison between services and physical goods with respect of several aspects related to management.

Non-inventoriability of Services

The other distinguishing feature of services as opposed to the physical goods is that the services are not inventoriable. A service is produced and consumed simultaneously. In this sense, a service does not exist; however, the results of the service last for some time.

This feature of services has several ramifications for the operations design, operations planning, implementation, monitoring, control and for the strategic aspects of operations.

One simple but important realisation is that there is no back up or supporting inventory if the service were to slip down or if it was rendered/delivered with defects. There is no room for error. There is no recall of the services possible. It has to be performed *right the first time*. This operations principle, which has assumed so much importance these days, appears to have its genesis with the

Table 3.4 A Comparison of Services and Goods

		Service	*Goods*
A	**Physical**		
	Entity	Intangible	Tangible
	Storage	Not Possible	Possible
	Quality	Varies with time and person	More standardised
	Producer	Inseparable from service	Can be separate from goods
	Labour intensity	Tends to be high	Lower (?)
	Life	Short	Longer
B	**Production**		
	Production	Spontaneous	Time-spread
	Customer involvement	High	Can be low
	Physical presence of the	Essential	May not be necessary customer
	Physical surrounding	Very important	May not be important
	Standardisation	Only for some routine services	Possible all over
	Facility location	Close to customer	Near supply (?)
	Facility design	To accommodate physical and psychological needs of the customer	To enhance production
	Product design	Environment plays a vital role	Only physical product
	Process design	Immediate effect on customer	Customer not involved
	Scheduling	As per customer interest	Completion dates
	Production planning	Smoothing results in losses	Possible
	Inventory	Personnel	Raw material
	Quality control	Varied quality standards	Fixed
	Quality objective	Zero defection	Zero defect
	Worker skill	Interaction	Technical
	Time standard	Loose	Tight
	Capacity planning	Fluctuating	Average
	Wage payment	Time-based	Unit-based
	Type of technology	Generally soft	Generally hard
C	**Marketing**		
	Delivery	Along with production	Separate from production
	Demand	Fluctuating	Stabilised
	Supply	Constrained	Flexible
	Title	No ownership	Ownership possible
	Seasonality	May be there	May be there
	Consumer reaction	Spontaneous	Delayed

(Contd.)

		Service	*Goods*
	Pricing	Labour-based	Material-based
	Basis of competition	Personalisation	Technology
	Channels	Shorter	Longer-usually
	Repairs	Impossible	Possible
	Need satisfied	More emotional	More physical
	Replacement	Rare	Common
	Forecasting	Short-run	Long-run
	Image	Corporate	Brand
	Physical movement	Of the provider	Of the goods
	Cost allocation	Difficult	Easier
D	**Strategy**		
	Orientation	External and Internal	External
	Focus	Customer expectations	Customer needs
	Approach	Focused	Can be diffused
E	**Organisation**		
	Structure	Flatter	Taller
	Role of higher levels of management	Supportive	Demanding
	Communication	Criss-cross	Vertical, mainly
	Desired design	Organic	Rational

growth of the services sector all over the world. A physical product is no longer just a physical entity, it has the company's reputation tagged on to it. This reputation gets damaged or reinforced depending upon whether the product is defective or defect-free. The transformation of the 3-sigma limits of quality into 6-sigma limits is due to the realisation of this aspect.

Customer Involvement

Besides the quality aspects, the non-inventoriability of services also means that the customer may be directly involved in operations, the production and consumption taking place simultaneously. The service provider and the service, both, are there with the customer. The implications are:

(i) Since the customer is involved directly, he introduces uncertainty into the design of the service product and into its production and delivery process, which is difficult to control.

(ii) Location of services have to be next to the customer or he has to be brought near the service.

The questions therefore are: How much of the product choice be left to the customer? How should customer be induced and/or disciplined to follow the production process designed by the service organisation? For instance, McDonald's has a certain limited choice of the burgers—big, regular, with/without cheese and vegetarian and of the French Fries. The customer coming there is happy to choose between these limited offers. He also follows the procedure of self-service by

picking up the tray as well as dropping it at an assigned place after the eating is over. Customer is provided all the conveniences in doing these jobs. He is also made to feel this as a superior experience.

Controlled Flexibility

The whole point raised by services is controlled flexibility. Flexibility should be present in the operations but without introducing chaos into the production/delivery system. Therefore, standardisation of the operations procedures and systems is as essential as the room provided for continual improvement.

MOMENTS OF TRUTH

Albercht and Zemke* have termed the points in time when the customer comes in contact with the service production/delivery system as 'Moments of Truth' during the cycle of service delivery. At that moment when the customer receives service, he forms an impression about the service received. The cumulative effect of these moments of truth is important. A bad moment of truth can nullify many good moments of truth. For a hotel, the cycle of service delivery could be as shown in Fig. 3.4.

Of course, within each broadly described contact point mentioned in Fig. 3.4, there could be many a 'Moments of Truth'. Every one of these moments is important. First in the sequence, the telephone receptionist has to be polite and pleasant even while she/he has to inform the customer about the unavailability of a room on a certain date. Whatever may be the quality of food, drinks, room conveniences, swimming pools and the shopping facilities offered at the hotel, the contact

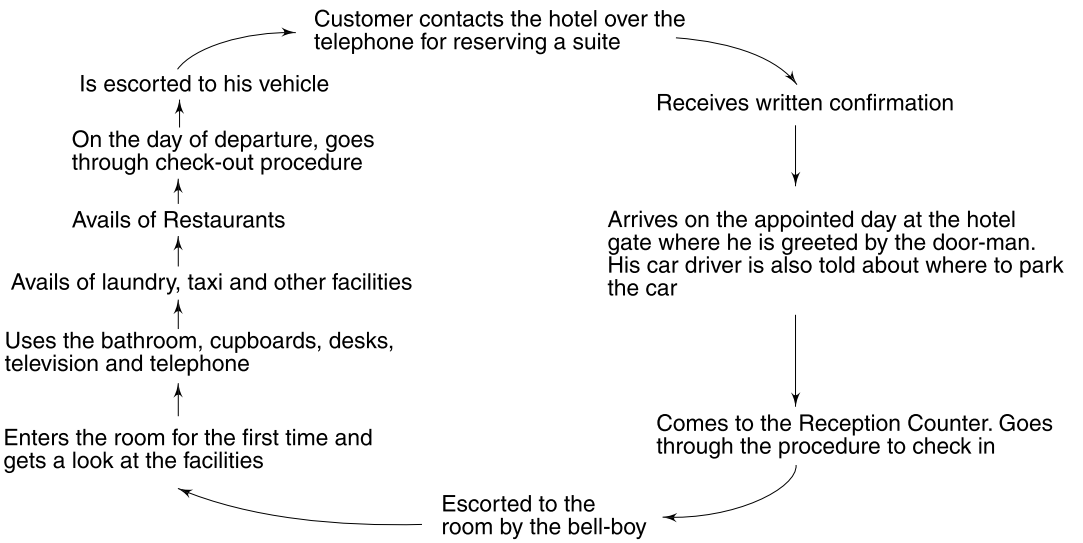


Figure 3.4 Cycle of Service for a Hotel

* Albrecht, Karl and Ron Zemke, '*Service America*', Dow Jones-Irwin, Homewood, Illinois, USA, 1985.

with telephone receptionist and then with the reservation staff forms the first impression. Then, it is the confirmation letter—the text, the tone, the unambiguity, the reassurance of an enjoyable stay. When the customer arrives at the hotel, it is the doorman's actions that matter and later those of the staff checking the customer in; it also includes the system/procedure of checking in. In short, there are so many moments of truth even before a customer has actually entered his suite. The customer's perception of service is a function of all the moments of truth he has experienced.

MANPOWER IMPLICATIONS

The distinguishing feature about services is that most of the moments of truth are involved with the lower or lowest level of staff. In a hotel, it is the bell-boy, room attendant, reception clerk, waiter or bar-tender. Rarely will the customer ever come into contact with the managerial or even supervisory staff. In an airline, it is the reception clerk, checking-in staff including the clerk and the porter, the air stewardesses and, again, the porters handling your luggage at the air terminal. Passenger satisfaction depends upon these persons, whether they have done their job to his expectations. How will they perform their tasks right?—Particularly, in light of the fact that each customer may have a different behavioural pattern. Certain problems, if and when they arise, have to be sorted out there and then. Firstly, the routine part of the operations needs to be well thought out with all micro-tasks properly planned. Secondly, the personnel have to undergo adequate training to perfect these micro-tasks along with appropriate verbal and facial expressions. Thirdly, they should be empowered to sort out any variations by themselves; because, in services the reaction of the customer is spontaneous and could be varied. This empowerment of people is an essential ingredient of the service operations management system, particularly the kind of service system where customer-contact is high. The traditional hierarchical pyramid may have to be inverted so that the emphasis is put where it belongs, where the rubber meets the road, with the customer contact people. Figure 3.5 is illustrative.

N.R. Narayana Murthy, Chairman of the IT major Infosys says, "Empowerment is important for a service company to succeed. Once budgets are set, the project people are free to take any decision".*

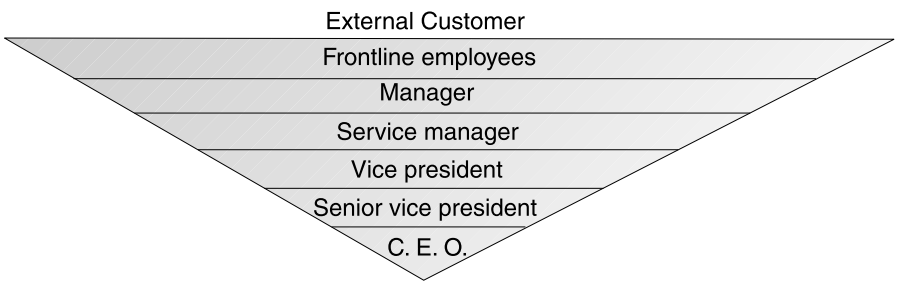


Figure 3.5 "Servant Leadership" and Inverted Hierarchical Pyramid

Source: Bounds, Greg, Lyle Yorks, Mel Adams and Gipsie Ranney, *Beyond Total Quality Management: Towards the Emerging Paradigm*, McGraw-Hill, Singapore (International Edition), 1994.

* Magsaysay, Jet, 'The Best Ideas for 1998', *World Executive's Digest*, (Jan. 1998), p. 26

SERVICE MATRIX AND IMPLICATIONS FOR OPERATIONS POLICY

Lovelock** classified the services in several ways, in order to find the implications of a particular class of service to the management actions necessary. One of the four-way classification involves:

1. Tangible actions to people's bodies, e.g. hair cutting, restaurants.
2. Tangible actions to physical goods, e.g. laundry or cleaning the clothes, air freight.
3. Intangible actions directed at people's minds, e.g. training and education, broadcasting.
4. Intangible actions directed at people's intangible assets, e.g. banking, legal service, insurance.

Figure 3.6 presents this classification. The two rows classify the service act into tangible and intangible in nature. The columnar division consists of who or what is the direct recipient of the service i.e. whether it is people or things (*Possessions*).

When tangible actions are directed at people's bodies, then the customers have to be physically present during the service operation/delivery. Customers must enter the 'service factory'. For instance, a customer must enter a taxicab in order to be transported or must enter a clinic/hospital in order to get better.

The customer satisfaction depends heavily upon the interaction with the service personnel, e.g. taxi driver, nurse, doctor; it also depends upon the nature of the service facilities and upon the characteristics of the other users of the service.

Aspects of location and convenient times assume great importance when customer has to be physically present during the service.

What is the Nature of the Service Act?	People	Things (Possessions)
Tangible Actions	Service directed at people's bodies: • Health care • Passenger transportation • Beauty salons • Exercise clinics • Restaurants • Haircutting	Service directed at goods and other physical possessions: • Freight transportation • Industrial equipment repair and maintenance • Janitorial service • Laundry and dry cleaning • Landscaping/lawn care • Veterinary care
Intangible Actions	Service directed at people's minds: • Education • Broadcasting • Information services • Theatres • Museums	Services directed at intangible assests: • Banking • Legal services • Accounting • Securities • Insurance

Figure 3.6 One Method of Classification of Services

** Lovelock, Christopher H., *Classifying Services to Gain Strategic Marketing Insights*, Journal of Marketing, Vol. 47 (Summer 1983), pp. 9–20.

If the direct recipient of the service happens to be a thing, then it may not be necessary for the customer to come in contact with the service personnel. While the outcome of the service is important, but the process of service production/delivery may not be of any interest to the customer. The number of 'moments of truth' are substantially lower in this case.

Due to this reason, sometimes organisations may prefer to convert a people-directed service into a thing-directed service. For instance, much of customer-interfaces in banking are reduced through credit cards and through ATMs.

Similarly, the service operation (imparting education) can be transformed into a manufactured product such as Video Films on various study topics or television-based educational programmes, e.g. Zed ('Z' education), UGC programmes, Brilliant's video films on management. In this manner the intangible action to people can be converted into a tangible action directed at a thing. Thus, the service product's outward shape and its delivery can be altered to suit the operational requirements.

CAPACITY MANAGEMENT

Capacity management is an important task faced by the service managers. When the demand fluctuations are present, a physical goods manufacturer can bank upon inventories of goods. But, services are not inventoriable. So, what could be the strategies to manage the demand variations? In order to understand this problem better, we must ask the following basic questions:

1. Are the demand fluctuations (cycle of fluctuations) predictable? For instance, the peak demand for accommodation in Goa comes during the Christmas–New Year season and the demand is fairly high from November end to June beginning. Thereafter, it is the monsoon season with incessant rains and the demand is very low. Thus, the demand fluctuations are predictable in this case.
2. What are the underlying causes of these fluctuations?
   - **(a)** If it is customer habits, could these be changed through pricing, promotion, place or product strategies?
   - **(b)** If it is the actions by third parties, could these third parties be influenced? (e.g. Working days and hours set by industries, businesses, offices, and institutions).
   - **(c)** If it is non-forecastable events, very little can be done to meet this sudden demand. Of course, the services could then be offered on a priority basis to a portion/section of the people demanding the service; others can be informed about alternative sources of service so that they are not neglected in their times of need.

METHODS TO DEAL FLUCTUATING DEMAND

1. One obvious way to deal the fluctuating demand is to plan the capacity based on peak demand as opposed to average demand. Of course, the relative economics of providing the service (costs) versus a dissatisfied customer (lost revenue, lost goodwill, damaged image) needs to be worked out.
2. Since service output is non-inventoriable, a *safety capacity* may be provided (in place of safety stock in a physical goods manufacturing company). Capacity includes in its gamut the service providers or manpower, the space where service is provided, the equipment in equipment-oriented services, and the materials. Capacity management is crucial to

the success of the service organisation. There are other types of questions like: Should a restaurant have a larger dining area to that of the waiting area? Bangalore's famous Mavalli Tiffin Room (MTR) has this capacity management problem during peak hours. But, since it has succeeded in creating an impression amongst the customers that the dining experience is worth waiting for, MTR has provided a large space for seating the waiting customers. To introduce order into the fluctuating demand on capacity, it has introduced a system of registering names on arrival and calling the customers on a strictly first come first serve basis. In MTR's case waiting, then, becomes a part of the service package.

Speaking about excess capacity or safety capacity, sometimes a decision is to be made regarding the distribution of the capacity: for instance, should an airline buy ten 727s or five 747s?

Extra capacity in terms of manpower can be created by scheduling the personnel in overlapping shifts.

3. In any case, the demand can be rationed through a queuing system or reservation system. This is much prevalent in India. However, in these cases, the organisation is basically inventorying the demand rather than the supply.
4. Other way to deal with fluctuations in demand is to influence customer demand by offering a different price and product package during periods of low demand. For instance, hotels have special season rates; airlines can offer special rates for weekday flights so as to reduce the peaks on weekends and increase the demand on weekdays.
5. Capacity management can also be done by capacity allocation. For instance, the airlines can change the percentage of the capacity allocated for first class, business and economy classes according to the season of demand. During the high demand season, it could have larger percentage of seats allocated to first and business classes as opposed to the economy. During low demand season, the airline could allocate a large percentage of seating capacity to the economy class and much less to the business and first classes.
6. If the degree of automation can be increased without affecting the overall quality to the customer, then this would help in meeting the peaks in demand for services. For example, part of the usual banking transactions can be done through Automatic Teller Machines (ATM). Of course, there is always a limit as to how much (what areas) of a particular service can be mechanised? And, how many of the customers would be willing to shift to a non-personalised service? In which case, the loss in personalisation has to be compensated by providing alternative components to the product package, such as convenient locations for the ATMs and substantial saving on time.

THE LINKS BETWEEN CUSTOMER, SERVICE STRATEGY, SERVICE PROVIDERS AND THE SERVICE SYSTEM

As services are customer-centred, the strategy, systems and people in the operations of services should also focus on the customer. Albrecht and Zemke's 'Service Triangle' diagram makes it more clear (refer Fig. 3.7).

Customer's expectations are central to the design of service strategy of the firm. This link is brought out by the line from customer (at the centre of the triangle) to strategy.

The line linking customer to people (service providers) signifies that the people are extremely important in producing and delivering service to the customer.

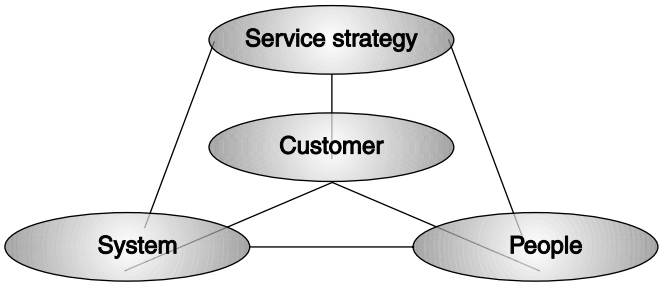


Figure 3.7 The Service Triangle

Source: Albrecht, Karl and Ron Zemke, *Service America*, Homewood, Illinois, USA, Dow Jones-Irwin, 1985.

The customer to systems link shows that the service operations/delivery system should also be designed with the customer in mind. Customer service should be an integral part of the design of the service system. It is not 'after sales service', but 'production and sales with service to the customer in focus'.

The strategy to system link means that the systems and procedures should follow from the service strategy. The systems should support the strategy.

The strategy to people link means that all the service providers (people in the service organisation) should be well aware of the organisation's strategy. Earlier in this chapter there was a mention about inverted pyramid and servant leadership, this cannot be effective unless the people at the grassroot level know and understand the service strategy very well. Empowerment of people without proper alignment of the mission, goals and attitudes of the management and the people, would be directionless.

The system to people link means that the service operations systems and procedures should be people-friendly. The empowered and motivated workforce (which understands the operations strategic focus and intention) should have adequate back-up of good systems. After the alignment of the people with the organization's goals, the processes and systems have to be designed to govern the people's daily activities.

All the above are important considerations in the design and implementation of service operations. The 'service triangle' as a diagram presents them in a concise and simple manner.

SERVICE QUALITY

A management guru, Phil Crosby defines quality as conformance to specifications.* Christian Gronroos** makes a distinction between:

Technical Quality … … … … What is being delivered, and
Functional Quality … … … … How it is delivered.

That is, customers do not evaluate a service solely on the outcome of the service. The 'how' i.e. the 'process' of service delivery—for instance, how the porters at the baggage counter of

* Crosby, Philip B., *Quality is Free*, McGraw-Hill, New York, 1979.

** Gronroos, Christian, *Strategic Management and Marketing in the Service Sector*, Marketing Science Inst., Boston, May 1983.

an air terminal handle the baggage—is critical to the perception of quality. Moreover, the only criteria that count in evaluating a service quality are defined by the customers. Only customers can judge quality; all other judgements are essentially irrelevant. That is the reason why competitors commonly offer the same services but different service. Table 3.5 provides several factors that could be important from the customer's viewpoint.

Service quality, thus, involves several aspects relating to customer's perception and their pre-purchase expectations.

Customer goodwill is very important in services. It makes the customer more tolerant when service problems occur. A service as mentioned earlier, is a social interaction. Relationships are the foundation stones on which the edifice of service is built. The more personalised a particular

Table 3.5 Determinants of Service Quality

Reliability	… …	Consistency of performance and dependability. It means the firm honours its promises and delivers the service at the appointed time.
Responsiveness	… …	Timely/prompt response to the service need of the customer. Readiness of the employees (of the firm) to provide service.
Competence	… …	Includes knowledge and skills not only of the contact personnel but also of the support personnel.
Access	… …	Involves the approachability and ease of contact. Includes the convenience of location of the service facility, its hours of operation, its communication and logistics facilities, as also the attitude of approachableness on the part of the people in the service organisation.
Courtesy	… …	Politeness, respect and consideration for the customer, and friendliness of the contact personnel and of the entire organisation.
Communication	… …	Communicate to the customer about the service, about the agreed terms, about the service organisation, so that there is no ambiguity and customers are properly informed and reassured. Similarly, perhaps more importantly the communication channels should be open to listen and thus understand the customer.
Credibility	… …	Trustworthiness of the service company. This can come from the company's reputation and brand name. Most importantly, it comes from basic honesty of the service firm and the same honesty exhibited by its contact personnel.
Security	… …	Involves: **(a)** Physical safety (will I get robbed at the bank's ATM?) **(b)** Financial security **(c)** Confidentiality (some services rendered need to be kept confidential; e.g. Psychiatrist's counselling.)
Understanding the Customer	… …	This consists of understanding customer's specific requirements, needs and expectations. This aspect is central to service quality. It deals with not only communication channels but also about the attitude of the service firm and its people.
Tangibles	… …	Consists of physical aspects of service—the physical evidence of the service: Physical facilities, equipment used, appearance of people delivering the service.

Source: Parasuraman A., Valerie A. Zeithaml and Leonard L. Berry, 'A Conceptual Model of Service Quality and its Implications for Future Research, *Journal of Marketing*, Fall 1985, pp. 41–50, American Marketing Association, Illinois, USA.

service, the more important it is to build this relationship. However less personal certain services may sound, they cannot be devoid of the emotional content. Even an Automatic Teller Machine, which apparently involves no human interface, is used by the customers on trust and dependability of the people in the Bank if anything were to go wrong. The customer operates it backed by the trust he places on the Bank, i.e., its people.

GLOBALISATION OF SERVICES

Most businesses, whether these are of the manufacturing or of the service kind, offer their customers a package that includes a variety of service-related activities. We have called it as 'service product' or 'service package'. In any service, there is the 'core product' and the supplementary elements (which are termed as 'augmented product' and 'extended product'). There can be several different supplementary elements. Lovelock* has called the service product, which consists of the core product surrounded by supplementary elements as the 'flower of service' (refer Fig. 3.8)

Increase in globalisation necessitates a firm to look for global standardisation with local customisation. We may call such a combination as 'mass customisation'. A global company can offer a globally standardised core service augmented and differentiated by nationally customised augmented/supplementary service elements. The 'petals' of the Flower of Service can be adapted according to the local preferences, their ability to pay, the local customs and cultural patterns.

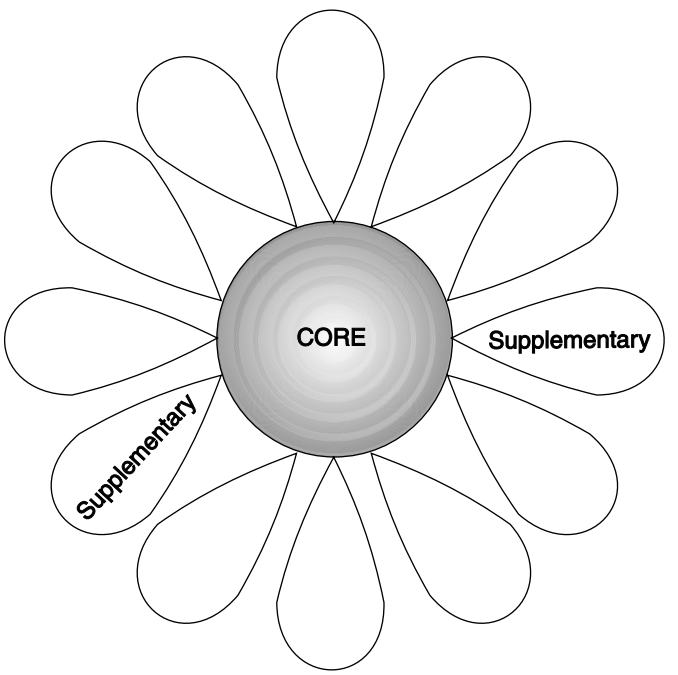


Figure 3.8 Flower of Service

* Adapted from Lovelock, Christopher H. and George S. Yip, 'Developing Global Strategies for Service Business', *California Management Review*, Vol. 38, No. 2, Winter 1996.

The service characteristic of 'customer involvement in production' puts a damper on the global standardisation. But, if this service characteristic assumes less importance, like in fast food business or airlines where the customer involvement is tightly controlled, global standardisation becomes much easier. Global customers for possession-processing services prefer common procedures and standards. For instance, airlines depend on their aircraft being maintained the same way all around the world. A possession-processing firm such as Citibank has expanded in banking service (any way, any where, any time) through Citicard Banking centres with their ATMs to 28 several countries, the banking centres being linked globally for 24 hours 7 days a week. Global customers of people-processing services may also like standardisation when they are travelling around the globe.

Globalisation of any business demands that at least the 'core product' be standardised. However, this is not possible in all types of businesses. Hotels, for instance, find it difficult to reproduce their core strength overseas; the reason is their heavy dependence upon people and, therefore, the vulnerability to varying labour attitudes and productivity across the globe. This is the reason why the multinational hotels cannot be a very big threat to Indian hoteliers. The multinational hotel chains can make a difference with advanced equipment and hi-tech; but, that is not the core product. In general, people-processing firms will find it harder to globalise than the possession-processing services. The latter kinds of services do not need to cope with cultural and taste differences; only, some technical specifications may vary from one country to another such as 230 volts in India to 110 volts in the USA.

Globalisation also raises the issue of location. People-processing firms, in general, would need a higher degree of local presence and more number of local sites than that required for possession-processing firms. Location decision has been one of the important strategic decisions for any firm. Service businesses, particularly the people processing kind, need local presence at least for their downstream activities. But, at the same time, they can take advantage of the different nations' differing comparative advantages and build more efficient and effective value chains. For instance, McKinsey & Company, the management consulting firm, now sends some of its work for clients from high-cost countries to its offices in a low cost country like India. To quote another example, some US banks and insurance companies now send their cheques and claims to be processed in Ireland or in East Asia. Needless to mention that only those links of the value-chain can be located outside the customer's country (or region) which do not involve aspects of differing local preferences and differing norms or those parts of the value chain which are immune to local differences.

Information-based services have less problems in globalising because of the availability of electronic channels of communication; thus, the logistics aspect is taken care of for most of the part. Firms providing information-based services can concentrate production in locations that have specific comparative advantages such cost savings or specific expertise or advantageous tax (and other) policies of the local government. For instance, India is one of the favoured locations for computer software production because of the low wages and acceptable expertise. Even in this business, certain client-specific and country-specific products have to be produced in the client's country or nearer to client's location. Information technology has been instrumental in minimising the logistics problems in services, making it possible to separate the value chain into its various constituent parts and thus, allowing the firms to benefit from the comparative advantages of different locations.

MANUFACTURING AND SERVICES

Although this chapter has been devoted to Services, it must have been clear by now that, there is no such dichotomy between manufacturing and services. No physical product can be devoid of services. First of all, the *raison-de-etre* of the product itself is some type of service. Secondly, a customer never buys a product as just a product; he looks at it with all the other sensual and psychological characteristics attached to it. For instance, he buys a Kirloskar Genset not only because it is a genset but because it comes with the Kirloskar brand name that spells several services (tangible or intangible actions) that accompany the product. With increasing degree of globalisation and rapidly accelerating speeds of information and technology transfers the chances are that the physical products of competing companies will be more or less the same; the avenues for product differentiation will arise mainly from the services.

Some would like to categorise the current business scenario as one belonging to 'information and knowledge'. It is true that there is a lot of information that is generated and shared within the organisation and outside the organisation. However, information is not enough. It has to be converted to 'knowledge' that could be used in the present and in the future in the face of unusual circumstances. The objective of these efforts is to serve the customer to her satisfaction. Service is the hallmark of the present times. The objective of manufacturing too is that of providing service. Once this principle is borne in mind, the various operations decisions fall in place. Decisions could be strategic or tactical; these could be for any type of an industry or sector, they could be about timing, supplies or space arrangement. No matter what kind they are, all of these decisions have the common focus of providing service.

QUESTIONS FOR DISCUSSION

1. Production of services is spontaneous as opposed to manufacture of goods which is spread over a time period. What managerial policy implications does this distinction have for increasing service content in a traditionally manufacturing industry?
2. What is controlled flexibility? Discuss in the context of managing services.
3. Take up a sales order. Trace it for all the 'moments of truth'. If you were to handle the sales order the next time over, how would you do it differently?
4. How can the inverted pyramid and the traditional vertical hierarchical pyramid coexist? Discuss.
5. Give two instances as to how a people-directed service can be converted into a things-directed service? Explain.
   Does such a conversion have any specific advantages? Also explain as to what could be the disadvantages.
6. A government hospital is overcrowded. How would you, as the hospital's chief administrator, manage the capacity? Elaborate.
7. Explain the links, in the Service Triangle, between people and customer, and the service strategy and people.
8. 'Access' is an important determinant of service quality. A company is in the manufacture of drawn wires. How would you apply the 'Access' determinant in the case of this wire-drawing company?

9. Compare the 'Singapore Girl' symbol of Singapore Airlines and 'Maharaja' symbol of Air India. the service management issues.
10. Are 'Economies of scale' possible in services? Discuss giving examples whenever necessary.
11. Production and operations management generates 'value' for the customer. What is that 'value' in a service? What are the objective and subjective components of that 'value'? Discuss.
12. What are the hurdles in the globalisation of services? Mention the managerial, social and political issues.
    Are services, generally more difficult to globalise? What are the implications in the Indian context of the newly liberalised economy?

ASSIGNMENT QUESTION

1. Visit any hospital. Observe and comment on the special aspects of its operations.

SECTION II

Useful Basic Tools

Chapter 4 Relevant Cost Concepts
Chapter 5 Linear Programming
Chapter 6 Capital Budgeting
Chapter 7 Queueing Theory
Chapter 8 Forecasting

There was a time, not too long ago, when Production and Operations Management was considered to be highly mechanistic—a discipline which engineers would prefer due to their familiarity with machines and ability to solve complex mathematical problems. Operations management meant putting everything in a quantitative framework. It was assumed that most of the operations decision-making, if not all, could be put into some mathematical relationship—the one relationship which they seemed to believe in strongly.

At the time when Production Management as a discipline was taking root, there was a sudden spurt in Statistics. Additionally, Operations Research (OR) used in the World War II presented hitherto unforeseen openings in the industrial world. In order to fight the small 'war' of competitive cost minimisation while meeting production schedules, manufacturing operations used OR techniques. Now that an era of human relationships—relationships upstream (with suppliers) and relationships downstream (with customers) —had begun, would hard math-based decision-making tools be of any help?

The answer to the above query is in a strong affirmative. Although operations management now has as many 'soft' issues to handle as the 'hard' ones, this does not lessen the need for hard-nosed mathematical analysis. In fact, help from such an analysis is all the more required because the number, variety and uncertainty of the needs has increased at a hypersonic speed.

The OR techniques of programming such as Linear Programming will guide an operations manager as to how he should produce the best results despite facing various limitations. Queuing Theory or Waiting Line Problem has had applications in the 'waiting' of jobs in a production department and in the 'waiting' of jobs (breakdowns) to attend to in maintenance. However, queuing theory could not have asked for a better ground than the service operations. No customer likes to wait, if she can help it. But, instant gratification comes at a price. So, a solution satisfactory to the customer and the operations-persons has to be found. Waiting line problem has immense utility in these situations, in both the manufacturing and the service industries.

Forecasting is a science that tries to locate or identify the trajectories of changes. In a world which is globalised, i.e., where a lot many more players are interacting and where the moods of the market keep swinging, forecasting is all the more necessary. Several items need to be forecasted: future economies, future demands on the production and/or service system, future technological developments and even future social and political trends. Operations management is no longer confined to manufacturing in a factory. This has, however, only increased the need for the application of scientific tools and techniques of decision-making.

It must be added that despite the changes in the character of the industry, from total emphasis on manufacturing to equal attention to service, no one is ever against thrift in the use of resources and funds. Therefore, attention to capital investments and various costs is essential. It is very necessary to analyse costs and investments and the good advice from such analysis should be taken due cognisance of. Relevant Costs analysis and Capital Budgeting are such essential topics.

Science in decision-making is good if used judiciously.

4 Relevant Cost Concepts

In the last section we identified three criteria of performance of an operations management system, viz. Customer Satisfaction, Effectiveness, and Efficiency. Whatever the criterion, cost is an important element in the decision-making process. However, a distinction needs to be made between the cost for accounting purposes and the cost for managerial decision-making. Financial accounting has basic objective of fulfilling the statutory requirements of a company in terms of the profits and losses incurred by the company being made public, which is quite different from costing for internal decision-making. Although Cost Accounting fills much of the latter requirements, it is still not totally decision-oriented. Every decision is made in the context of the circumstances which are unique to that decision. When the context of the decision varies, the type of costs to be considered will also vary. This gives rise to the term relevant cost. What is relevant in one situation, at one point of time, may not be relevant to another kind of decision at another point of time. This is the distinction which relevant costs make vis-a-vis the other costing methods. In fact, the concept of relevant cost is very simple. Let us describe some of the relevant costs starting with what are known as fixed and variable costs.

DISTINCTION BETWEEN FIXED AND VARIABLE COSTS

Fixed costs are those costs which remain unchanged in spite of a change in the volume of output or in the level of activity. For instance, the rent to be paid on the office buildings or the allocated depreciation of machinery remains the same irrespective of the volume of the output. Many a time another term called overheads is used in the accounting systems. This leads to confusion with the fixed cost. In fact, 'overheads' could be either fixed or variable. Fixed costs refer to the non-variability of a certain class of costs with respect to a decision to vary the output from a plant. If a plant were to produce one lakh units instead of 75,000 units per year, the fixed cost would remain the same in both the cases. The decision as to whether a cost is fixed or not fixed is related to the question of whether the output should be increased or not. The distinctions between the costs is according to the question to be answered.

As opposed to fixed cost, those costs that vary continuously with respect to change in the production output or the level of activity are termed as variable costs. If one were to increase the

production output from 75,000 units to 1,00,000 units, that much more raw material has to be procured. The cost of the raw materials is a variable cost. Similarly, more labour hours are to be spent in making the finished product in more quantity; and therefore, the labour-hours are also a variable cost.

Of course, not all fixed costs are fixed over the entire range of output or entire range of time. When we say that a cost is fixed, it refers to a certain range of output and a particular time or a particular time span for which this is applicable. If the production capacity in the earlier example were to be increased to 1,50,000 per year, then the plant capacity would be inadequate and therefore, more machinery would have had to be procured increasing the fixed cost. This means for a range of 75,000 to 1,00,000 units per annum the fixed costs were 'X', whereas for the range from 1,00,000 to 1,50,000 the fixed cost could have been X plus another Y. Many people would like to term such cost-behaviour as semi-fixed; but, the concept of semi-fixed and semi-variable costs is only notional. The fixed or the variable nature of the costs refers to a particular decision situation.

The electricity, steam, and water consumed in a plant could be treated as a fixed cost provided there is no such decision regarding the output level being made. But when the decision regarding increasing or decreasing the output is to be made, such costs can partially vary with respect to the level of activity. Although illumination load might remain the same, the load on the machinery will increase. Although the basic heating facilities for the plant will have to be provided, additional steam input might be required to heat or to dry or to process the raw material. Even the cost of supplies such as cottonwool, grease, etc. may be variable to some extent for this decision. A decision has to be weighed in terms of its impact on the variable components of cost. Therefore, the cost for one decision cannot be treated as being the same for another kind of a decision. This is particularly relevant in break-even analyses to determine the desirable output level. A break-even analysis for one type of product is presented in Fig. 4.1.

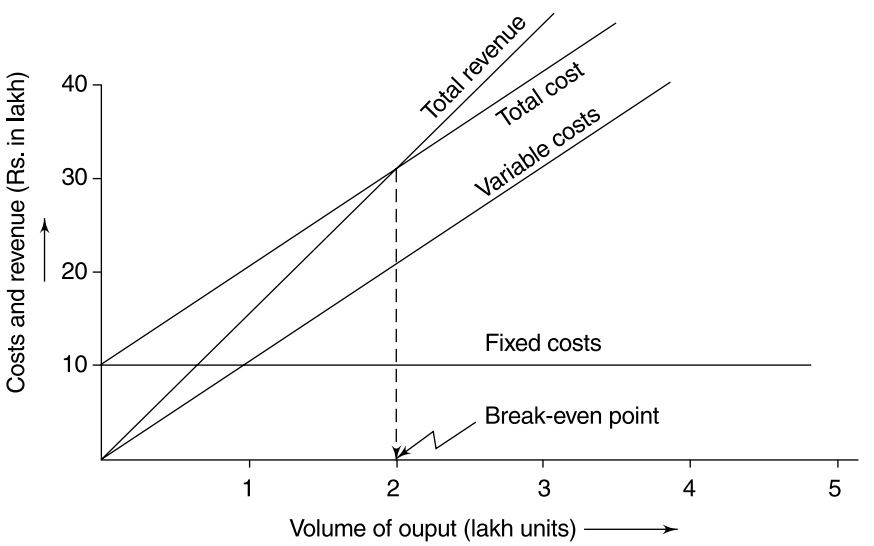


Figure 4.1 Break-even Analysis

NOTE: Fixed Costs, F = Rs. 10,00,000
Variable Costs, v = Rs. 10 per unit
Revenue, R = Rs. 15 per unit

Total costs, T_c for a volume of output = (Fixed Cost + Variable Cost for that volume of output)
Break-Even Point (or Break-Even Volume of Output), BEP, is where the Total Revenue and Total Costs are equal.

$$\text{BEP} = F/(R - v)$$

The fixed cost in Fig. 4.1 was taken to be Rs. 10,00,000 over the span of output pertaining to the decision. Similarly, the variable cost of Rs. 10 per unit was considered not to vary (per unit) over the span of the decision being taken. One has to note that the variable costs do not always remain the same in terms of their incremental value. The variable cost might increase (per unit) at a certain rate during a certain range of production and at another rate during another range of production. Similarly, as was said earlier, the fixed cost could be different for different ranges of production activity. If one takes these into account, the Break-Even Analysis will be more accurate. It is possible that even two break-even points may emerge. These will be the boundaries within which the production level has to be confined in order to make a profit. Thus, break-even need not necessarily be one particular level of activity; but, depending upon the behaviour of the variable and fixed costs one can have multiple breakeven points showing the desired output volume ranges for profitability.

The focus here is on the relevancy of cost—relevancy with respect to the question in front of the manager, relevancy in terms of the type and the quantity of cost entering into the analysis, and relevancy with respect to the time at which the decision is being made (because various times may produce different behaviours of the cost with respect to the level of the activity).

OPPORTUNITY COSTS AND THEIR USE

Opportunity cost is another important concept with respect to relevancy. The opportunity cost for a particular decision is the benefit derived from the best of the alternative opportunities lost due to the decision to choose a particular line of action. If you had Rs. 10,000 which you kept at home instead of depositing in a bank, the decision to keep the money at home has an opportunity cost of the 4% bank interest which you would have earned on Rs. 10,000. Reversely, the opportunity cost of keeping the money in a bank instead of keeping it at home, is zero; because by keeping the money at home, you would have earned no interest. To give another example, the opportunity cost of using a particular machine to produce product X is the benefit that the company would forgo in terms of not using the machine to produce other products. The opportunity cost in such a case, is the benefit that would have been derived for the best of the available alternatives which is foregone. Opportunity cost figures are important in many cases including that of materials management. When a company decides to invest Rupees one crore in the inventory of raw materials, that much of money is locked, which could have been put to alternative uses or projects. If the return on the various other projects had been 10%, 15%, 20%, then the opportunity cost of the decision to invest the money in raw materials is 20%. This is the cost of capital which needs to be charged to the raw materials. You might have borrowed money from some source at the rate of 15%. But, this is immaterial in terms of the wisdom of your decision (provided there is flexibility in your using the money borrowed from that source).

This brings us to the distinction between accounting profit and economic profit.* The accounting profit is the profit shown on the P&L Account of the company, that is, as per statutory requirements and for the information of the shareholders and other public. Although the accounting profit may be high enough, it does not show as to whether the company could have made more profits. The efficiency of the management-decision is never reflected in the accounting profits. The economic profit is for the internal use of the management of the company for giving them guidance in investment and other decisions. The opportunity cost of capital is not reflected in the P&L Accounts, whereas there are implicit costs which need to be taken into account while considering the wisdom of one decision over the other. Opportunity cost considers the full economic cost of scarce resource.

The relevant costs which should enter any decision-making are termed many a time as incremental costs. Incremental cost is the change in the total cost resulting from a decision; it is not necessarily the marginal cost which refers to a unit of output. Only the variable costs pertaining to the decision are relevant in any Incremental Cost Analysis.

SUNK COSTS

Another distinction is between the incremental and the sunk costs. The incremental costs are those that result from a particular decision, while sunk cost would be incurred regardless of the decision. For instance, the obsolescence part of the depreciation is a sunk cost which is irrelevant for a decision once the equipment is bought. Whether we drive a car 500 km more or less has no effect on the obsolescence portion of its depreciation; regardless of our decision to put in 500 km less or more, this cost will be incurred. Whereas, any extra wear-and-tear incurred would be quite relevant. In effect, costs incurred in the past which are irrelevant to future decisions are called sunk costs.

DIRECT AND INDIRECT COSTS

Direct cost is one of the various terminologies used regarding costs, which needs to be explained. Many accountants confuse direct cost with variable cost. For instance, the direct labour cost and the direct material cost are referred to in the context of the variable costs. However, 'direct' actually refers to a particular category of cost which could be attributed to a particular product or to a department. The word 'direct' refers to the traceability of a cost-factor to a product. It does not mean that a traceable-cost is necessarily a variable cost. For instance, the advertising expense incurred for a particular brand of soap can be directly attributed to that particular brand of soap. Now, this advertising cost is not necessarily variable with respect to the volume of output of that soap product. So, it is not a variable cost, yet it is a direct cost. The power consumption in a plant producing a number of products cannot be traced or directed to a particular product. But with a significant variation in the volume of output the power consumption would also increase. Therefore, a part of the power consumption is a variable cost, yet it is not a direct cost. In fact, it is an indirect cost.

OVERHEADS

Similar confusion exists regarding the overheads. Many a time all the indirect costs are lumped under the category of overheads. This accounting terminology again does not make the distinction

* W.R. Henry and W.W. Haynes, *Managerial Economics, Analysis and Cases*, 4th Edition, Business Publications Incorporated, Dallas, Texas, 1978.

between the fixed and the variable components of the overheads. Such a distinction may be extremely crucial for a management decision to either increase or decrease the level of activity in the organisation. Such so-called overheads are allocated to different products or product lines, on various bases such as the total sales of each of the products or the total production costs or the value added or the direct labour cost incurred. Although, such allocation to either different product-lines or departments may help the financial accounting, it does not help in decision-making.

CONTROLLABLE AND NON-CONTROLLABLE COSTS

Distinction between controllable and non-controllable costs is very important in monitoring the performance of the various executives on the basis of predetermined budgets or standards. There are various instances when certain departmental or divisional managers have to explain for cost-variances over which they have little or no control. The executive should be held responsible only for those costs over which he has control. Otherwise, the entire monitoring and performance-evaluation procedure becomes spurious and corrupt. Distinction between the controllable and non-controllable cost ensures more effective and responsible accounting.

RELEVANT COSTS AS DIFFERENT FROM ACCOUNTING COSTS

The effort in this chapter has been to emphasise the need for a proper consideration of the relevant cost concept, i.e. costs which should enter into analysis for an optimal management decision. It has also been stressed that since the major function of accounting is reporting, the accounting costs will not be very useful when the objective before the manager is to choose between various alternative lines of action open to him. Accounting costs are usually past-oriented and report the status of the income or profit-and-loss during a given period, whereas cost data are needed to help the manager in his choice of a future course of action.

Historical cost data cannot reflect the contemporary cost of inputs. The input raw material might have cost Rs. 1 lakh during the last quarter but it may be worth Rs. 1,50,000 today. The bank loan secured the previous month may have been secured at an interest of 11% and may have been invested in a project fetching 15% returns. But there is no information as to how the same capital could possibly have been better utilised in other ventures fetching over 20% returns. Such cost figures of the lost opportunities, or sacrifices, do not exist in any of the historical accounting cost data. We have also seen how the allocation of overheads to different products or departments is erroneous. If the overheads, for instance, were to be allotted based on the total sales of the product or on the direct labour used in the product, then any varia-tion in the direct labour used or in the sales of the product will produce corresponding variation in the allocation of the overhead of that product. Actually, the variation in the direct labour used or in the sales may not have any relation at all with the management decision regarding the output level of the product. The production process may be made more labour-intensive and therefore may invite more allocation of the total factory-overhead. Thus allocation of overheads is meaningless as far as any decision regarding that product is concerned. The accounting cost does not properly make a distinction between the fixed and the variable cost, the sunk or the incremental cost. This is so because accounting costs are neither decision-oriented nor future-oriented. The cost analysis for decision-making should take only the relevant costs into consideration and therefore, the cost analysis is tailor-made for a particular decision. What is necessary is that managers should take the help of the accounting cost data, screen it, modify it or make use of it or interpret it to suit their particular decision-making need.

Example Illustrating Relevant Cost Analysis

Kartik & Co.

Kartik & Co. is a manufacturer of motorised cycles popularly known as mopeds. Many components in the mopeds are bought-out parts. Due to a sudden spurt in demand in the years 2007 and 2008, the company underwent considerable expansion. The year 2009 marked a lower demand for mopeds than anticipated. The situation, it appears now to the company, may not improve in the near future. Due to this reason the equipment capacities in the forging and machining sections are being utilised to the extent of 65% only, at present.

C. Sathya, the Company's Deputy General manager (Operations), feels that the excess capacity in the plant can be utilised by manufacturing an important forged (and machined) component which is presently being bought from an outside supplier Suman Enterprises, within Kartik's plant itself.

Roughly 10,000 pieces of this forged com ponent are being bought annually from Suman at the average rate of Rs. 200 per piece. The delivery charges are extra and amount to Rs. 7000/- per lot of 1,000 pieces. The forged piece is sent by the supplier in lots of 1,000 pieces each. The cost of receiving and inspection is figured to be around Rs. 1,40,000 per annum attributable to this bought-out part.

Suman is not an extremely dependable supplier. But most of the suppliers in the region are no better. About twice during the past year Suman failed to deliver the component on time and Sathya estimates that the loss in revenues to the company amounted to Rs. 5,00,000 due to such uncertainty.

But Sathya concedes that in spite of the vagaries of the supplier, Suman Enterprises provides good quality material. In fact, the average figure for the defectives can be put at 2%, which is quite good compared to the performance of many other vendors in the area. If Kartik & Company were to make the same component, the rejects could be higher by almost 5%.

The cost accountants of Kartik estimate that, if Kartik were to make the component internally, the direct material costs would be Rs. 95.50 per piece, and the tools and supplies may cost around Rs. 5000 per per 1000 pieces of component. The direct labour involved comprises two elements: **(i)** Forging, and **(ii)** Machining. The costs of direct labour are estimated at Rs. 10.50 and Rs. 44.40 per piece for the two elements respectively. The plant overheads are generally taken at 250% of the direct labour; the fixed overheads are Rs. 10,00,000.

Sathya wants to know whether his hunch "that making the component internally is better" is right.

Analysis

This is a typical make or buy decision and the relevant costs for the two options need to be considered.

Presently the component is being bought and the relevant costs are: (for, 10,000 pieces)

(a)	Purchase price @ Rs. 200 per piece	: Rs.	20,00,000
(b)	Costs of delivery @ Rs. 7,000 per 1000 pieces	: Rs.	70,000
(c)	Cost of receiving and inspection	: Rs.	1,40,000
(d)	Costs of bad quality (@ 2% rejects)		
	$0.02 \times$ (purchase price + delivery costs)	: Rs.	41,400
(e)	Costs due to uncertainty of supplies	: Rs.	5,00,000
		Total costs : Rs.	27,51,400

The McGraw·Hill Companies

If Kartik & Co. were to make the components internally the relevant costs would be:

(i)	Direct material @ Rs. 95.50 per piece	: Rs.	9,55,000
(ii)	Direct labour @ Rs. (10.50 + 44.00) per piece	: Rs.	5,45,000
(iii)	Tools and supplies @ Rs. 5000 per 1000 pieces	: Rs.	50,000
*(iv)	Plant overheads which vary with the output, $\left(\frac{250}{100}\times 5,45,000\right) - (10,00,000)$	: Rs.	3,62,500
	* Note: The fixed overheads are sunk costs which continue to accumulate whether the component is produced in the shop or not.		
		Total : Rs.	19,12,500
	The rejects are expected to be 5%.		
	Therefore, Total Costs will be	: Rs.	20,13,000

Obviously, in the present circumstances, Sathya's hunch is correct. The company is justified in making the product internally.

Observations

(a) Kartik's plant capacity is not going to be fully utilised in the near future. So, the answer obtained from the analysis is appropriate for that period of time. But, suppose, in the long run the demand for Kartik's products picks up. The plant capacity will then be fully utilised. If Kartik made the component internally, the plant capacity used for this purpose could have alternative uses which could fetch revenues. Will the answer to the make/buy decision remain the same?

(b) Similarly, the costs of input materials, labour, etc. assumed in the make/buy analysis could be quite different in the distant future. Will this not change the result of the make/buy analysis?

(c) If the long-term analysis indicates that buying is better than making, it may be wise not to change to policy of buying in the interim period of the near future. It may not be possible to disengage a vendor and then again engage him.

(d) Moreover, by making the component internally, although the idle capacity is there, Kartik & Co. might be increasing some of its managerial work components. The organisational cost is nowhere accounted, although in practice it is very much there.

To Summarise

1. For managerial decision-making only costs relevant to the decision need to be taken into account.
2. The time-frame for which the decision is being made is important for considering what costs should be included in the analysis.
3. The level of output or the scale effects are also important in the relevant cost analysis. It decides (i) what costs should enter the analysis, and (ii) how these costs will change with the output volume.
4. A clear consideration of all available opportunities is important.
5. Closely related to the level of output is the question of technological change. This may give rise to new cost elements and changed cost elements in the analysis. This consideration needs to be borne in mind.

QUESTIONS FOR DISCUSSION

1. Are direct costs always variable? Are indirect costs always fixed? Explain.
2. What is the distinction between accounting profit and economic profit? How is such a distinction linked with the concept of opportunity costs?
3. I desire to own an apartment. Towards this, I have already made part payment to a housing society. Rs. 5,00,000 is paid and Rs. 8,00,000 remains to be paid. Only after the complete payment, I shall get the title to the apartment. If I do not make the remaining payment, I lose the money which I have already paid.
   At this time a friend comes up with a proposition to sell his flat which is as good as the first apartment. He is going abroad for an assignment of a long duration and would like to sell the flat for Rs. 7,00,000. But if I buy this, I shall lose Rs. 5,00,000 which I have already paid for the apartment.
   Should I stick to my original apartment or buy my friend's flat?
4. What distinction can be made between long run costs and short run costs? For a company manufacturing consumer products, such as toothpastes and soaps, list the long run and short run costs.
5. The break-even analysis as presented in this chapter was for a single product. Present your analysis for a company manufacturing a number of different products. Will the analysis be substantially different for a multi-product situation? If so, how?
6. Why, in some cases, are there multiple break-even points? How should one go about choosing the output volume?
7. What costs are incurred if a company is shut down temporarily and if it is totally abandoned?
8. If a company is totally abandoned, will the depreciation of the assets be based on the sales value or on the original cost?
9. A company enters into a contract with a government department for the supply of its product. The contract is for 1,00,000 ± 10% items of product during this year. The exact number required is not given. The product price is Rs. 10 per unit. Excess units manufactured, if any, can be accepted by the department up to the maximum limit of the contract at a reduced price of Rs. 7 per unit. The penalty for not supplying enough items, as demanded by the department, is Rs. 2 per unit short. The direct labour, direct material and other variable costs account for Rs. 6 per unit. The fixed costs are Rs. 1,00,000. What is the production volume at which the company should aim?
10. Take the case of the housekeeping department in a hotel. List all the 'controllable' and 'non-controllable' costs.
11. In Q. 10, would the costs of laundering linen be direct or indirect? Would it be a variable cost? Explain.

5 Linear Programming

Linear Programming is an Operations Research technique which originated during the early 1950s. Having diverse practical applications, this technique has benefitted immensely various organisations in their production and other operations. Prof. G.B. Dantzig is one of the pioneers in formulating the procedure of Linear Programming.

This technique can be applied in various situations: long range planning, production planning, warehousing decisions, physical distribution decisions, marketing and product-mix decisions, fluid-blending problems, exploration of oil deposits, purchasing decisions, quality control decisions, material utilisation decisions, etc.

DEFINITION

The basic problem solved by Linear Programming is that of optimising either profit or total costs or some other utility function. It takes into consideration the limitations or constraints on the availability or usage of different resources such as manpower, machinery, materials, time and money as also other limitations and constraints such as those existing in the market (e.g. only so many units of a product could be sold) or specification for quality such as the maximum or minimum limits on the performance characteristics of a particular product, etc. In short, linear programming deals with optimising a desired objective under a situation where there are various constraints. Most of the management problems are optimal decision-making problems made under the various limitations. Therefore, linear programming rightly attracts the attention of practising executives.

We shall illustrate what linear company programming means through a simple example. Suppose a Company produces two products X and Y, both of which require a particular raw material and a particular machine. Product X requires 4 machine hours and 3 kg of the raw material per unit of the product, and product Y requires 2 machine hours and 6 kg of raw material per unit of the product. Suppose that the availability of the raw material and machine hours is limited. The raw material is available to the maximum extent of only 240 kg per month and the machine hours are available to a maximum extent of only 200 machine hours per month. Each of the products X and Y contribute to the profit margin by Rs. 7 and Rs. 9 respectively per unit of the product. How many units of products X and Y should the company produce every month?

FORMULATION OF A LINEAR PROGRAMMING PROBLEM

In the above problem, the company has to decide on the quantities of X and Y which are the decision variables, and this is to be done so as to maximise the profit margin which is the objective, under the limitations or constraints of resources. Linear programming problems, typically, have three elements:

(i) Decision variables, the determination of whose value is the problem to be solved.

(ii) Objective function, which is to be either maximised or minimised (e.g. maximisation of profits or minimisation of total costs, as the case may be).

(iii) Constraints or limitations or conditions related to the decision variables.

The solution of a Linear Programming problem involves:

1. Expressing the objective in an algebraic form involving the decision variables in algebraic notations. This expression is called the objective function, which is either to be maximised or minimised.
2. Expressing the constraints in algebraic inequalities involving the decision variables in algebraic notations.
3. The above two steps complete the formulation of the linear Programming problem. This, now, is solved for the determination of the optimal values of the decision variables by means of a mathematical procedure. Simple linear Programming problems can be solved as a graphical procedure. The graphical procedure is shown for the solution of our product-mix problem.

Example Let X and Y denote the quantities of the products X and Y. The Objective Function is given by: Maximise profit contribution, $P \equiv 7X + 9Y$;

Subject to the constraints:

$4X + 2Y \leqq 200$ … constraint for machine hour;

$3X + 6Y \leqq 240$ … constraint for raw material;

and $X \geq 0$

$Y \geq 0$

The last two constraints express that the quantities of X and Y cannot be negative. These are known as non-negativity constraints which are necessary for all Linear Programming problems.

Having formulated the problem, thus, we shall now try to solve the problem for the decision variables X and Y by means of a graphical technique.

Taking the first constraint of machine hours, let us convert it into the following:

$$Y + 2X \leq 100 \quad (1)$$

Similarly, the second constraint of raw materials can be converted into

$$Y + 0.5X \leq 40 \quad (2)$$

Graphical Solution Let us plot the above given inequalities with Y on the vertical axis and X on the horizontal axis (Fig. 5.1). Since we cannot plot the inequality, we plot the maximum limitation on these relations since these give equalities, e.g.: $Y + 2X = 100$ expresses the maximum limit or the boundary for the macghine hour resource constraint; and $Y + 0.5X = 40$ expresses the boundary for the raw material constraint.

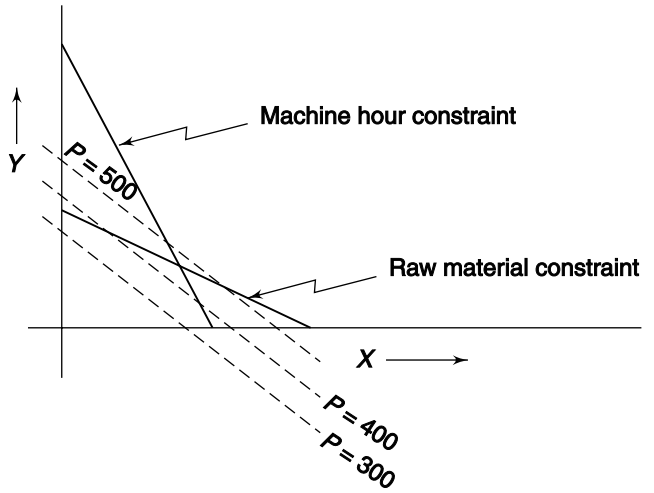


Figure 5.1 Graphical Representation and Solution of the Linear Programming Problem

Since the boundaries of the constraints are straightline relationships as shown in Fig. 5.1, these have been easily plotted, by considering their slope and intercept.

Corresponding to the constraint of raw materials, the decision variables X and Y can take any of the infinite different values falling below the line for this constraint (taking only positive values or zero value). The other constraint of machine hours limits or reduces these possibilities, because the values of X and Y have to reconcile with not only the machine-hour constraint but also with the raw material constraint. Therefore, X and Y can take only those values that correspond to points which fall within the polygon described by the boundary lines for all the four constraints. Still, there are theoretically an infinite number of possibilities or combinations of the values of X and Y which can meet all these constraints.

For this we shall bring in the objective Function, because besides working within the constraints we have also to maximise the profit margin. The objective function is

$$\text{Maximise } P \equiv 7X + 9Y$$

Depending upon the values of X and Y, the profit margin function P will take a number of values. To find out that particular value or those values of the mix of X and Y which will maximise the profit margin, we shall proceed by assuming various values of the profit margin.

Let us take the value of the profit margin as 300. Now we can express the earlier objective function as:

$$P = 300 = 7X + 9Y$$

Note that this is the expression of a straight line. We plot this straight-line on the graph in Fig. 5.1 and check as to whether this (a part of it or a point of it) falls within the polygon described by the constraints. This check is necessary, because P should take only those values which are possible under the given constraints. We notice that corresponding to P = 300, the Objective Function does fall within the constraints' polygon.

(Note: $7X + 9Y = 300$ has a slope of $-\frac{7}{9}$ and an intercept on the vertical axis of 33.33.)

Any value of X and Y corresponding to a point on the part of this line falling within the constraints' polygon will meet the constraints and give the company a profit margin of 300.

But, we are interested in maximising the profit margin. Therefore, we consider various values of the profit margin (increasing values) and the corresponding lines and check whether a part or point of the line lies within the constraints' polygon. We have plotted in the above diagram the various profit margin lines for profit margins of 300, 400 and 500. We notice that while the profit margin line of 400 lies partly within the polygon, the profit margin line of 500 does not have any part or point of it within the constraints' polygon. Therefore, the line of 500 does not help us in any way. We shall therefore now consider higher and higher values of the profit margin (between 400 and 500) so as to find out the profit margin which is maximum under the constraints.

By this procedure we see that the profit line which gives maximum profit under the given constraints is one which passes through the intersection of the lines expressing the boundary of the constraints of raw materials and of machine hours. The point corresponding to this intersection, or *that particular 'corner' of the constraint polygon*, gives the optimal solution for the decision variables X and Y. The values of X and Y are therefore:

$$X = 40 \text{ units}$$

$$Y = 20 \text{ units}$$

This is the optimal product-mix for our problem.

This was a very simple example with only two decision variables, two real constraints, and two non-negativity constraints. Had there been three decision variables, we would not have been able to solve this problem on a piece of paper, because the graphical part of it would invole three dimensions for the three decision variables. The constraints involving all three variables would have been planes and not straight lines. Imagine that there are more than three decision variables. Then, we would have to solve the problem in an 'n-dimensional space'. The constraints' polygon will then be the polygon in the n-dimensional space. In spite of the complexity, the basic procedure of Linear Programming is the same: *to find a corner of the constraints' polygon which optimizes the Objective Function*. This is, in fact, a problem related to the mathematical discipline called Topology.

MATHEMATICAL PROCEDURES AND COMPUTER SOFTWARE PACKAGES

A problem cannot be merely solved by a graphical method when there are a large number of decision variables and constraints. Iterative mathematical procedures exist to solve such complex problems. One such procedure is called the Simplex Method. Such procedures for the solution of the Linear Programming problem can be referred to in any book on operations Research. The idea behind this chapter is to explain the concepts and applications of linear programming in the area of production and operations Management. The manual solution by simplex method may not be difficult when the number of variables and the number of constraints are one-digit numbers. Beyond that, the manual procedure may become laborious and cumbersome. Today there are computers and readymade computer software packages available to take care of this problem.

ASSUMPTIONS

The assumptions underlying linear programming are:

1. Objective function and the constraints are all linear relationships.

The corrollaries of this assumption are that:

(a) We assume that there are no economies of scale or diseconomies of scale; six units of product *Y* require six times as much of raw material as required for one unit of *Y*.

(b) We assume that there are no interactions between the decision variables; the total raw material required for *X* and *Y* was a simple addition of individual requirements for *X* and *Y*.

2. There is only one objective function. In our product-mix problem there was only one objective and that was to maximise the profit. But, the case is not always so simple in practice. Often, for a particular decision, an organisation may have a number of objectives with possibly some priorities between them, all of which need to be considered together. For instance, the production planning should be such that both the total costs of production as well as the time delays for delivery of the products need to be minimised. This type of a problem cannot be solved by simple linear programming. Linear programming, therefore, confines itself to a single objective or to a situation where the multiple objectives need to be transformed/modified into a single objective function.

OTHER RELATED METHODS

There are procedures by which a multiple objectives problem can be transformed to a single objective problem. This can be done by considering the trade-offs between different objectives or by ranking different objectives in terms of priorities and converting the problem to a series of single objective problems. A procedure called Goal Programming can also be used in such a case.

The case where the decision variables cannot take fractional values, a related technique called *Integer Programming* can be used.

APPLICATION OF LINEAR PROGRAMMING

Linear programming can be used effectively for Production and Operations Management situations. Usually the objective is to either maximise the profit or minimise the total cost or the delay factor. There are always constraints or limitations on production capacity, the quality of the products and constraints on the saleability of a product in a particular period of time. There may be different constraints related to the decision variables based at different time periods. For instance, in the months of harvest the labour availability is very low, or that in a company, absenteeism is high during the months of summer due to the wedding season. Many of the production problems can be formulated into linear programming problems. Thus it is a very useful technique for various planning and other decisions in production operations.

The basic work content in solving a linear programming problem is not in its solution per se, but in its formulation. Mathematical formulation of the problem is the first step in linear programming. Needless to say, if the formulation is wrong the solution would also be wrong.

COMPUTER SOLUTION OF THE PROBLEM

Since practical problems might involve many decision variables and many constraints, the use of a computer may be essential. Fortunately, and because there is a very large market, Information Technology companies have come up with readymade software packages for the solution of linear programming problems. One need not be an expert in computer programming; in fact, one need not even know computer programming to solve a linear programming problem. All that one needs

to do is to feed information regarding things such as the number of decision variables, number of constraints, the coefficients of the decision variables in the objective function, the coefficients of the decision variables in the constraints, the maximum or minimum limit of the constraints, and whether the objective function is to be maximised or minimised. Which means, one need only to formulate the linear programming problem in the algebraic form suggested earlier.

SENSITIVITY ANALYSIS, SLACK VARIABLES AND SHADOW PRICES

For any optimisation technique such as linear programming, we would be interested in the sensitivity of the obtained solution at or near the optimal point to small changes in the constraints and other estimated values. In other words, a sensitivity analysis is of importance. It should be noted that estimates regarding the requirements of resources, the availability of resources, the costs associated with resources, or the profit margins associated with products, etc. are subject to some error by virtue of being only estimates. By means of a sensitivity analysis we can check or find out the effect of small changes in the estimated figures on the optimal solution to the problem. For instance, we would be interested in knowing that by relaxing our product-mix constraints slightly in our earlier problem, how would the profit margin change? We may find the marginal change in the profit margin with marginal relaxation of the product-mix constraints.

Expressing the machine hour constraint as an equality by incorporating the idle capacity available within the constraint (denoting idle capacity as M), we have

$$2Y + 4X + M = 200$$

Similarly, we can incroporate the idle capacity of materials and express the materials constraints as an equality, as given below:

$$6Y + 3X + N = 240$$

The above two equations give us the following relations:

$$X = 40 - \frac{M}{3} + \frac{N}{9}$$

and

$$Y = 20 + \frac{M}{6} + \frac{2N}{9}$$

And we have, our earlier relation for the profit margin:

$$P = 7X + 9Y$$

Incorporating the preceding two relations and substituting for X and Y in the above relation for the profit margin, we get

$$P = 460 - \frac{5}{6}M - \frac{11}{9}N$$

or

$$P = 460 - 0.83\,M - 1.22\,N$$

This is an important relation in terms of the meaning of the coefficients of M and N. It states that if there was one unit of machine capacity unused, the profit margin would have been affected by 0.83 rupees, this 0.83 being the coefficient of the idle capacity variable or *slack variable M*. Similarly, if the materials capacity was unused by one unit then the profit margin would have been reduced by 1.22 rupees, where 1.22 is the coefficient of the slack variable for material N. Putting it in reverse, if we had one unit of extra machine capacity, we would have made 0.83 rupees in

addition to the maximum (optimal value) profit of Rs. 460. Similarly, if we had one unit of extra materials capacity, we would have made Rs. 1.22 in addition to the earlier obtained maximum profit of Rs. 460. Therefore, these coefficients of the slack variables provide an insight as to how a slight relaxation of the constraints might prove useful or profitable. The coefficients of the slack variables are many a time referred to as the *shadow prices* of the constraints. Shadow price of a constraint is the marginal increase/decrease in the objective achieved by a marginal change in the constraint. It is very important for decision-making, because in practice there is always some amount of freedom available with the constraints. Although the budget may be of Rs. 1 lakh, still there is the flexibility of allowing for a few thousand more. Although the raw material availability may be one tonne, still the possibility of procuring a few more kilograms of the material exists, albeit with difficulty. Although the availability of a machine capacity is limited, there is still a possibility that a few more hours can be squeezed in. The management would like to always know as to whether these little flexibilities available to them might make a significant difference with respect to the achievement of the desired objectives such as profits or costs. Therefore, a constraint which has a considerable positive shadow price can be relaxed within the available flexibility; whereas a constraint which has a very small shadow price need not be relaxed.

VALIDITY OF THE SOLUTION

It needs to be mentioned here that besides the sensitivity of the solution, one must also check the validity of the solution obtained. This is so because most of the practical linear programming problems involve a large number of constraints and decision variables. A linear programming model built for such a complex decision-making situation is an abstraction of the practical situation. Therefore, it is not always certain that the linear programming model will provide a solution that is practical: because, a number of different aspects of the practical problem may not have been explicitly taken into consideration in the mathematical modelling procedure. In fact, the check on practicability should come before the sensitivity analysis.

CARE IN FORMULATION OF THE PROBLEM

The sensitivity analysis, which questions whether the obtained solution depends critically on the exact values of the particular data, brings us to another important consideration while formulating the Linear Programming problem. That is, to obtain the necessary data very carefully. This is, in fact, the most important job in formulating a linear programming problem in practice.

Also, a decision-maker should be careful in the selection of the constraints in practice. All important constraints should be included in the linear programming problem but, at the same time, too many constraints may tend to make the problem too large and unwieldy.

Lastly, since for a practical problem a number of objectives may be possible, the decision-maker should analyse the data for different objective functions to check whether they indicate different strategic actions.

A DECISION-MAKING TOOL

Linear Programming is a very useful and important tool in the hands of the manager. Having diverse practical applications its usefulness for appropriate decision-making solely depends upon the manager and how he takes maximum advantage of the tool. In this book we will be referring to this technique over various chapters.

QUESTIONS FOR DISCUSSION

1. What are the basic assumptions in linear programming?
2. Why is it called 'linear' programming?
3. If in the graphical approach indicated in this chapter, the line of objective function is parallel to the line corresponding to one of the constraints, what is the effect?
4. What are the limitations of using the graphical approach to the solution of linear programming problems?
5. Typical linear programming has one objective function. But, in many practical situations, there could be more than one objective. How can one take care of such a situation? Explain by means of an example.
6. What is 'shadow price'? How would you use the information?
7. Can you solve the following Linear Programming problem?

   Maximise $P = 10q + 9r$

   $5q + 4r \leq 14$

   $4q + 5r \leq 9$

   $7q - 9r \leq 11$
8. In a linear programming problem, is it necessary to have at least as many constraints as the number of decision variables? Explain.
9. Will 'topology' be useful in Linear Programming? How?
10. Check up on the dynamic programming approach in other literature. Note its basic premises and utility in production and operations Management.
11. Ten girl students of a post-graduate science college are residing in the same hostel as the other 200 boy students because the college does not provide separate accommodation for girl students. The boys are rather troublesome and the girls, therefore, want to keep them at a safe distance. With this in view, the girls have discovered two chemicals available in the laboratory, nicknamed 'Ugh' and 'No-no', which can be mixed in certain proportion with bathing shampoo and facial cream. Amazingly, these chemicals have repelling properties only for the male sex with no effects at all for the female sex.

    Now, for proper effect, the shampoo needs 1.1% of Ugh and 0.1% of No-no to be mixed with it. The Facial Cream needs 0.5% and 0.25% of Ugh and No-no, respectively, for the desired effect. Every girl needs a minimum of 2 ml of shampoo and 1 ml of facial cream every day. The price of Shampoo and Cream in the market are respectively Rs. 10 per 100 ml and Rs. 18 per 20 ml. The amounts of Ugh and No-no that can be obtained from the laboratory are limited to 15 ml and 5 ml (per month) only, due to very limited yields of these special chemicals. If the expenses on these cosmetics are to be no more than Rs. 450 per month, and if the proportionate 'repel' effects of Shampoo and facial cream are 2:3, then what are the optimal quantities of shampoo and facial cream the girls should procure?

    (*Assume*: **(i)** A month has 30 days.

    (ii) Ugh and No-no are available free.

    (iii) The college has no male teachers, surprisingly.)
12. A hospital's performance is being judged by the number of patients treated in a month. The facilities in the hospital can basically be divided into five categories:

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(i) Beds, **(ii)** Operating rooms, **(iii)** X-ray, **(iv)** Physiotherapy, and **(v)** Laboratory.

The available capacities of the above, expressed for a month (30 days) are as follows:

Beds : 100 beds

Operating facility : 10 operations per day

X-ray : 36 per day

Physiotherapy : 25 patients per day

Laboratory : 100 tests per day

If a minimum of 10 medical and 5 surgical cases must be admitted every day, what should be the optimum feasible output of the hospital in terms of medical and surgical cases treated?

In attempting to solve the problem, you may note the following:

(a) A medical patient requires the bed for 7 days while a surgical patient requires it for only 3 days, on an average.

(b) A medical patient requires 10 laboratory tests as compared to only 5 for a surgical patient.

(c) A medical patient requires, on an average, 1 physiotherapy treatment while a surgical patient requires 2 per day.

(d) A medical patient needs 5 X-ray tests as compared to only 2 for a surgical patient.

ASSIGNMENT QUESTION

1. Choose a business organisation. Select any aspect of its operations and apply Linear Programming. Present your report.

6 Capital Budgeting

Capital budgeting is the process of allocating available funds to different investment possibilities. The questions that capital budgeting addresses itself to are:

1. Is it wise to invest a certain amount of funds in a particular project or not?
2. If investment funds are limited or if the investment opportunities are mutually exclusive, how can we establish priorities, or choose between the different viable investment possibilities?

These are the real-life problems faced during the formulation or feasibility studies of projects requiring capital investment. The following different criteria are used for the appraisal of different investment opportunities.

CRITERIA FOR APPRAISAL OF INVESTMENT OPPORTUNITIES

Payback Period

The payback period is the span of time within which the investment made for the project will be recovered by the net returns of the project. Let us consider the following example where the revenues (gross) and the operating costs in different periods of a project are as given in Table 6.1.

The payback period for this example will be 4 years. Within 4 years, the initial investment will be recovered by means of the net returns to this project. If this period of recovery (4 years) is acceptable to the management, the project will be approved for making an investment.

The same calculations could be summarised in terms of the following expression. The payback period is the value of n which satisfies the following equation:

$$\frac{I}{\sum_{p=0}^{n} R_p - D_p} = 1$$

Table 6.1 Benefit-and-Cost Streams of a Project

Period (Year)	*Revenue or Income (Rs. in lakhs)*	*Operating Costs (Rs. in lakhs)*	*Net Returns (Rs. in lakhs)*
1	100	70	30
2	150	90	60
3	150	90	60
4	150	90	60
5	150	90	60
6	150	90	60
7	150	90	60

Initial investment made during period 0: Rs. 200 lakhs.

where R_p is the income during the period p;
D_p is the operating cost during the period p; and
I is the initial investment made in period 0.

Using payback period as the criterion, projects with lower payback periods are preferred.

Merits and Demerits of Payback Period

1. One shortcoming of this criterion is that it overlooks the net incomes made available by the project after the payback period. For instance, in the above example the income streams generated by the project during the 5th, 6th and 7th years, i.e. the years after the payback periods, are totally overlooked by this criterion.
2. Another drawback of this criterion is that the value of money is assumed to be the same over the different years of the payback period. This is obviously wrong, since the value of one rupee available today is not the same as the value of the same rupee received the next year.
3. The merit of the payback method lies in its implicit coverage of risk. The user of the payback period criterion may not be sure about the revenues and costs of the project in the long-term future. His anxiety is to get back the money he has invested (by means of net returns) as soon as possible. This anxiety is taken care of by this criterion by choosing that alternative which promises the earliest return on the investment money.

Net Present Value

As mentioned earlier, the value of one rupee available today is not the same as the value of the same rupee received a year later. This is so because, had we received the rupee today we could have invested the same in a project, or in a bank and earned the interest. Let us say the return or interest was 10%. Then, receiving one rupee today is as good as receiving Rs. 1.10 a year later; it is as good as receiving Rs. 1.21 two years later, and so on. It implies the revenues and costs generated or incurred for the future years of a project have to be *discounted* by the appropriate cost of the money. It is not inflation that we are talking about, but rather the interest or return on capital which we would normally expect of our investments. This normally expected return on capital is called cost *of capital*. The revenues and costs should be discounted by this expected return on capital which is necessary for the firm or organisation. The values of the future net incomes discounted by the *cost*

of capital are called *net present values* (NPVs). Tables giving the present value of a rupee, payable in different years for different rates of discount, are furnished as an Appendix to this chapter.

The Net Present Value for the earlier example at a cost of capital at 10% would be

$$\underset{\text{(Rs. in lakhs)}}{\text{NPV}} = -200 + \frac{100-70}{(1+0.10)} + \frac{150-90}{(1+0.1)^2} + \frac{150-90}{(1+0.10)^3}$$

$$+ \frac{150-90}{(1+0.1)^4} + \frac{150-90}{(1+0.10)^5} + \frac{150-90}{(1+0.10)^6} + \frac{150-90}{(1+0.10)^7}$$

The general equation for the same is as follows:

$$\text{NPV} = -I + \frac{R_1 - D_1}{1+i} + \frac{R_2 - D_2}{(1+i)^2} + \cdots + \frac{R_n - D_n}{(1+i)^n} = -I + \sum_{p=1}^{n} \frac{R_p - D_p}{(1+i)^p}$$

where i is the cost of capital; the other notations remain the same as earlier.

Under the NPV criterion, a project is approved if its Net Present Value is positive and the funds are unlimited. When the funds are limited, the projects cannot be selected on this basis alone. One may have to rank the projects in terms of their Net Present Values and allocate funds accordingly. Such situations will be discussed later under 'Capital Rationing'.

There is one problem with the NPV technique. It is the determination of the appropriate cost of capital. Cost of capital is not the interest to be paid on the borrowed capital *per se*, although it may have some relation to it. It may also have some relation to the particular opportunity cost of investing in projects, although it is not the specific opportunity cost prevailing at the time of consideration (appraisal) of the project. Several weighting procedures have been suggested in the literature on Finance Management to arrive at the cost of capital for a firm or an organisation.

Some have defined the cost of capital as the weighted arithmetical average of the cost of various sources of financing employed by the firm. To obtain the cost of capital of the firm, one needs to know:

(i) the cost of different sources of financing employed by the firm (debt, equity, etc.);

(ii) the weights that should be applied to the cost of different sources of financing in calculating the weighted average.

The determination of the cost of capital is difficult, but it is certainly not impossible.

The obvious advantage of the NPV criterion is that the income and cost streams for the future are brought to a common basis and this gives us a measure of the absolute value of profits to be gained by investment in a project.

Internal Rate of Return (IRR)

The Internal Rate of Return is that rate of discount that equates the initial investment in the project with the future net income stream. Mathematically, it is expressed as given below:

IRR is that value of i which satisfies the following equation:

$$-I + \sum_{p=1}^{n} \frac{R_p - D_p}{(1+i)^p} = 0$$

The IRR criterion for project acceptance, under theoretically infinite funds is: accept all projects which have an IRR greater than the cost of capital.

The procedure in applying this criterion is

(i) Assume different values of the discount rate, *i*.

(ii) For each value of the discount rate, find if the equation given above balances.

(iii) That discount rate for which the equation fits, is the Internal Rate of Return.

Under the capital rationing, i.e. when the capital availability is limited, different alternative projects may have to be ranked in terms of their Internal Rates of Return and the available funds allocated to the projects in terms of their priority rank.

IRR calculations for the previous example (Table 6.1) are shown in Table 6.2:

Table 6.2 Trial-and-Error Calculations for Arriving at the Internal Rate of Return

	Assumed IRR for Trial and Corresponding Present Value Streams			
	50%	*25%*	*20%*	*18%*
1	20.00	24.00	25.00	25.42
2	26.66	38.40	41.66	43.09
3	17.77	30.72	34.72	36.52
4	11.85	24.58	28.94	30.95
5	7.90	19.66	24.11	26.23
6	5.27	15.72	20.09	22.23
7	3.50	12.58	16.74	18.84
Total of Present Values (Rs. in lakh)	92.95	165.66	191.26	203.28

The initial investment was Rs. 200 lakh. Therefore, IRR is approximately 18%.

Merits and Demerits of IRR The IRR criterion is often preferred since it involves minimal use of a given cost of capital (which is controversial conceptually and is difficult to arrive at). Although it does away with the cost of capital assumptions, it still has certain drawbacks:

1. It is cumbersome in calculation.
2. For mutually exclusive projects (i.e. if Project A is to be undertaken, Project B cannot be selected) and in cases of capital rationing, IRR is not the best criterion to be used. (This is discussed in more detail later.)
3. IRR is only a figure reflecting the rate of return or the efficiency in the use of the capital; it does not give an absolute value of the benefits or net incomes generated by the project; or, in other words, it does not consider the size or amount of outlay involved in the project.

Profitability Index (PI)

This is the ratio of the net present value of the future benefits minus costs divided by the initial investment. It can mathematically be expressed as follows:

$$\text{PI} = \frac{\sum_{p=1}^{n} \frac{R_p - D_p}{(1+i)^p}}{I}$$

The project is accepted if the profitability index is greater than unity and the funds are unlimited. Those projects whose profitability index is equal to or less than unity are rejected.

For example in Table 6.1, the PI is

(i) at a cost of capital of 20% = 0.9563; and

(ii) at a cost of capital of 25% = 0.8283.

Therefore, had the cost of capital been either 25% or 20% the project would have been rejected.

When there is capital rationing, the PI may be utilised for ranking the different alternative investment projects. To this extent PI facilities prioritisation among different investment proposals. But this ranking of projects might prevent us from considering the *total* absolute value or net present value of the projects because PI is only a relative figure giving the yield of a project. Some projects may have low PI but a high capital outlay, giving thereby large net returns. Whereas, another project may be more efficient having high PI but involving small capital outlay and thereby giving small net returns. If the objective is to maximize profit, the former project may be preferred over the latter.

Where *capital availability is unlimited and the projects are not mutually exclusive,* (i.e. if Project A is accepted, Project B cannot be accepted and *vice versa*) for the same cost of capital any of the three criteria (1) NPV, or (2) IRR, or (3) PI can be used. All the three *criteria* are equivalent. The ranking of the projects might differ according to the three different criteria; but that is immaterial, since the decision is merely one of accepting or rejecting a project. When NPV is greater than 0, IRR will be greater than the cost of capital, and the PI will be greater than unity.

MUTUALLY EXCLUSIVE PROJECTS

Often we encounter mutually exclusive projects and most of the situations have limitations on the availability of the funds. For example, an organisation may have to choose between two available technologies. It cannot have both at the same time. Now, if there are no limitations on the availability of funds, the choice between mutually exclusive projects can be made based upon their net present values. The projects need not be selected, in such a case, based on IRR or PI, because NPV is the one criterion which concretely considers the addition to the value or profits to the firm, whereas IRR is only a rate and does not provide absolute values of the contribution to the profits of the firm. There is no purpose served, here, by ranking the projects in terms of their internal efficiency. What is necessary is to judge their total output in terms of the NPV.

CAPITAL RATIONING

In addition to mutual exclusivity, the firm could have constraints on the availability of funds. There may be a number of project proposals which have NPV greater than zero or IRR greater than the cost of capital and the PI greater than unity. But, because of the budget constraints, all of these projects cannot be accommodated or undertaken. How should we go about selecting projects from this list? Should we select the projects based on their ranking in terms of their net present value? Or

should we select the projects in terms of their ranking based on the IRR, or PI? The basic objective of any firm is to maximise the total profit. And the best expression of profit, by means of investing in the projects, is given by their net present values. Therefore, ranking by IRR or PI may be less desirable than NPV considerations.

With limited finance and a number of project proposals at hand, one can maximise profit by maximising the NPV of a combination or package of project investments. Therefore, the procedure for selection will be:

1. Identify the different packages of projects which can be considered under the funds constraints.
2. Select that package of projects which has the maximum net present value.

Example The different investment project opportunities available, their investment outlays, NPVs and IRRs are as given in Table 6.3.

Table 6.3 A Capital Rationing Situation

Project	*Investment (Rs. in lakhs)*	*NPV*	*IRR*
1	100	40	16%
2	90	30	12%
3	80	30	17%
4	70	25	13.5%
5	60	20	12%
6	50	20	16%
7	40	20	18%

Budget Constraint, Rs. 300 lakhs.

Under the given budget constraint of Rs. 300 lakhs, which of the projects should we invest in?

Solution: The packages of proposals which can be accommodated within the budget of Rs. 300 lakhs and their respective NPVs are shown below:

Package of Projects	*Total Investment (Rs. in lakhs)*	*Total NPV*
1 + 2 + 3	270	100
2 + 3 + 4 + 5	300	105
3 + 4 + 5 + 6 + 7	300	115
1 + 4 + 5 + 6	280	105

Since the combination of projects 3, 4, 5, 6 and 7 yields the maximum net present value, that package of investment is most preferable.

Linear Programming Model

A Linear Programming model has been developed by Martin Weingartner to handle the selection of projects under capital rationing. This model, while maximising the NPV, selects a particular package of projects within the given budget constraints.

The objective function is given by

$$\text{Maximise NPV} = \sum_j X_j\, b_j$$

where X_j is the fraction of the jth project undertaken, and b_j is the present value of that jth project when discounted at the cost of capital.

The set of budget constraints are given by

$$\sum_j X_j\ C_{jt}\ \leq C_t$$

where C_{jt} are the present values of the investment outlays during the period t. The C_t's are the budget constraints in different periods corresponding to t (these are the present values of the actual constraints in period t).

The other constraints in this programming model are that of non-negativity and non-repetition of the same project. These can be expressed as:

$$0 \leq X_j \leq 1$$

Till now we have discussed the capital budgeting principles based on conditions of certainty. We have indicated that in most such cases the NPV criterion is better than other criteria.

CONSIDERATIONS OF RISK IN THE APPRAISAL OF PROJECTS

In real life the projections of the revenue and costs into the future (particularly long-term) are only subjective or judgemental values. Each projected cash flow is, in fact, the mean of the expected values (considering an appropriate probability distribution). What might be thought of now as the best project in terms of its NPV, may turn out in the future to be a not-so-good project. We are speaking here of the consideration of 'risk' of different projects. A project may be lucrative in terms of its projected net present values but, it may be the riskiest of the available projects. Another project may be not very lucrative (although an acceptable kind) but may have very little risk associated with it. It is clear that while evaluating projects, one has to consider or make adjustments for the 'risk' associated with different projects.

Risk-Adjusted Discounting Rate

One method of adjustment for risk is to increase or decrease the cost of capital to be used in discounting a project. Depending upon the riskiness of the project, the project may be discounted at a higher rate or a lower rate (for a more risky or a less risky project, respectively).

Example A firm's cost of capital was 15%. Three different investment project proposals were available, namely *A*, *B* and *C*. *A* was somewhat risky, *B* was little more risky, and *C* was the riskiest of all. During the appraisal process, the discounting rate used for each project was different: $A = 18\%$; $B = 20\%$; and $C = 25\%$.

The expected cash flow for the three projects were as follows:

Year	*A*	*B*	*C*
1	50	100	150
2	90	100	150
3	120	130	170
4	130	150	180
5	130	150	180
6	130	150	180
7	130	150	180

Note: All figures in lakh Rupees.

The initial investment outlay in each project was Rs. 300 lakh.

If the projects were mutually exclusive, which project should have been chosen?

Solution: Applying the NPV criterion, and risk-adjusted discount rates, we have

$$\text{NPV for Project A} = -300 + \frac{50}{(1+0.18)} + \frac{90}{(1+0.18)^2} + \frac{120}{(1+0.18)^3} + \frac{130}{(1+0.18)^4} + \frac{130}{(1+0.18)^5} + \frac{130}{(1+0.18)^6} + \frac{130}{(1+0.18)^7} = +92.89$$

$$\text{NPV for Project B} = -300 + \frac{100}{(1+0.20)} + \frac{100}{(1+0.20)^2} + \frac{130}{(1+0.20)^3} + \frac{150}{(1+0.20)^4} + \frac{150}{(1+0.20)^5} + \frac{150}{(1+0.20)^6} + \frac{150}{(1+0.20)^7} = +152.89$$

$$\text{NPV for Project C} = -300 + \frac{150}{(1+0.25)} + \frac{150}{(1+0.25)^2} + \frac{170}{(1+0.25)^3} + \frac{180}{(1+0.25)^4} + \frac{180}{(1+0.25)^5} + \frac{180}{(1+0.25)^6} + \frac{180}{(1+0.25)^7} = +220.69$$

Therefore, Project C should be preferred for investment.

Some organisations establish classes of risk and establish the corresponding cost of capital adjustment for each class of risk. This might help in standardising the risk-adjustment.

The risk involved in a project can be evaluated by means of sensitivity analysis or a simulation analysis using data on the estimated probabilities of different items such as price of inputs, price of products, quantity produced, life-time of the project, sales of product, etc. These need not be continuous probability distributions. These could be discrete values of the estimated probabilities corresponding to the different values of the parameters involved in a project.

It may also be noted that 'risk' is a relative term, and any project which has a large deviation of outcomes need not necessarily be regarded as a high-risk project. One has to take into account the *over-all activities* of the organisation *and the overall profitability of the organisation*. If a project has a large variation of outcomes but involves a small capital outlay, it cannot be classified as a high-risk project, because its impact on the overall profitability of the organisation is very small. Whereas, a project that has smaller variance of outcome but a high initial investment may be regarded as a high-risk project since it affects the firm's overall profitability considerably.

Risk Equivalence Coefficient Method of Incorporating Risk in Capital Budgeting

Another method of taking care of the risk factor in the choice of projects is that of multiplying the NPVs by "risk equivalence coefficients". Mathematically, this can be described as follows:

$$\text{NPV} = -I + \sum_{p=1}^{n} \frac{X_p\,(R_p - D_p)}{(1+i)^p}$$

where 'i' is the cost of capital for the firm.

The values of the risk equivalence coefficients X_p, may be different in different years. This method of risk adjustment has one advantage over the earlier method, it does not assume that risk increases with time at a constant rate. If the income in the 10th year is going to be more certain than the income in the 5th year, the risk equivalence coefficient for the 10th year will be higher than that for the 5th year.

Example The expected net cash flows of the two different Projects A and B are given below:

Initial Investment: Rs. 30 lakh

Year	*Project A*	*Project B*
1	Rs. 10 lakh	Rs. 15 lakh
2	Rs. 20 lakh	Rs. 25 lakh
3	Rs. 20 lakh	Rs. 30 lakh
4	Rs. 20 lakh	Rs. 15 lakh
5	Rs. 10 lakh	Rs. 15 lakh

The cost of capital for the firm is 20%. The initial investment required is Rs. 30 lakh.

The cash flow streams given above are estimated figures, but the actual cash flow stream may be different. The following risk equivalence coefficients are estimated, to take care of the adjustments for risk:

Year	*Project A*	*Project B*
1	0.95	0.85
2	0.90	0.75
3	0.85	0.70
4	0.80	0.60
5	0.95*	0.60

* Project A's cash flows in the terminal (5th Year) are more certain than during the 2nd, 3rd and 4th years.

Which project is preferable for investment?

Solution: Let us compare the NPVs of the two projects, taking into account the risk equivalence coefficients.

$$\text{NPV for Project A} = -30 + \frac{10\times0.95}{(1+0.2)} + \frac{20\times0.90}{(1+0.2)^2} + \frac{20\times0.85}{(1+0.2)^3} + \frac{20\times0.80}{(1+0.2)^4} + \frac{10\times0.95}{(1+0.2)^5}$$

$$= +\,11.07 \text{ lakh Rupees}$$

$$\text{NPV for Project B} = -30 + \frac{15\times0.85}{(1+0.2)} + \frac{25\times0.75}{(1+0.2)^2} + \frac{30\times0.70}{(1+0.2)^3} + \frac{15\times0.60}{(1+0.2)^4} + \frac{15\times0.60}{(1+0.2)^5}$$

$$= +\,13.76 \text{ lakh Rupees}$$

Therefore, Project B should be selected for investment.

We have discussed a number of useful capital budgeting concepts in this chapter. However, in India these methods of analysis are rarely ever used. Usually the reliance is on some thumb-rules or at best on the payback period criterion. The criterion of 'average rate of return' is used sometimes. Generally, unscientific methods of analysis are used. The simple concept of discounting cash flows has found acceptance only in a minority of cases. The projects are usually reviewed at four or five levels. The judgement of the review authorities is considered more valuable than the calculated figures of financial analysis.

The reasons advanced for a low level of acceptance of the financial management principles are well-known, viz. the revenue and cost figures are quite subjective and the errors involved are large, thus making detailed financial analysis meaningless. Needless to say, such reasoning is based more on ignorance, or a resistance to change than on real problems. The solution to this lies in the management of change, probably through increased training effort.

SOLVED PROBLEMS

1. Dr. Geetha wants to set up an ENT clinic for which she wants to borrow Rs. 20 lakh from the bank which is to be repaid in seven annual installments. The bank charges an interest rate of 14%. What are Dr. Geetha's annual installments ?

Answer

Present value of Re. 1 received at the end of each period for 'n' periods, at the interest rate of 'i' is :

$$= [1/(1+i)] + [1/(1+i)^2] + [1/(1+i)^3] + \ldots\ldots + [1/(1+i)^n]$$

$$= \{1/(1+i)\}[1 + 1/(1+i) + 1/(1+i)^2 + 1/(1+i)^3 = \ldots\ldots + 1/(1+i)^{n-1}]$$

This geometric progression, as per mathematical laws, can be simplified as :

$$= \{1/(1+i)\}[1-(1+i)^{-n}]/[1-(1+i)^{-1}]$$

$$= (1/i)[1-(1+i)^{-n}]$$

The above expression may be repeated for the purpose of clarity :

$$\frac{1-(1+i)^{-n}}{i}$$

This figure is called the Present Value Factor for Annuity ($PVFA_{i,n}$). If R rupees are received at the end of each year, then the present value will be :

$$PV = R \times (PVFA_{i,n})$$

'*R*' is called the Uniform Annual Series (UAS).

From the above, UAS = $PV / (PVFA_{i,n})$

In Dr. Geetha's case : PV = 20,00,000 i = 14% and n =7.

For i = 14% and n = 7, $(PVFA_{i,n})$ = 4.2883

Hence, $R = PV/(PVFA_{i,n})$ = 20,00,000/4.2883 = 4,66,385

Thus, Rs. 4,66,385 is Dr. Geetha's annual installment.

(*Note : While $PVFA_{i,n}$ can be calculated, ready tables are available giving values for different 'i' and 'n'.*)

The 'uniform annual series (UAS)' is a very useful concept and, among other uses, it can be used to decide on optimal replacement cycle for machines (i.e. how long should a machine/asset be used before it is abandoned and replaced with an identical machine/asset) as the following example shows.

2. An operations manager is deciding on whether to replace a machine after 1 year, 2 years or 3 years. The net cash flows for each of the three alternatives are as follows. Help the manager decide. Company uses a discount rate of 12%.

	Cash Flows			
	Year 0	*Year 1*	*Year 2*	*Year 3*
Replacement Period				
1 year	–100	130	–	–
2 years	– 100	70	80	–
3 years	– 100	70	50	40

(note : the cash flows for the three alternatives are different because the outputs deteriorate as the machnie gets older by a year, the upkeep costs increase and the salvage value decreases with every passing year.)

Answer

The three alternatives, or mutually exclusive projects, have unequal lives. Therefore, these three cannot be compared in the usual manner. Instead, these may be compared for their individual UAS.

UAS = $NPV/(PVFA_{i,n})$

NPV for 'project' of replacing every 1 year (NPV_1) is = $-100 + 130\ (1.12)^{-1}$ = 16.07

NPV for 'project' of replacing every 2 years (NPV_2) is

$$= -100 + 70\ (1.12)^{-1} + 80(1.12)^{-2} = 26.28$$

NPV for 'project' of replacing every 3 years (NPV_3) is

$$= -100 + 70\,(1.12)^{-1} + 50\,(1.12)^{-2} + 40(1.12)^{-3} = 30.83$$

The three different $PVFA_{i,n}$ are (for $i = 12\%$ and $n = 1$, 2 and 3):

$PVFA_{i,1} = 0.8929$,

$PVFA_{i,2} = 1.6901$ and

$PVFA_{i,3} = 2.4018$.

Therefore, the UAS for each 'project' (alternative) can be calculated as given below.

$UAS_1 = NPV_1/\,(PVFA_{i,1}) = 16.07/0.8929 = 18.00$

$UAS_2 = NPV_2/(PVFA_{i,2}) = 26.28/1.6901 = 15.55$

$UAS_3 = NPV_3/\,(PVFA_{i,3}) = 30.83/2.4018 = 12.84$

UAS_1 has the highest value; therefore, the first alternative is chosen. That is, the machine is replaced every year.

3. A project has the following cash flows.

year	*Cash flow (Rs.' 000)*
0	–1000
1	+2350
2	–1375

The cost of capital is 15%. Use IRR criterion and decide whether the project should be accepted.

Answer

Since the cash flow changes signs twice (– + –), there may be two IRRs for this project. In order to get over this problem of multiple IRRs, let us discount the negative cash flow in the year 2 back in time, i.e. to the year 1. The discount rate to be used will be the firm's cost of capital, which is stated to be 15%.

Year 1 cash flow = 2350 – [1375/(1 + 0.15)] = 1154.3

Thus, the set of cash flows is :

Year	*Cash flow*
0	–1000
1	1154.3

Therefore, it is seen that the rate of return is 15.43%. This is the IRR. Since this greater than the cost of money (15%), the project should be accepted.

QUESTIONS FOR DISCUSSION

1. What is the importance of capital budgeting in Operations Management?
2. Do sunk costs affect the capital budgeting process? Explain.

3. Does depreciation figure in the capital budgeting process? Explain.
4. What are the merits and demerits of NPV and IRR?
5. For mutually exclusive project proposals, what should be the criterion for the selection—NPV or IRR? Why?
6. What is the meaning of Internal Rate of Return?
7. How do the two methods of incorporating risk, viz. (a) risk-adjusted discounting rate, and (b) risk equivalence approach differ from each other? What are their similarities, if any?
8. If Rs. 10,000 invested in a project yields a benefit stream of Rs. 3,000 per annum for 5 years:
   (a) Compute the payback period.
   (b) Compute the NPV at 10% discount rate.
   (c) Compute the IRR.
9. The following table gives information regarding the two mutually exclusive Projects X and Y.

Period	*Net cash flows from Project X*	*Net cash flows from Project Y*
0	– 700	– 7000
1	450	4100
2	450	4100

   (a) Compute the NPV at 10% discount rate.
   (b) Compute the IRR.
   (c) If there is *no* capital rationing, which project should be selected?
   (d) If there is capital rationing, how would you approach the project selection problem?
10. Consider the following two mutually exclusive projects. The net cash flows are given in the table below:

Year	*Net cash flows from Project A*	*Net cash flows from Project B*
0	– Rs. 1,00,000	– Rs. 100,000
1	+ Rs. 30,000	+ Rs. 15,000
2	+ Rs. 35,000	+ Rs. 17,500
3	+ Rs. 40,000	+ Rs. 20,000
4	+ Rs. 45,000	+ Rs. 22,500
5		+ Rs. 25,000
6		+ Rs. 27,500
7		+ Rs. 30,000
8		+ Rs. 32,500

    If the desired rate of return is 10% which project should be chosen?
11. Suppose the average cost of maintenance for a piece of equipment is related to its life as follows:

Period	*Cost, Rs.*	*Period*	*Cost, Rs.*
1	50	7	230
2	70	8	270
3	90	9	340
4	120	10	410
5	150	11	480
6	190	12	560

If the purchase price of the new equipment is Rs. 1,600, what is the optimal life of the equipment (when replacement with new equipment is done)?
(Assume that there is no salvage value. The firm uses 10% discount rate per period.)

12. Calculate the IRR of the following:

Year	*Cash Flow*
0	– 25,000
1	+ 20,000
2	+ 10,000
3	– 10,000
4	+ 15,000
5	+ 10,000

13. Would IRR criterion be different while evaluating projects in the social sector? Discuss.

14. Would considerations of 'Risk' differ in the case of projects in the social sector? Discuss.

ASSIGNMENT QUESTION

1. Apply 'Capital Budgeting' principles to the management of the environment and sustainability. Present your arguments and observations.

APPENDIX

PRESENT VALUE TABLES

Present Value of One Rupee Payable after n Years at Discount Rate i

$(1 + i)^{-n}$

n/i	*2%*	*3%*	*4%*	*5%*	*6%*	*7%*	*8%*	*9%*	*10%*	*11%*	*12%*	*13%*	*14%*	*15%*	*16%*	*18%*	*20%*	*25%*	*30%*
1	0.980	0.971	0.962	0.952	0.943	0.935	0.926	0.917	0.909	0.901	0.893	0.885	0.877	0.870	0.862	0.847	0.833	0.800	0.769
2	0.961	0.943	0.925	0.907	0.890	0.873	0.857	0.842	0.826	0.812	0.797	0.783	0.769	0.756	0.743	0.718	0.694	0.640	0.592
3	0.942	0.915	0.889	0.864	0.840	0.816	0.794	0.772	0.751	0.731	0.712	0.693	0.675	0.658	0.641	0.609	0.579	0.512	0.455
4	0.924	0.888	0.855	0.823	0.792	0.763	0.735	0.708	0.683	0.659	0.636	0.613	0.592	0.572	0.552	0.516	0.482	0.410	0.350
5	0.906	0.863	0.822	0.784	0.747	0.713	0.681	0.650	0.621	0.593	0.567	0.543	0.519	0.497	0.476	0.437	0.402	0.328	0.269
6	0.888	0.837	0.790	0.746	0.705	0.666	0.630	0.596	0.564	0.535	0.507	0.480	0.456	0.432	0.410	0.370	0.335	0.262	0.207
7	0.871	0.813	0.760	0.711	0.665	0.623	0.583	0.547	0.513	0.482	0.452	0.425	0.400	0.376	0.354	0.314	0.279	0.210	0.159
8	0.853	0.789	0.731	0.677	0.627	0.582	0.540	0.502	0.467	0.434	0.404	0.376	0.351	0.327	0.305	0.266	0.233	0.168	0.123
9	0.837	0.766	0.703	0.645	0.592	0.544	0.500	0.460	0.424	0.391	0.361	0.333	0.308	0.284	0.263	0.225	0.194	0.134	0.094
10	0.820	0.744	0.676	0.614	0.558	0.508	0.463	0.422	0.386	0.352	0.322	0.295	0.270	0.247	0.227	0.191	0.162	0.107	0.073
11	0.804	0.722	0.650	0.585	0.527	0.475	0.429	0.388	0.350	0.317	0.287	0.261	0.237	0.215	0.195	0.162	0.135	0.086	0.056
12	0.788	0.701	0.625	0.557	0.497	0.444	0.397	0.356	0.319	0.286	0.257	0.231	0.208	0.187	0.168	0.137	0.112	0.069	0.043
13	0.773	0.681	0.601	0.530	0.469	0.415	0.368	0.326	0.290	0.258	0.229	0.204	0.182	0.163	0.145	0.116	0.093	0.055	0.033
14	0.758	0.661	0.577	0.505	0.442	0.388	0.340	0.299	0.263	0.252	0.205	0.181	0.161	0.141	0.125	0.099	0.078	0.044	0.025
15	0.743	0.642	0.555	0.481	0.417	0.362	0.315	0.275	0.239	0.209	0.183	0.160	0.140	0.123	0.108	0.084	0.005	0.035	0.020
16	0.728	0.623	0.534	0.458	0.394	0.339	0.292	0.252	0.218	0.188	0.163	0.141	0.123	0.107	0.093	0.071	0.054	0.028	0.015
17	0.714	0.605	0.513	0.436	0.371	0.317	0.270	0.231	0.198	0.170	0.146	0.125	0.108	0.093	0.080	0.060	0.045	0.023	0.012

(Contd.)

Present Value of One Rupee Payable after n Years at Discount Rate i $(1 + i)^{-n}$																			
n/i	*2%*	*3%*	*4%*	*5%*	*6%*	*7%*	*8%*	*9%*	*10%*	*11%*	*12%*	*13%*	*14%*	*15%*	*16%*	*18%*	*20%*	*25%*	*30%*
18	0.700	0.587	0.494	0.416	0.350	0.296	0.250	0.212	0.180	0.153	0.130	0.111	0.095	0.081	0.069	0.051	0.038	0.018	0.009
19	0.686	0.570	0.475	0.396	0.331	0.277	0.232	0.194	0.164	0.138	0.116	0.098	0.083	0.070	0.060	0.043	0.031	0.014	0.007
20	0.673	0.554	0.466	0.377	0.312	0.258	0.215	0.178	0.149	0.124	0.104	0.087	0.073	0.061	0.051	0.037	0.026	0.012	0.005
21	0.660	0.538	0.439	0.359	0.294	0.242	0.199	0.164	0.135	0.112	0.093	0.077	0.064	0.053	0.044	0.031	0.022	0.009	0.004
22	0.647	0.522	0.422	0.342	0.278	0.266	0.184	0.150	0.123	0.101	0.083	0.068	0.056	0.046	0.038	0.026	0.018	0.007	0.003
23	0.634	0.507	0.406	0.326	0.262	0.211	0.170	0.138	0.112	0.091	0.074	0.060	0.049	0.040	0.033	0.022	0.015	0.006	0.002
24	0.622	0.492	0.390	0.310	0.247	0.197	0.158	0.126	0.102	0.082	0.066	0.053	0.043	0.035	0.028	0.019	0.013	0.005	0.002
25	0.610	0.478	0.375	0.295	0.233	0.184	0.146	0.116	0.092	0.074	0.059	0.047	0.038	0.030	0.024	0.016	0.010	0.004	0.001
26	0.598	0.464	0.361	0.281	0.200	0.172	0.135	0.106	0.084	0.066	0.053	0.042	0.033	0.026	0.021	0.014	0.009	0.003	0.001
27	0.586	0.450	0.347	0.268	0.207	0.161	0.125	0.098	0.076	0.060	0.047	0.037	0.029	0.023	0.018	0.011	0.007	0.002	0.001
28	0.574	0.437	0.333	0.255	0.196	0.150	0.116	0.090	0.069	0.054	0.042	0.033	0.026	0.020	0.016	0.010	0.006	0.002	0.001
29	0.563	0.424	0.321	0.243	0.185	0.141	0.107	0.082	0.063	0.048	0.037	0.029	0.022	0.017	0.014	0.008	0.005	0.002	0.001
30	0.552	0.412	0.308	0.231	0.174	0.131	0.099	0.075	0.057	0.044	0.033	0.026	0.020	0.015	0.012	0.007	0.004	0.001	
40	0.453	0.307	0.208	0.142	0.097	0.067	0.046	0.032	0.022	0.015	0.011	0.008	0.005	0.004	0.003	0.001	0.001		
50	0.372	0.228	0.141	0.087	0.054	0.034	0.021	0.013	0.009	0.005	0.003	0.002	0.001	0.001	0.001				

Source: P. Chandra, *Projects—Preparation, Appraisal, Implementation*, Tata McGraw-Hill, New Delhi, 1980.

7 Queueing Theory

The word 'queue' is not unfamiliar to us. We have all stood in a queue for railway reservations, or airline tickets, in a ration shop, or for water from a municipal tanker. Just as people wait for these services, materials wait at a work centre to be worked-on, and papers wait at a section in an office to be processed. Queueing theory tries to analyse why such waiting lines occur and what solutions can be offered to improve the desired performance. Should there be one clerk, or two, or three clerks at a counter? How should jobs waiting at a work centre be taken up for processing—in the order they arrive, or in accordance with their increasing processing times, or in accordance with their due dates? Do the latter alternatives make much difference? What service system can be thought of to avoid making housewives wait for long, for a rationed supply of kerosene? What should be the number of maintenance mechanics so that too many machines, which have broken down, are not kept waiting for repair thus holding up productive work for long? Such are the questions which queueing theory attempts to answer.

Thus, from the above, it is obvious that the delays or stoppages in a flow system are called 'Queues' or 'Waiting Lines'.

FEATURES

Queueing Systems have the following three features:

Arrival

(a) Commuters arriving to buy railway tickets.
(b) Parts arriving to be assembled in an Assembly department.
(c) Invoices arriving at an order desk.

The characteristics of the waiting line depend on the characteristics of the arrival process. Arrivals could be *single* or *bunched; controlled* or *uncontrolled*. Occasions, where the arrival process is almost under control may be called 'deterministic'; while occasions where there is no absolute control may be called 'probabilistic'.

Arrivals could be state-dependent or independent. For example, a long line of queue may either discourage or encourage people to join the queue. Even with materials and machines, there could be a system-dependence on the part of the arrivals. Thus 'arrivals' may depend upon the characteristics of preceding 'arrivals' and/or the 'servicing characteristics' and/or the result of it, that is the 'waiting line' characteristics.

SERVICE

Examples of service are as follows:

(a) The number of commuters that a railway ticket counter clerk attends to.
(b) The number of parts assembled in an Assembly Shop.
(c) The number of breakdowns that are repaired in a Maintenance Shop.
(d) The number of orders or invoices processed by the order clerk.

The characteristics of the waiting line depend also upon the characteristics of the services offered. It may be important to analyse:

(i) Whether the service-time or service-rates as mentioned above, are constant or are probabilistic?
(ii) Whether service-rates are dependent upon the queue-system itself? For instance, does a barber consciously or subconsciously increase his speed looking at the number of people waiting for his services on a Sunday morning?

Queueing Discipline

This is a rule or a set of rules which describes the order in which the arrivals will be serviced, for example:

(a) First come first served.
(b) Serve the shortest duration next; this means that you service the operation taking the shortest time first, next shortest second, and so on. (For instance, a barber trims the moustache first, shaves next, and does the hair-cut job thereafter.)
(c) When there are more than ten commuters waiting in a queue at the booking office, open another counter for issuing tickets.
(d) Serve the last arrival first.
(e) Serve the job taking the longest amount of time first, and proceed to the next longest job.
(f) Serve each unit in the queue system partially. (Like barbers who attend partially to one customer and then move on to the second, thereby keeping all customers waiting. Many manufacturing systems behave on similar lines.)
(g) Serve the jobs that are intrinsically high-priority jobs by stopping work on lower-priority jobs. If an order from a prestigious firm arrives, give it preference over all others, even those in process, and take it up immediately for manufacture.

Thus, Queue discipline is basically the priorities scheme operating in the servicing of the units in a system.

DESIGN

The design of the queue system, i.e. the service process, the prioritisation of the units for service, and perhaps the arrival process as well, depends upon what the queue system wants to achieve

ultimately, i.e. the desired objectives or the set of criteria with which the system will be measured for performance. One cannot expect the criteria to be the same for a consumer-product industry and a defence industry or ordnance factory, an outpatient check-up ward and a casualty section in a hospital.

First let us analyse why queues or waiting lines form. One answer is: Queues form if the service rates are slower than the rate of arrivals. In fact, the waiting line, in such a case, may go on extending with time. Naturally, we would require that the service rate be equal to or greater than the arrival rate. If the service rate, on an average, is higher than the mean arrival rate, will there be a waiting line? One may be tempted to answer quickly that there would be no waiting line. But, this answer could be true only for a part of the time. At times there are long waiting lines at others smaller lines, and at some other times no lines, for the same queueing system. This happens generally, because the arrival and/or service processes are probabilistic. It is because of the variability in the inter-arrival times and/or in the service times for individual units, that a waiting line forms in spite of the mean service rate being faster than mean arrival rate.

To understand flow-oriented systems we shall, therefore, have to use models of a statistical nature. It will be necessary on our part to analyse the statistical pattern of the inter-arrival time and of the service times and how these two may be related to the question of the waiting line through the queueing discipline. Thus a particular inter-arrival or service time may be thought of as having been drawn from a population of possible inter-arrival or service times. When the population of these times can be approximated by common statistical distributions, it is easier to make predictions about the waiting line systems.

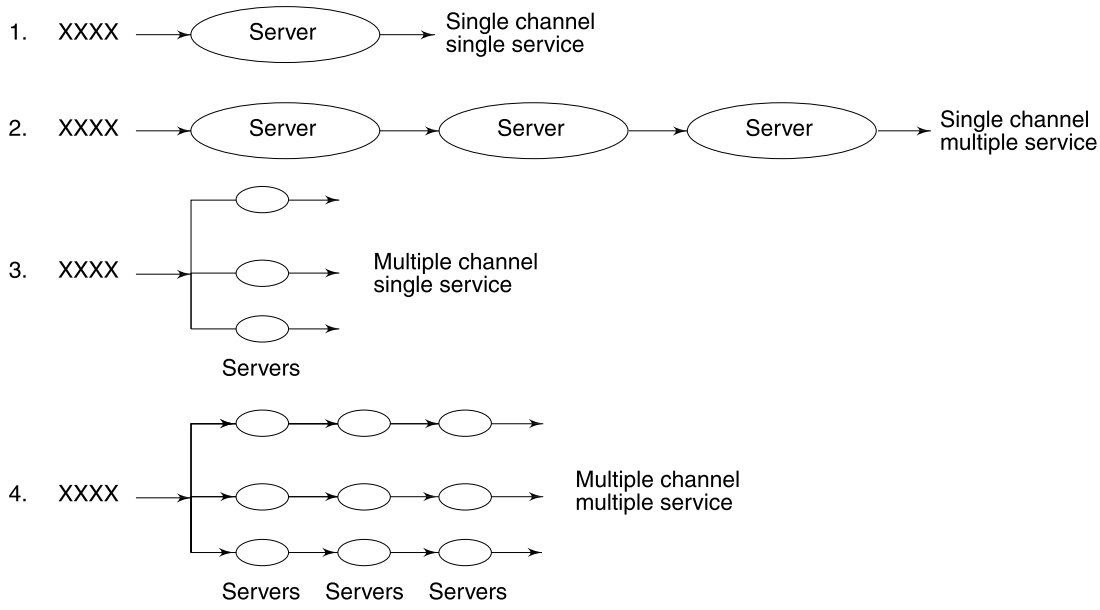


Figure 7.1 Queueing Systems

TYPES OF QUEUEING SYSTEMS

Queueing systems can be divided into four categories as shown in Fig. 7.1.

System 1 in Fig. 7.1 shows a simple system where there is one servicing person or servicing point and one line of customers waiting to be serviced. The second system shows a single waiting line of customers with a number of services to be performed on them. A customer will go through all these multiple services. The third system shows a number of servers performing the same type of service who are available for the customers waiting in line. As soon as any one of the servers becomes available, the customer waiting in the line can go to that particular free server to get the desired service. The fourth category of the queueing system has a number of different kinds of services to be performed one after another where a number of servers are available to perform the same kind of service. This is the generalised version of the queueing system. Queueing theory models are different for these different categories of queueing systems.

ANALYSIS

The questions to be asked in queueing theory analysis are, for example:

(a) What is the average number of units (i.e. customers, jobs) waiting in the queue?

(b) What is the average waiting time for the units in the queue system? What is the waiting time for the different types of units (if such a differentiation exists and is necessary)?

(c) What are the criteria of performance for the queue system?

(d) How might one design/change the service and/or arrival characteristics of the system?

(e) How might one, suitably, design the queueing discipline to achieve the desired objective/s?

(f) In the achievement of one objective, how can the other objective/s possibly be compromised?

The analysis of the Queueing systems should provide us with a number of scenarios for policy alternatives with the corresponding expected results. Queueing theory is a decision-making tool for the manager's benefit, just as the other Operations Research techniques. In other words, waiting line length may be designed to be longer or shorter, depending on the class of 'customers', or the waiting line length and waiting time may not be of primary significance—all depending upon the objectives and criteria for the system.

CHARACTERISTICS OF SINGLE CHANNEL SINGLE SERVICE QUEUEING SYSTEM

This is one of the basic analytical queueing models. The assumptions are:

(i) Single channel single service.

(ii) The distribution of arrival rates is modelled by poisson distribution.

(iii) The distribution of service rates is also modelled by poisson distribution.

(iv) The queue discipline is first come first served (FCFS).

(v) It is possible for the waiting line to grow infinitely long.

(vi) The queue system does not influence either the arrival or service rates.

(vii) Each arrival (customer) needs the same unit of service.

Let λ and μ represent the means of the poisson distribution of the arrival rate and the service rate, respectively. For such a system with the above-mentioned assumptions, the various characteristics of the waiting line have been given in Table 7.1.

Table 7.1 Characteristics of a Single Service Single Channel and Poisson Service and Arrival Distributions Model

(i)	Mean number in the system, including the one being serviced:
	$N_s = \dfrac{\lambda}{\mu - \lambda}$
(ii)	Mean number in the waiting line:
	$N_w = \dfrac{\lambda^2}{\mu(\mu - \lambda)} = N_s - \dfrac{\lambda}{\mu}$
(iii)	Mean time in the system, including the service time:
	$T_s = \dfrac{1}{\mu - \lambda} = \dfrac{N_s}{\lambda}$
(iv)	Mean waiting time:
	$T_w = \dfrac{\lambda}{\mu(\mu - \lambda)} = \dfrac{N_w}{\lambda}$
(v)	Probability of n units in the system:
	$P_n = \left[1 - \dfrac{\lambda}{\mu}\right]\left[\dfrac{\lambda}{\mu}\right]^n$
(vi)	Probability of 'zero' units in the system (i.e. the servers are idle):
	$P_0 = \left[1 - \dfrac{\lambda}{\mu}\right]\left[\dfrac{\lambda}{\mu}\right]^0 = 1 - \dfrac{\lambda}{\mu} = 1 - \rho$

Note: 'ρ' is called the *traffic intensity factor or the utilisation factor*. Since $\mu > \lambda$, therefore $0 \leq \rho \leq 1$.

The following example may be illustrative. Suppose the Bharathiya Vignyana Sanstha receives applicants at an arrival rate of 16 applicants per hour, who are seen by an assistant dean (academic) at an average time of three minutes per applicant. If the arrival rate and the service rate are both Poisson,

(i) What is the average number of applicants waiting in line?

(ii) What is the average waiting time?

$$\text{The average number waiting in line} = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(16)^2}{20(20 - 16)} = 3.20$$

$$\text{The average waiting time} = \frac{\lambda}{\mu(\mu - \lambda)} = 0.20 \text{ hour.}$$

ARRIVAL FROM A FINITE POPULATION

The above example and the formulae given in Table 7.1 have assumed that the source from which the arrivals come is infinite. While the case of the applicants can be from an infinite (almost) source, the cases of **(i)** machines breaking down and arriving for service, or (ii) second year MBA repeater students coming to a teacher for doubts, are not arrivals drawn from an infinite source. The source is finite and hence the arrival process characteristics get affected by the number in the queueing system. Generally, with a number in the source above 30, the assumption of infinite source holds quite well. However, with a finite source, the formulae are different and are cumbersome for manual computations. Finite queueing tables will help in such cases.*

CHARACTERISTICS OF A MULTIPLE CHANNEL SINGLE SERVICE QUEUEING SYSTEM

For a multiple channel single service (infinite arrival source) queueing system, with all the earlier assumptions for the Single Channel Single Service (infinite arrival source) system, the formulae for the various features are shown in Table 7.2:

Table 7.2 Multiple Channel Single Service Queue System (Infinite Arrival Source). (Mean service rates of different servers are equal and independent of one another)

$\rho = \dfrac{\lambda}{s \cdot \mu}$ where s is the number of servers
$N_s = \left[\dfrac{(s \cdot \rho)^{s+1}}{(s-1)!(s-\rho \cdot s)^2} \cdot P_0 \right] + (\rho \cdot s)$
where $P_0 = \dfrac{1}{\left(\sum_{i=0}^{s-1} \dfrac{(\rho \cdot s)^i}{i!} \right) + \dfrac{(\rho \cdot s)^s}{s!(1-\rho)}}$
$N_w = N_s - \rho \cdot s$
$T_s = \dfrac{N_w}{\lambda} + \dfrac{1}{\mu}$
$T_w = \dfrac{N_w}{\lambda}$
$P_n = \begin{cases} \dfrac{(\rho \cdot s)^n}{n!} \cdot P_0 & \text{for } 0 \le n \le s \\ \left[\dfrac{(\rho \cdot s)^n}{s!(s)^{n-s}} \right] \cdot P_0 & \text{for } n \ge s \end{cases}$

* L.G. Peck and R. N.Hazelwood, *Finite Queueing Tables*, John Wiley & Sons, New York, 1958. (The tables are given for finite populations of 4 to 250.)

Example There are two counters for issuing tickets at a suburban railway station. Both clerks at the counters work at the same average rate of 40 passengers an hour. The mean arrival rate is 64 passengers an hour. If Poisson rates for arrival and service are assumed, what are the salient features of the queueing system?

$$\rho = \frac{64}{(2)(40)} = 0.80$$

$$P_0 = \frac{1}{(1+(0.80)(2)) + \dfrac{(0.08\times 2)^2}{(2)(1-0.8)}} = \frac{1}{9} = 0.11$$

$$N_s = \left[\frac{(2)^3 (0.8)^3}{(1)(2-1.6)^2} \times \frac{1}{9}\right] + (0.8)(2) = 4.43$$

$$N_w = 4.43 - 0.80(2) = 2.83$$

$$T_w = \frac{2.83}{64} = 0.0442 \text{ hour}$$

$$T_s = 0.0442 + \frac{1}{40} = 0.0692 \text{ hour}$$

Limitations of Analytical Models

Analytical queueing models are being applied, advantageously, to many practical situations in operations management. However, when the real-life situations are portrayed by an analytical queueing theory model, various assumptions creep in. For instance, in our models presented herein we have assumed a convenient poisson distribution. Analytical models are available for constant service rate and for assumptions of erlangian arrival or service rates. The assumptions regarding any statistical distribution should satisfy two criteria: **(a)** they should represent the reality fairly well, and **(b)** they should be such that analytical solutions can be worked out without too much complexity. In many real-life situations, both these criteria cannot be met simultaneously. Can arrivals at a shopping centre be approximated by a Poisson distribution?

Many different behavioural patterns have to be considered where arrivals depend upon the state of the queueing system. In addition to finding a suitable statistical distribution, there is the problem of various possible queue disciplines. Further the problem of transient (time dependent) solutions as against the simpler steady-state solutions exists.

Multiple channel multiple service problems are even more complex to be handled analytically. This situation is encountered all the time in a make-to-order production business.* Here, the jobs have to go through a number of processes. The jobs 'wait' at every work centre. The typical problem is one of finding a suitable 'dispatch rule', which is the 'queue discipline', so as to achieve the desired criteria such as **(a)** minimum total flow time, or **(b)** machinery/labour utilisation, or **(c)** minimum standard deviation of the distribution of completion, or **(d)** minimise the percentage of orders completed late, etc.

* This is called 'Job-shop' type of production system.

USE OF SIMULATION

Analytical solutions are available for two/three work centres cases, and that too for a limited number of situations. This is where digital simulation by means of a computer facility comes in handy. Job-shop problems have been handled by 'simulating' the arrival, processing, and queue discipline and then evaluating the simulated system's performance on the desired criteria.

Monte Carlo Simulation

Monte Carlo is an approach for simulating the probability distribution by associating and then selecting random numbers.

In this technique, we can incorporate with more ease many of the real-life constraints. For instance, if the customers go to the shop mostly during the evening or on holidays, such constraints could be incorporated into the digital simulation model. Various complex rules encountered in the queueing discipline can also be easily incorporated by means of this technique. We shall explain the basic elements of this technique by means of an example given below. The same basic principles could be extended to complex problems such as multiple channel-and-multiple services with a variety of queueing disciplines.

Let us consider over here a shop with *one* server who performs *one* type of service for *one customer at a time*. Suppose he has observed the following inter-arrival times and their frequencies (that means, the number of times this particular inter-arrival time was observed). Table 7.3 not only shows the inter-arrival times and corresponding frequencies but also calculates the probability of occurrences, the cumulative probability, and based on the cumulative probability the associated random numbers.

Table 7.3 Monte Carlo Simulation

Minutes Between Arrivals	*Frequencies*	*Probability of Occurrence*	*Cumulative Probability*	*Associated Random Numbers*
1	29	0.29	0.29	00-28
2	23	0.23	0.52	29-51
3	13	0.13	0.65	52-64
4	10	0.10	0.75	65-74
5	8	0.08	0.83	75-82
6	6	0.06	0.89	83-88
7	5	0.05	0.94	89-93
8	4	0.04	0.98	94-97
9	2	0.02	1.00	98-99

Now, we refer to a random number table and pick out, say, 10 random numbers which will be our representative sample. For instance, if our first random number happens to be 81, then the corresponding inter-arrival time is 5 minutes. Similarly, if our second random number happens to be 54, then the second inter-arrival time is 3 minutes (for the example given above), and so on. This way we are creating a simulation sample for the customer arrival rates. Now, depending upon the sample of these arrival rates or the inter-arrival times of the customers of our example we can

corresponding inter-arrival time is 5 minutes. Similarly, if our second random number happens to be 54, then the second inter-arrival time is 3 minutes (for the example given above), and so on. This way we are creating a simulation sample for the customer arrival rates. Now, depending upon the sample of these arrival rates or the inter-arrival times of the customers of our example we can calculate by simple arithmetic, the number of minutes a customer/number of customers who have to wait in order to be serviced, the amount of time that the server remains idle in our sample, and the number of people on an average waiting to be served in our sample. In this way, we can find the average waiting time, the average waiting line and the idle time for the server from our sample data. (A random number table is shown in the Appendix to this chapter.)

Monte Carlo Simulation, as discussed above is useful for complex queueing situations because complex queueing disciplines, complex distributions of inter-arrival times and service times can all be included in the simulation model without much difficulty. Of course, if such a simulation exceeds a certain number of observations, it has to make use of a computer facility. The data on the inter-arrival times and the service times can be stored and a computer programme can specify the random selection of the sample as well as the queueing discipline and other important features of the flow problem.

SOLVED PROBLEMS

1. At a toll-booth on a state roadway, there is only one toll-gate collecting toll from commuting vehicles. The vehicles' arrival rates and the toll collection rates show Poisson distributions. The vehicles arrive at an average rate of 55 vehicles per hour. The toll collection takes, on an average, 1 minute per vehicle.

(a) If there is a waiting line, on an average how many vehicles may be found waiting ?

(b) What may be the mean waiting time ?

(c) By providing two toll collection gates, will the average waiting time substantially reduce ?

Answer

(a) The case is that of a single channel single service queuing system. It is given in the case that : mean arrival rate $\lambda = 55/60 = 0.9167$ vehicles per minute and mean service rate $\mu = 1$ per minute. As per the formula, the mean number in the waiting line $N_w = [\lambda^2/(\mu)(\mu - \lambda)]$

$$= (0.9167)^2/(1)(1 - 0.9167) = 10.09$$

(b) Mean waiting time T_w for the single toll collection gate case is :

$$= N_w/\lambda = 10.09/0.9167 = 11 \text{ minutes}$$

(c) If there are two collection gates, the queuing system is that of multiple channel single service and we can read off the corresponding value from the table provided for such a system at the end of this chapter. Some interpolation may be necessary while taking the value from the table.

For the case of $(\lambda/\mu) = (0.9167/1) = 0.9167$ and $s = 2$ we have

Mean number waiting in the line $N_w = 0.245$

Mean waiting time $T_w = N_w/\lambda = 0.245/0.9167 = 0.267$ minute

This is a substantial improvement over the earlier case of having just one collection gate.

2. The maintenance manager of a company is deciding on the number of attendants to deploy in operating the tool-crib. He is driven by the considerations of cost economy. Neither should there be too many attendants, nor should the highly skilled mechanics – to whom the attendants provide service – be kept waiting and thus wasting their precious time. The attendants cost Rs. 40 per hour while a mechanic's time costs Rs. 500 per hour. The demands for service at the tool-crib depict a negative exponential distribution for the inter-arrival times and comes at a mean rate of 30 per hour. The tool-crib attendant can service 12 requests per hour on an average and the service rates show a poisson distribution. What should be the optimum number of tool-crib attendants ?

Answer

This is a multiple channel single service queuing system.

$\lambda = 30$, $\mu = 12$; so $(\lambda/\mu) = 2.5$

For different values of '*s*', we shall find out T_S (mean time in the system). The latter will give us the cost of the mechanics in waiting for and collecting the tools.

The starting value of '*s*'(i.e. the number of servers) has to be more than λ/μ. So, let us start at $s = 3$ and compute T_s also for $s = 4$ and $s = 5$. The cost implications of these alternatives are compared as shown in the table furnished.

Case /: $s = 3$

$$\rho = \lambda/(s.\mu) = 30/(3 \times 12) = 0.8333$$

Corresponding to various values of (λ/μ) and various number of service channels (s), the values of N_w are given in Queuing tables.

For $s = 3$ and $(\lambda/\mu) = 2.5$, corresponding value of N_w is interpolated in the table and we get $N_w = 3.03$

Therefore, the time in the system $T_s = (N_w/\lambda) + (1/\mu) = (3.03/30) + (1/12)$

$= 0.1010 + 0.0833 = 0.1843$ hour.

Case II : $s = 4$

$$\rho = \lambda/(s.\mu) = 30/(4 \times 12) = 0.625$$

For $s = 4$ and $(\lambda/\mu) = 2.5$, corresponding value of N_w is interpolated in the Queuing table and we get $N_w = 0.545$

Therefore, the time in the system $T_s = (N_w/\lambda) + (1/\mu) = 0.545/30) + (1/12)$

$= 0.0182 + 0.0833 = 0.1015$ hour.

Case III : $s = 5$

$$r = \lambda/(s.\mu) = 30/(5 \times 12) = 0.500$$

For $s = 5$ and $(\lambda/\mu) = 2.5$, corresponding value of N_w is interpolated in the Queuing table and we get $N_w = 0.132$

Therefore, the time in the system $T_s = (N_w/\lambda) + (1/\mu) = (0.132/30) + (1/12)$

$= 0.0044 + 0.0833 = 0.0877$ hour.

All the above results are presented in the table below.

No. of Attendants	*Mean time in the system* *Ts*	*Cost of Mechanics* *(Rs.)*	*Cost of Attendants* *(Rs.)*	*Total cost* *(Rs.)*
3	0.1843	92.15	120	212.15
4	0.1015	50.75	160	210.75
5	0.0877	43.85	200	243.85

The lowest cost is observed at $s = 4$. That is the manager may have 4 attendants for the tool–crib.

3. Consultation is offered for 4 hours between 3 p.m. and 7 p.m. A simulation exercise for a customer consultation service produced the following results for a 4-hour consultation period.

Consultation time needed, (minutes)	*Probability*
10	0.2
20	0.3
30	0.4
40	0.1

The customer inter-arrival times also have been observed, as follows.

Time between a customer and the next one (Minutes)	*Probability*
20	0.3
30	0.4
40	0.3

A customer's waiting time is valued at Rs. 50 per mintue of her/his wait. A consultant's wages are Rs. 500 per hour (whether s/he is working or idle).

Carry out one simulation run. Start it at 3:00 p.m. and consider that the first customer is available exactly at 3:00 p.m.

(a) What are the wait times for the customers ?

(b) Would adding one more consultant have been economically justified ? Consider both the notional wait costs for the customer and the tangible wages for the consultant. If the consultation proceeds beyond 7:30 p.m. add Rs. 1000 for supplementary administrative cost.

(Note : A number of simulation runs are required to come to a recommendation. Show one run out of the several simulation runs.)

Answer

Corresponding to the probabilities, write the associated random number group.

Following is the result.

Consultation time (Minutes)	*Probability*	*Associated Random Numbers*
10	0.2	00–19
20	0.3	20–49
30	0.4	50–89
40	0.1	90–99

Inter-arrival time (Minutes)	*Probability*	*Associated Random Numbers*
20	0.3	00–29
30	0.4	30–69
40	0.3	70–99

Draw the random number referring to the random number table.

Random Nos.	*Corresponding Consultation time (Minutes)*
27	20
76	30
74	30
35	20
84	30
85	30
30	20
18	10

Random Nos.	*Corresponding Inter-arrival time (Minutes)*
80	40
21	20
73	40
62	30
92	40
98	40
52	30

Start the simulation run at 3:00 p.m. as specified in the problem. The time of arrival of a customer, the clock-time of start of consultation by the consultant, the clock-time of finish of the consultation, and the wait time of the customer are all easily computed for the above simulation run. This is furnished below.

Customer arrives (pm)	*Consult starts (pm)*	*Consult ends (pm)*	
3:00	3:00	3:20	
3:40	3:40	4:10	
4:00	4:10	4:40	Customer waits 10 mins.
4:40	4:40	5:00	
5:10	5:10	5:40	
5:50	5:50	6:20	
6:30	6:30	6:50	
7:00	7:00	7:10	

In this simulation run, only one customer has waited for 10 minutes. This notionally costs Rs. 50×10 = Rs. 500. An additional consultant would have cost an additional Rs. 1000. If one was to only conclude from this single run, the additional consultant is not justified. Of course, a simulation is best judged by having several runs and then computing the averages from them. A computer simulation would be ideal

QUESTIONS FOR DISCUSSION

1. What are waiting times 'in the system' and 'in the line'?
2. What is a 'transient' solution to a queueing problem? What kinds of solutions are tabulated in this chapter? Give an example of a 'transient' behaviour.
3. What are finite queueing tables?
4. How would different Queueing Disciplines affect waiting line characteristics? Explain by giving examples.
5. What is the relation between the server utilisation and average waiting time for customers? What is the practical significance of this relation.
6. In an airline hangar, jet-engines arrive at a rate of 2 per week. A jet engine costs nearly Rs. 1 crore. There are 30 aircraft, each with 4 engines. When an engine breaks down, it is sent for reconditioning, and the engine is immediately replaced by one from the spare engines' bank of the reconditioned engines. If mean rate of reconditioning is 3 engines per week, what should be the optimum number of spare engines to be kept? Note that the cost of unavailability of a plane, if it is grounded, is Rs. 25 lakh per week.
7. Tax-payers are lining up, on June 29th, in order to file their income-tax returns. The arrival of the tax-payers is Poisson, at a mean rate of 5 per minute. The I.T. Officer wishes that no tax-payer should suffer for more than 10 minutes in the queueing system. If only one clerk is serving, what should be the rate at which the clerk disposes the tax returns? What if the number of clerks is two?
8. For the above two cases plot the server utilisation vs. length of the queue.
9. IIM faculty members (Prof. Chary's team) are interviewing the applicants for admission. The interviews start at 9.00 a.m. and each applicant has been asked to come at 15 minutes interval starting from 9.00 a.m. (each applicant is given a specific time).
   In spite of the apparent constancy of the interview timings and applicant arrival times, there are variations. The probabilities for the different times are given below:

Interviewing period

4 out of 10 cases will take 15 minutes.
2 out of 10 cases will take 20 minutes.
1 out of 10 cases will take 25 minutes.
2 out of 10 cases will take 10 minutes.
1 out of 10 cases will take 5 minutes.

Times of arrival for the interview

2 out of 10 cases will come 5 minutes earlier than scheduled.
2 out of 10 cases will come 10 minutes earlier than scheduled.
3 out of 10 cases will come on right time.
2 out of 10 cases will come 5 minutes late.
1 out of 10 cases will be absent.

The appointments, as earlier scheduled, are as follows: 9.00, 9.15, 9.30, etc. up to 11.00 a.m. 11.00 to 11.15 a.m. is coffee-time for the faculty. Next from 11.15 a.m., the interviews are scheduled up to 1.00 p.m. 1.00 p.m. to 2 p.m. is lunch hour. The interviews are scheduled again up to 4 p.m. at 15 minutes intervals. It may be noted that the coffee-break and lunch-break have to be of 15 minutes and 1 hour duration even if they are delayed or early. Also, if a candidate is available earlier than his scheduled time and if Prof. Chary's team is free, they will take the candidate for interviewing.

Prof. Chary has promised to fetch his father from the airport at 4.00 p.m.

By simulating the day's activities 10 times, answer:

Would Prof. Chary be able to leave for the airport at 4.00 p.m.?

If not, what changes in the queue system do you suggest in order that the Professor be able make it to the airport on time?

10. How can simulation be used for incorporating 'risk' into the capital budgeting decision under uncertainty?

ASSIGNMENT QUESTION

1. Observe a busy traffic junction. Present a report on easing traffic jams by means of the application of Queuing principles.

APPENDIX I

RANDOM NUMBER TABLE

27767	43584	85301	88977	29490	69714	94015	64874	32444	48277
13025	14338	54066	15243	47724	66733	74108	88222	88570	74015
80217	36292	98525	24335	24432	24896	62880	87873	95160	59221
10875	62004	90391	61105	57411	06368	11748	12102	80580	41867
54127	57326	26629	19087	24472	88779	17944	05600	60478	03343
60311	42824	37301	42678	45990	43242	66067	42792	95043	52680
49739	71484	92003	98086	76668	73209	54244	91030	45547	70818
78626	51594	16453	94614	39014	97066	30945	57589	31732	57260
66692	13986	99837	00582	81232	44987	69170	37403	86995	90307
44071	28091	07362	97703	76447	42537	08345	88975	35841	85771
59820	96163	78851	16499	87064	13075	73035	41207	74699	09310
25704	91035	26313	77463	55387	72681	47431	43905	31048	56699
22304	90314	78438	66276	18396	73538	43277	58874	11466	16082
17710	59621	15292	76139	59526	52113	53856	30743	08670	84741
25852	58905	55018	56374	35824	71708	30540	27886	61732	75454
46780	56487	75211	10271	36633	68424	17374	52003	70707	70214
59849	96169	87195	46092	26787	60939	59202	11973	02902	33250
47670	07654	30342	40277	11049	72049	83012	09832	25571	77628
94304	71803	73465	09819	58869	35220	09504	96412	90193	79568
08105	59987	21437	36786	49226	77837	98524	97831	65704	09514
64281	61826	18555	64937	64654	25843	41145	42820	14924	39650
66847	70495	32350	02985	01755	14750	48968	38603	70312	05682
72461	33230	21529	53424	72877	17334	39283	04149	90850	64618
21032	91050	13058	16218	06554	07850	73950	79552	24781	89683
95362	67011	06651	16136	57216	39618	49856	99326	40902	05069
49712	97380	10404	55452	09971	59481	37006	22186	72682	07385
58275	61764	97586	54716	61459	21647	87417	17198	21443	41808
89514	11788	68224	23417	46376	25366	94746	49580	01176	28838
15472	50669	48139	36732	26825	05511	12459	91314	80582	71944
12120	86124	51247	44302	87112	21476	14713	71181	13177	55292
95294	00556	70481	06905	21785	41101	49386	54480	23604	23554
66986	34099	74474	20740	47458	64809	06312	88940	15995	69321
80620	51790	11436	38072	40405	68032	60942	00307	11897	92674

55411	85667	77535	99892	71209	92061	92329	98932	78284	46347
95083	06783	28102	57816	85561	29671	77936	63574	31384	51924
90726	57166	98884	08583	95889	57067	38101	77756	11657	13897
68984	83620	89747	98882	92613	89719	39641	69457	91339	22502
36421	16489	18059	51061	67667	60631	84054	40455	99396	63680
92638	40333	67054	16067	24700	71594	47468	03577	57649	63266
21036	82808	77501	97427	76479	68562	43321	31370	28977	23896
13173	33365	41468	85149	49554	17994	91178	10174	29420	90438
86716	38746	94559	37559	49678	53119	98189	81851	29651	84215
92581	02262	41615	70360	64114	58660	96717	54244	10701	41393
12470	56500	50273	93113	41794	86861	39448	93136	25722	08564
01016	00857	41396	80504	90670	08289	58137	17820	22751	36518
34030	60726	25807	24260	71529	78920	47648	13885	70669	93406
50259	46345	06170	97965	88302	98041	11947	56203	19324	20504
73959	76145	60808	54444	74412	81105	69181	96845	38525	11600
46874	37088	80940	44893	10408	36222	14004	23153	69249	05747
60883	52109	19516	90120	46759	71643	62342	07589	08899	05985

Source: R.G. Schroeder, *Operations Management—Decision Making in the Operations Function*, McGraw-Hill Kogakusha, International Student Edn, 1985.

APPENDIX II

Values of N_w for $s = 1 - 15$, and various values of $\gamma = \lambda/\mu$ in a Multiple Channel Single Service Queueing Model with Poisson Arrivals, Negative Exponential Service Times and Infinite Arrival Source

	Number of Service Channels, s														
γ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
0.10	0.0111														
0.15	0.0264	0.0008													
0.20	0.0500	0.0020													
0.25	0.0833	0.0039													
0.30	0.1285	0.0069													
0.35	0.1884	0.0110													
0.40	0.2666	0.0166													
0.45	0.3681	0.0239	0.0019												
0.50	0.5000	0.0333	0.0030												
0.55	0.6722	0.0449	0.0043												
0.60	0.9000	0.0593	0.0061												
0.65	1.2071	0.0767	0.0084												
0.70	1.6333	0.0976	0.0112												
0.75	2.2500	0.1277	0.0147												
0.80	3.2000	0.1523	0.0189												
0.85	4.8166	0.1873	0.0239	0.0031											
0.90	8.1000	0.2285	0.0300	0.0041											
0.95	18.0500	0.2767	0.0371	0.0053											
1.0		0.3333	0.0454	0.0067											
1.2		0.6748	0.0904	0.0158											
1.4		1.3449	0.1778	0.0324	0.0059										
1.6		2.8444	0.3128	0.0604	0.0121										

	Number of Service Channels, s														
γ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1.8		7.6734	0.5320	0.1051	0.0227	0.0047									
2.0			0.8888	0.1739	0.0398	0.0090									
2.2			1.4907	0.2770	0.0650	0.0158									
2.4			2.1261	0.4305	0.1047	0.0266	0.0065								
2.6			4.9322	0.6581	0.1609	0.0426	0.0110								
2.8			12.2724	1.0000	0.2411	0.0659	0.0180								
3.0				1.5282	0.3541	0.0991	0.0282	0.0077							
3.2				2.3856	0.5128	0.1452	0.0427	0.0122							
3.4				3.9060	0.7365	0.2085	0.0631	0.0189							
3.6				7.0893	1.0550	0.2947	0.0912	0.0283	0.0084						
3.8				16.9366	1.5184	0.4114	0.1292	0.0412	0.0127						
4.0					2.2164	0.5694	0.1801	0.0590	0.0189						
4.2					3.3269	0.7837	0.2475	0.0827	0.0273	0.0087					
4.4					5.2675	1.0777	0.3364	0.1142	0.0389	0.0128					
4.6					9.2885	1.4867	0.4532	0.1555	0.0541	0.0184					
4.8					21.6384	2.0708	0.6071	0.2092	0.0742	0.0260					
5.0						2.9375	0.8102	0.2786	0.1006	0.0361	0.0125				
5.2						4.3004	1.0804	0.3680	0.1345	0.0492	0.0175				
5.4						6.6609	1.4441	0.5871	0.1779	0.0663	0.0243	0.0085			
5.6						11.5178	1.9436	0.6313	0.2330	0.0883	0.0330	0.0119			
5.8						26.3726	2.6481	0.8225	0.3032	0.1164	0.0443	0.0164			
6.0							3.6828	1.0707	0.3918	0.1518	0.0590	0.0224			
6.2							5.2979	1.3967	0.5037	0.1964	0.0775	0.0300	0.0113		
6.4							8.0768	1.8040	0.6454	0.2524	0.1008	0.0398	0.0153		
6.6							13.7692	2.4198	0.8247	0.3222	0.1302	0.0523	0.0205		

	Number of Service Channels, s														
γ	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
6.8							31.1270	3.2441	1.0533	0.4090	0.1666	0.0679	0.0271	0.0105	
7.0								4.4471	1.3471	0.5172	0.2119	0.0876	0.0357	0.0141	
7.2								6.3135	1.7288	0.6521	02677	0.1119	0.0463	0.0187	
7.4								9.5102	2.2324	0.8202	0.3364	0.1420	0.0595	0.0245	0.0097
7.6								16.0379	2.9113	1.0310	0.4211	0.1789	0.0761	0.0318	0.129
7.8								35.8956	3.8558	1.2972	0.5250	0.2243	0.0966	0.0410	0.0168
8.0									5.2264	1.6364	0.6530	0.2796	0.1214	0.0522	0.0220
8.2									7.3441	2.0736	0.8109	0.3469	0.1520	0.0663	0.0283
8.4									10.9592	2.6470	1.0060	0.4288	0.1891	0.0834	0.0361
8.6									18.3223	3.4160	1.2484	0.5286	0.2341	0.1043	0.459
8.8									40.6824	4.4806	1.5524	0.6501	0.2885	0.1298	0.577
9.0										6.0183	1.9368	0.7980	0.3543	0.1603	0.0723
9.2										8.3869	2.4298	0.9788	0.4333	0.1974	0.899
9.4										12.4189	3.0732	1.2010	0.5287	0.2419	0.1111
9.6										20.6160	3.9318	1.4752	0.6437	0.2952	0.1367
9.8										45.4769	5.1156	1.8165	0.7827	0.3588	0.1673
10.0											6.8210	2.2465	0.9506	0.4352	0.2040

Source : Buffa E.S, "*Modern Production/Operations Management*", John Wiley & sons, 7th Edition, (1983) pp. 660–661 (Appendix G).

8 Forecasting

Planning is a fundamental activity of management. Forecasting forms the basis of planning. Be it planning for sales and marketing, or production planning or manpower planning, forecasts are extremely important.

WHAT IS FORECASTING?

Forecasting is a scientifically calculated guess. It is basic to all planning activity—

(i) whether it is national, regional, organisational, or functional planning; and

(ii) whether it is a long range plan or a short-range plan.

"My salesman looks out of the window and gives me the sales forecast for the next year" said one senior manager. This salesman may be quite effective in his job, but he is only predicting and not forecasting. Forecasting is a little more scientific than looking into a crystal-ball. The scientific basis of forecasting lies in studying past, present and future trends, present and future actions and their effects. What happened in the past is relevant to what is happening now and what could happen in the future. Thus, forecasting takes into account all the three dimensions of time—past, present and future. In spite of all the calculations, forecasting remains a calculated guess. Errors are bound to be there, but it remains the foundation for management planning.

One point needs a little emphasis. Many tend to think that forecasting is important only for marketing planning and not for production, because the figures for production planning are received from marketing planning anyway. This is an erroneous view. Production planning need not necessarily follow marketing planning. There are many situations where production planning and marketing planning have to be done together and many other situations where production planning may be done separately from marketing planning. Therefore, forecasting is a very important activity for production planning, be it strategic or tactical.

ELEMENTS OF FORECASTING

Forecasting consists basically of analysis of the following elements:

1. Internal factors:
   (a) Past
   (b) Present
   (c) Proposed or future

2. External factors:
   (i) Controllable
      (a) Past
      (b) Present
      (c) Future
   (ii) Non-controllable
      (a) Past
      (b) Present
      (c) Future

Forecasting is essentially the study of internal and external forces that shape demand and supply. The shape of the things to come will depend partially upon how one shapes the controllable factors. With different strategies, the forecasting will be different, offering multiple scenarios for management decision-making.

METHODS OF FORECASTING

Extrapolation

The easiest method of forecasting is that of *extrapolation*. If sales or production capacity needs in the past years have been 85, 90, 95 units, then in the coming year we could expect a sales/production capacity requirement of 100 units. This is very simple extrapolation and is illustrated in Fig. 8.1.

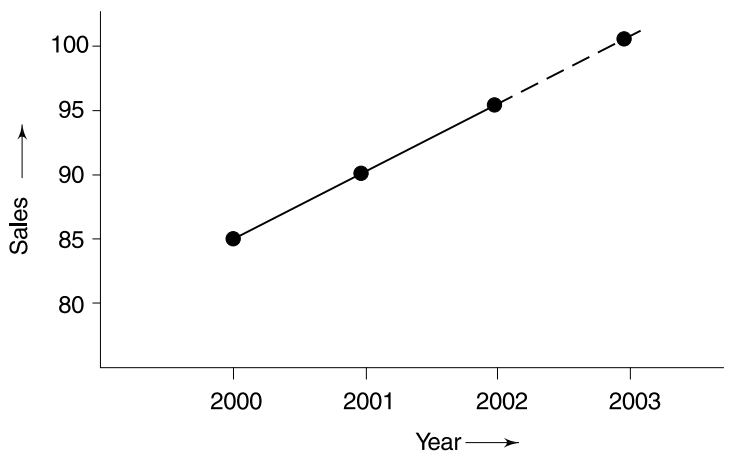


Figure 8.1 Extrapolation

If previous data is all linear, there is no problem in extrapolation. But if the previous data shows upward swings as well as downward swings then how is one to extrapolate? Many a time the upward and downward swings are quite random or one-time effects. For instance, in one particular year, a company may have received a substantial government order which may not be repeated again for many years to come. It is, therefore, better not to consider such one-time or random phenomena for forecasting purposes. And that is why, an average taken over a number of past years or time periods is more reliable as a forecast for the future year. This is what is done

in the averaging techniques. One can have a continuous average or an average only over a certain number of years or periods in time. Both 'continuous' and 'discrete' averaging methods are used, which we discuss below.

Moving Averages Method

The *moving average* is a 'discrete' averaging method, where periods in the past beyond a certain number are considered irrelevant for the analysis. Suppose a company wants to use a 10-week moving average for forecasting sales of a particular item; they will add sales for the last 10 weeks and divide by 10 to get the average. A week later, they would *add* the newest weeks' sales and discard the oldest, so that once again they have a current total of the past 10 weeks of sales. Again this needs to be divided by 10 to get the new moving average. This is illustrated in table 8.1.

Table 8.1 Moving Averages Method

Month	*Sales, units*	
January	50	
February	40	
March	90	Total of 10 months
April	45	= 540 units
May	55	
June	60	Forecast for November
July	55	$= \frac{540}{10} = 54$ units
August	50	
September	45	
October	50	

Now, if the observed sales for November happen to be 60:

The forecast for December $= \frac{540 + 60 - 50}{10}$

$= 55$ units

The message given by the moving averages technique is that, history helps to plan the future, but history beyond a certain time period in the past has very little influence on the future. The moving averages technique retires the old data and inducts fresh data into its calculation at every forecasting period. What we saw above was the case of a simple moving average. One could have also *weighted moving averages*, where different weights are given to the different periods of time in the past. For instance,

Time in the past	*Weightage*
4 years ago	0.05
3 years ago	0.25
2 years ago	0.3
Last year	0.4

Note: Forecast is being made for the current year which is just beginning.

In this case, the most recent data is considered to be more important than the past data and therefore, a heavy weightage is given to the more recent figures. Such a method could be suitable for certain businesses under certain conditions. Of course, much depends upon what the weightage factors are and to how many years in the past the forecasting information extends.

OTHER TIME-SERIES METHODS

A modified version of the weighted moving average technique is the *Exponential Smoothing* Method. The simplest way in which it could be expressed is as follows:

Suppose we have an old forecast made for the present period as 100, the actual sales observed in the present period is let us say, 90. Then the new forecast (for the next period) by the exponential smoothing method is obtained by giving weightage to the old forecast and the actual sales. Let us say the weightage given to the current actual sales is 0.2 and the weightage given to the old forecast is 0.8.

Now, the new forecast = $(100 \times 0.8) + (90 \times 0.2) = 98$

The same can be expressed algebraically as follows:

$$F_{t+1} = \alpha \cdot D_t + (1 - \alpha) \cdot F_t$$

where

D_t = demand during the present period t;
F_t = forecast of the demand made *for* the present period t;
F_{t+1} = forecast for the next period made during the present period.
α = weightage factor for the current demand.

The advantage of this method over the moving average method is that, one needs to have only two figures: one for the old forecast and another for the actual sales observation. It is not necessary to store the data on a number of past periods.

Although, the method seems so simple, this technique takes into account the demands for all the past periods with exponentially decreasing weightages being given to each one of them. This can be seen if we try to expand the above given formula, as follows:

$$\begin{aligned}
F_{t+1} &= \alpha \cdot D_t + (1 - \alpha) F_t \\
&= \alpha \cdot D_t + (1 - \alpha) [\alpha D_{t-1} + (1 - \alpha) F_{t-1}] \\
&= \alpha \cdot D_t + \alpha (1 - \alpha) D_{t-1} + (1 - \alpha)^2 F_{t-1} \\
&= \alpha \cdot D_t + \alpha (1 - \alpha) D_{t-1} + (1 - \alpha)^2 [\alpha \cdot D_{t-2} + (1 - \alpha) F_{t-2}] \\
&= \alpha \cdot D_t + \alpha (1 - \alpha) D_{t-1} + \alpha (1 - \alpha)^2 D_{t-2} + (1 - \alpha)^3 F_{t-2} \\
&= \alpha \cdot D_t + \alpha (1 - \alpha) D_{t-1} + \alpha (1 - \alpha)^2 D_{t-2} \\
&\quad + \alpha (1 - \alpha)^3 D_{t-3} + \alpha (1 - \alpha)^4 D_{t-4} + \cdots + (1 - \alpha)^n F_{t-n+1}
\end{aligned}$$

The weightages for each of the demands in the past is discounted by a factor of $(1 - \alpha)$. The last term is negligible for a very large 'n'. In effect, exponential smoothing is a weighted average of all the demands in the past, the weightages decreasing exponentially by the factor $(1 - \alpha)$. This is why it is called exponential smoothing. The smoothing part occurs because the one-time or random fluctuations in the demand are filtered out by taking an average over a long period of time.

The extent of smoothing, that is, the filtering-out process for random fluctuations, depends upon the *alpha factor*. When this factor is small, it leads to giving lower weightages to recent demands and more consideration to old demands. If alpha is large, the reverse is true. A proper study of the business of a particular organisation would indicate as to what would be an appropriate value of alpha.

The point to be noted is that recent figures should definitely be considered for future forecast, but with a certain amount of scepticism or caution. What has been observed in the long past cannot be straightaway discarded in the light of the new data. Because, the new data may not yet have established its genuineness in terms of expressing real strong industrial or business trends.
There is an approximate relation of *alpha factor* (α) to the moving average which needs mention:

$$\text{Alpha factor } (\alpha) = \frac{2}{(\text{Number of periods in the moving average} + 1)}$$

An alpha factor of 0.1, for example, is roughly equivalent to a 19-period moving average, and alpha factor of 0.2 approximates a 9-period moving average. A sensible approach in choosing a value for the alpha factor is to pick one that approximates the number of periods in the moving average that makes sense. For an industry which is dynamic in its business (such as an industry which depends upon styles and fads of consumers) a low value of alpha factor such as 0.1 used to calculate a quarterly forecast would hardly seem to be appropriate; rather, an alpha factor of 0.3 with a smaller forecast-interval might prove to be more appropriate. The reverse is true for a more stable product.

The exponential smoothing as described above, is a simplistic model which smoothes the random fluctuations, but does not take into account the other factors such as seasonality of demand, the business cycles, and the complete consideration of the trends in the demand. The above model is, therefore, further refined for these components.

Trend Correction

The correction to the trend component *combined with* the *cyclical* component is done as follows:

$$T_{t+1} = \alpha\,(F_{t+1} - F_t) + (1 - \alpha)\,(T_t)$$

$$RF_{t+1} = F_{t+1} + \frac{(1-\alpha)}{(\alpha)}\,T_{t+1}$$

where T_t is the "trend factor" for the period t;
RF_t is the revised (i.e. corrected) forecast for the period t;
F_t is the *uncorrected* forecast for the period t; and
α is the alpha factor.

In addition to the above, the demand may have seasonal factors such as depicted in Fig. 8.2.

Correction for Seasonality

Seasonality may be due to various reasons such as company policies of the buyers, preferences of the consumers, government policies which may be periodic, and seasonal pattern due to the cli-

mate. The corrections for such seasonal peaks and valleys in demand can be made by comparing these peaks/valleys with the general average demand during the non-seasonal periods. Comparative indices could be formulated for the seasons where the demand is over-shooting or under-shooting the average. The multiplication of the corresponding seasonal indices with the forecast average should give the forecast for the different seasonal periods.

Often, when forecasts are made for the total demand during the next year, the demands in the various months are expressed seasonally in terms of the fractions of the annual demand observed generally. For instance, if the March and September demand is observed to be 0.25 fraction of the total annual demand, and the rest of the months are equally distributed in terms of the demand, the forecast for next year's annual demand of one lakh items can be forecasted as 25,000 items each for the months of March and September and 5,000 items each for the rest of the months. Often such a simple forecast serves adequately. But, sometimes a more rigorous forecasting model is necessary. In such cases we further correct our earlier exponential forecast model for seasonality.

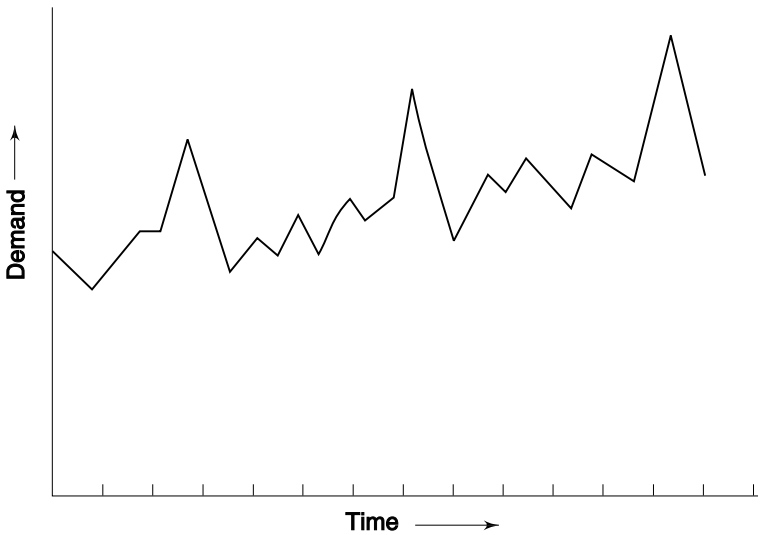


Figure 8.2 Demand with Seasonality and Overall Trend

Procedure for Using Exponential Smoothing

1. The demand for the past year is noted, say in terms of monthly demands in the past year.
2. If significant seasonal variation is observed, then a base series is formed. This series could be the demand for the last year repeated verbatim, or if the seasonal periods themselves are slightly fluctuating, (say, if it is undecided as to whether the seasonal peak comes during February, March or April) a centred moving average is found for all the past data (with the number of periods being 3, in the case mentioned here).
3. After finding the base series, the ratio of the current month's demand and the corresponding base series demand is calculated. This is called the demand ratio.

4. The demand ratio is now forecast for the next period. This forecast is called the forecast ratio.
5. A forecast for the next month's demand ratio is made by noting the previous month's forecast ratio, the alpha factor and the current month's demand ratio. This is similar to what we did earlier for non-seasonal data. The only difference is, here the data has been processed in terms of demand ratios—which need to be smoothened for the random component, and a trend component has to be incorporated.
6. The forecast ratio now is corrected for the trend component by first finding the trend factor from the previous observations of the demand ratio. So, the corrected forecast ratio for the next period (month) is given as follows:

$$\text{RFR}_{t+1} = \text{FR}_{t+1} + \left\{\frac{1-\alpha}{\alpha}\right\} T_{t+1}$$

7. The corrected forecast ratio has now been rectified for any random component as well as for trend and cyclical factors. You may note that the seasonality has already been taken into account *because of the* ratio. Therefore, the next step is to get the forecast of the *demand* (not the demand ratio) by multiplying the forecasted demand ratio by the base series demand observed for the corresponding month. Table 8.2 gives an illustration of the calculations for a particular product. The demand history up to August 2009 is given. The forecast for the next period, i.e. September 2009 is made giving trend and seasonality corrections.

LIMITATION OF TIME-SERIES METHOD

Many more refinements are to be found in the research literature for the above-mentioned method. They may be good for certain special situations, but for most situations, what we have covered here may be adequate. One needs to consider these models in terms of their relevance and peculiar drawbacks. The methods we have considered so far, viz. moving averages, exponential smoothing, etc. can be grouped under the category of time series models. In actuality, the demand may vary due to various market and other external and internal factors. The time-series models club together a whole lot of possibilities or reasons for variations in demand in terms of one factor, that is, time. This model rather than neglecting the total environmental multiplicity of factors, has rather implicitly considered these factors. The drawback however, is that the various influencing factors have not been explicitly considered. Anything implicitly assumed may result in a simplistic averaging procedure. The same drawback can, however, be an advantage for these models, because with a simple past history of the demand and seasonal and other corrections made, the necessity to consider each and every environmental factor is obviated.

After making the forecast, it needs to be monitored for errors or deviations from the actuals observed. This is necessary in order to make any modifications in the originally assumed forecasting model. There are two measures of deviations.

Table 8.2 Forecast of Demand taking Random, Trend, Cyclical and Seasonal Factors into account. 'a' is assumed to be 0.3.

Year and Month	*Observed Demand*	*Base Series*	*Demand Ratio (DR)* $DR_t = \frac{(\text{Observed Demand})}{(\text{Corresponding Base Series Demand})}$	*Forecast Ratio (FR)* $FR_{t+1} = \alpha\,(DR_t) + (1-\alpha)FR_t$	*Trend Factor* $T_{t+1} = \alpha\,(FR_{t+1} - FR_t) + (1-\alpha)T_t$	*Revised Forecast Ratio (RFR)* $RFR_{t+1} = FR_{t+1} + \frac{1-\alpha}{\alpha} T_{t+1}$	*Final Forecast of the Demand (FD)* $FD_{t+1} = (RFR_{t+1}) \times (\text{Base series Demand}_{t+1})$
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
2008 Jan.	10						
Feb.	10						
Mar.	13						
Apr.	15						
May	12						
Jun.	11						
Jul.	14						
Aug.	16						
Sep.	20		$\alpha = 0.1$				
Oct.	15		December 2008 values of Forecast Ratio and				
Nov.	14		Trend Factor are taken to be 1.200 and + 0.030 respectively.				
Dec.	14						
2009 Jan.	14	10	1.400	1.260	+ 0.039	1.351	
Feb.	14	10	1.400	1.302	+ 0.040	1.395	13.51
Mar.	16	13	1.231	1.281	+0.022	1.332	18.14
Apr.	19	15	1.267	1.277	+ 0.014	1.310	19.98
May	16	12	1.067	1.214	– 0.009	1.193	15.72
Jun.	15	11	1.364	1.259	+ 0.007	1.275	13.12
Jul.	17	14	1.214	1.246	+ 0.001	1.248	17.85
Aug.	19	16	1.188	1.229	– 0.004	1.220	19.97
Sep.	?	20					24.40

NOte : The forecast of demand for September 2009 is, therefore, 24.40 units

FORECAST ERROR MONITORING

Mean Absolute Deviation (MAD)

'Absolute' here means that the plus or minus signs are ignored; and 'deviation' refers to the difference between the forecast and the actuals. See Table 8.3.

Table 8.3 Mean Absolute Deviation (MAD)

Period	*Forecasted Demand (units)*	*Actual Demand (observed units)*	*Deviation*
1	900	1000	– 100
2	1000	1100	– 100
3	1050	1000	+ 50
4	1010	960	+ 50
5	980	970	+ 10
6	985	970	+ 15
7	980	995	– 15
MAD = 340/7 = 48.6			

Running Sum of Forecast Errors (RSFE)

This is the algebraic sum of the forecasting errors, which means the negative and positive signs are given their due significance. Table 8.4 illustrates this.

Table 8.4 Running Sum of Forecast Errors (RSFE)

Period	*Forecast*	*Actuals*	*Deviation*
1	900	1000	– 100
2	1000	1100	– 100
3	1050	1000	+ 50
4	1010	960	+ 50
5	980	970	+ 10
6	985	970	+ 15
7	980	995	– 15
RSFE = – 90			

Another entity called "tracking signal" is defined as follows:

$$\text{Tracking signal} = \frac{\text{RSFE}}{\text{MAD}}$$

$$\left(\text{In the above case, tracking signal} = \frac{-90.0}{48.6} = -1.852 \right)$$

The RSFE is a calculation to determine whether or not the forecast has any positive or negative bias. A good forecast should have approximately as much positive as negative deviation. MAD indicates the volume or 'amplitude' of the deviation from the actuals. Both the 'bias' as well as the 'amplitude' of the forecast errors are important. Therefore, it is important to monitor both the tracking signal and MAD for any modifications to be made in the original forecasting model.

CAUSAL MODEL OF FORECASTING

Let us now turn to the causal models of forecasting. If one were to make a forecast of demand for tea in India, one would consider various factors influencing the demand such as:

(i) Total population.
(ii) Sectoral/regional distribution of population.
(iii) Age distribution of population.
(iv) Disposable income distribution of the population.
(v) Price of tea.
(vi) Price of competing items/substitutes such as coffee.
(vii) Amount of 'leisure time' available or an index of leisure time available (in time units, or in proportion of the population enjoying leisure).

MULTIPLE REGRESSION MODEL

Considering similar factors, a multiple regression type of model was constructed* as given below: The demand for tea (data of 1954–55 through 1972–73) for India:

$$\log D_T = 7.95 + 0.56 \log Y - 0.33 \log \left(\frac{P_T}{P_C} \right) + 5.01 \log \left(\frac{UP}{TP} \right)$$

where D_T = Tea Demand, in millions of kg.

Y = Private Disposable Income, at 1960–61 prices measured in millions of rupees.

P_T = Tea Price Index, with base 1961–62 = 100.

P_C = Coffee Price Index, with the same base as P_T.

UP = Urban Population, in millions.

TP = Total Population, in millions.

The measure of the goodness of fit for the regression model is given by R^2, which in the above case was found to be 0.97.

The merit of the multiple regression model is that, it considers the effect of a number of causative factors explicitly; therefore, by manipulating one of the independent variables, or due to a change in the value of one of the independent variables, the value by which the dependent variable (the item being forecasted) will change can be computed and thus forecasted. It thus allows for an analysis of policy-and-other controllable elements' changes, so that forecast scenarios can be painted for suitable decision-making. However, the merits of the method depend upon the comprehensive inclusion of all relevant influencing factors, and upon validating of the model for

*V.L. Mote, S. Paul and G.S. Gupta, *Managerial Economics—Concepts and Cases*, Tata McGraw-Hill Publishing Company Ltd., New Delhi, 1977, p.38.

its goodness of fit with the help of past data. Also, in order to accurately forecast the desired variable, one needs also to forecast the quantity of the causative factors accurately. Thus, if the latter forecasts have any drawbacks, the same will be transmitted (amplified or otherwise) to the forecast of the final/ultimately desired item. Moreover, multiple regression analysis could get complicated with the correlation or interdependence of the various causative factors.

INPUT-OUTPUT ANALYSIS

Many input-output type of models are also useful in forecasting. Input-output analysis takes into consideration the interdependence of the different sectors in the economy. An input to a sector is an output from another sector. For instance, an input from the steel sector might give rise to an output from the electricity sector, which in itself is an input to the steel sector. There are many such seemingly cyclical relations within the various sectors of the economy. If such input and output flows from the different sectors of the economy are indicated, what results is a matrix as shown in Table 8.5.

Table 8.5 Input-Output Table

		Inputs to Industry				*Final Demand*		
		I	*II*	*III*	*IV*	*Persons*	*Government*	*Demand*
Output of industry	I	18		29	3	31	9	90
	II	23	10	55	27	10	55	180
	III		63		45	99	63	270
	IV		77	36		27		140
Value added	Wages	38	25	100	45			208
	Other	11	5	50	20			86
	Total	90	180	270	140	167	127	

Such analysis is very useful because it takes into account all the intricate relationships in the economy. But still each technique has its own drawback. The drawback here is that the utility is restricted to economic analysis, not considering the *other* business, governmental, technological, and internal factors. It is a limited but useful analysis. The analysis need not be restricted to a macro-level, speaking only in term of the steel sector and electricity sector. It may be more 'micro', by considering the inputs and outputs within a general product group in the total economy. Such analysis has been done in practice and has been found to be useful.

If one surveys the literature on forecasting in marketing management, one comes across other kinds of methods such as market surveys, intention-to-buy surveys, consumer surveys, market tests, life cycle analysis, delphi method, the end-use analysis, etc. Some of these methods need a mention here.

LIFE CYCLE ANALYSIS

The *Life Cycle Analysis* is based on the premise that every category of product has a certain marketable life period. There are definite stages in the life cycle of a product and they are:

(a) Product development
(b) Early introduction
(c) Rapid growth
(d) Steady-state
(e) Decline and death

Depending upon the type of the product the life span will vary; also the relative time-spans for each of the stages of life will vary. By an analysis of the life-cycle of a product, and noting the stage in which a product exists at a time, one can forecast the demand for the item in the future.

DELPHI METHOD OF OPINION GATHERING AND ANALYSIS

For a new product or service, the Delphi method, consisting of systematic gathering, analysis, and convergence of experts' opinions, is very useful. This method occupies an important place in 'technology forecasting' which in itself is a very vital aspect of forecasting, living as we are in an age of rapidly changing technology. A note on Technology Forecasting is furnished at the end of this chapter.

END USE ANALYSIS

End Use Analysis, as the term indicates, thoroughly considers all the different uses to which a product will be put and traces the entire chain of uses in order to arrive at a forecast. Still, this may be a limited approach since it considers only the demand side picture and not the supply side picture. Secondly, it does not consider explicitly the various other economic factors influencing the demand of a product.

MARKET SURVEYS AND SIMILAR TECHNIQUES

Market Surveys, Consumer Opinion Studies, and the like feedback important information regarding changing consumer tastes and preferences for a product or a service. Some of these studies may consist of behaviouristic research and therefore, may give more insight into the psychological motives behind the consumers' purchase of a product or a service. These are also good forecasting techniques but they do not take into account other external factors such as government licensing policies, credit policies, state of the economy, competitors in the market, etc.

In addition to the above, a lot of information can be gathered through the government records such as the National Plan documents, the National Industrial Policy documents, and various other statistical information supplied by the Central and State governments.

A COMPLETE FORECASTING PROGRAMME FOR A COMPANY

A total forecasting programme may, therefore, consist of the following:

(i) Observing and listing important external factors and studying the cultural, social, political and international atmosphere; getting data from the government, academic research institutions and other industries.

The above told are the non-controllable factors for the company.

(ii) Gathering information regarding internal company policies and their effects on the demand. Design changes, quality changes, sales changes, technology changes, etc. have all to be taken into account.

(iii) After gathering the external and internal information, it will be necessary to analyse the data to establish various relationships and patterns and the relative effect of each of the factors on the final demand. This is where the time series analysis, multiple regression analysis, input-output analysis, consumer surveys, technology forecasting, etc. will be of much use. The objective is to find out or establish a mosaic of relationships, a template for deducing the future from available data.

One has to remember also that not all the data is quantitative and much of it is also qualitative. For instance, aspects such as the political atmosphere, either national or international, or the social forces operating cannot be quantified. Even consumer surveys provide more of qualitative information than quantitative information. Yet all these informations are of importance, depending upon the situation.

Effective forecasting should provide the broad cone of context that informs the decision-making. It should reveal overlooked possibilities and expose unexamined assumptions regarding outcomes.

(iv) Various scenarios have to be constructed, assuming certain feasible happenings in the external environment and various alternative internal organisational policies. Models are there to help the forecasters, but they cannot give a ready made solution. Forecasters should not seek solutions by one model.

Forecasting is a process of examination and unravelling of our past, our beliefs and assumptions and that of looking at a range of futures in the context of the past and present.

(v) Now the forecast should be operationally applied. This can be done by breaking it down on the basis of the number of product-lines (when we say product-lines, this also includes the 'service products' for the service industry), the types of customers, the various management polices, etc. The various scenarios derived earlier must be compared in light of the operational feasibility. For example, there must be enough capacity to produce enough profits. A Break-Even Analysis might indicate as to what is operationally feasible and what is not. The sales forecast translated into operations planning, materials planning, financial planning and personnel planning will give more information regarding feasibility in these various functions. The idea here is to determine what is feasible internally, and what is profitable, from the total volume of forecast sales. Such an analysis may result in changing the internal business environment suitably.

(vi) After the various feasibilities have been studied the forecast becomes really usable. After using the forecast or as the forecast is being used, the forecast errors are monitored regularly. The reasons for the deviations should also be investigated regularly. The future forecast or the forecast techniques can then be modified to take into account the changed condition, if any.

A good forecasting process is always an iterative process. Forecasting is about mapping uncertainty; uncertainty is a part and parcel of forecasting. But, the forecasting programme should neither be too broad to lose focus nor should it be too narrow to leave the organisation open to avoidable unpleasant circumstances or miss out on very important opportunities. Forecasts are not

synonymous to removal of uncertainty, but are warning signals of hidden—hitherto unknown—dangers and, equally importantly, of opportunities that the future may otherwise suddenly present.

Some of the pitfalls in forecasting need mention.

PREREQUISITES AND PITFALLS IN FORECASTING

The most important question in forecasting is that of the determination of the objective or purpose behind the forecast. The purpose determines the accuracy required of the technique and the techniques chosen for forecasting. The techniques vary in the cost, scope and accuracy. What information is necessary for production planning may be different in terms of detail and scope from what is needed for market planning. Supposing there were 100 different products produced by a stamping process. For the production planner to find out what capacities are needed in the future in terms of heavy stamping or light stamping, the detailed forecast and the factors influencing the 100 products is not at all necessary. Probably, a simple time-series model might provide him with adequate information for planning. This is not the case with market planning.

Similarly, if no changes are being made in the internal company policy, general trend models may be sufficient. Whereas, if there are some strategic actions to be taken, then a very detailed analysis for each of the alternative actions is necessary.

Depending upon the life cycle of the product and the stage at which the product exists at the time of forecasting, the techniques and the detail with which the forecasting information is gathered will vary. It can be easily understood that in the new product development stage, information has to be gathered regarding similar products in the market or the consumer opinion has to be collected regarding what the product market is likely to be. It may also be necessary to find what input-output analysis has to offer in terms of projecting the broad future changes in the economy. Even a Delphi method might be useful in such cases; or one may use what it called the Product Differences Measurement Technique where one compares a proposed product with competitors' present and planned products and ranks it on a quantitative scale for different factors. Whereas, in the steady-state of the product life-cycle, the main considerations are trend and seasonal effects, and the time-series analysis might be good enough in such situations.

In short, there is no single forecasting technique which is always of more value than others; rather one or more techniques may be relevant depending upon the situation. Forecasting, although a science, is also an art in this sense.

Besides defining the purpose of the forecast, it should also be noted that forecasting should be a combined effort organisationally. Since the external and internal environment of the company cannot be perceived in its complete perspective by an individual or a functionary, it is necessary to include a number of functionaries in the forecasting procedure. Such a procedure helps people who use the forecast for different functional planning processes to get an insight into what is behind the forecast figures. A poor understanding of the sales planning by the production planner affects his production planning too.

To do a good job of materials planning it is necessary to know, in addition to what is planned to be produced, also the reasons as to why it is done. It means, a sales planner, production planner and materials planner, must collectively involve in the forecasting process.

Another point to be noted in forecasting is that quite often wrong things are forecasted. For instance, one need not forecast the requirement for bought out and internally manufactured com-

ponent parts going into an assembly. The forecast for the final product may be good enough to calculate the requirements. Similarly, the materials requirements for a project-oriented industry need not be forecasted. They can be read from the PERT/CPM network. Very often people go for minute forecasting for all the odd products that they manufacture. Often it is enough if one has information regarding the families of products rather than individual products. In fact, the forecasting for a family of products is more accurate.

Another pitfall in forecast is that there is no timely tracking of forecasting. The deviations of the forecast from the actuals should be monitored continuously or periodically. This is necessary to find out as to whether the assumed environmental conditions have changed in the present or for the future.

RANGE OF FORECAST

A forecast may be in terms of ranges rather than exact figures. Although one may hit upon the exact figure after calculations, assuming various plausible changes in the environmental conditions, it is better to give a range for the forecast. This helps in many ways. It shows what is the highest figure to be expected and what is the lowest. Accordingly, judicious planning for either production or sales or materials or manpower can be done. Certain components of such planning may be linked to the higher figure, whereas certain other components of the planning may be linked to the lower figures. For instance, low value, low turnover items in inventory can be procured with a higher forecast figure in mind. Whereas, capital-intensive machinery need not be procured in such a haste. It can be procured based upon the lower figure and one can watch for future developments. Also, it may depend upon the strategic posture of the organisation: whether it wants to satisfy maximum number of customers or it wants to utilise its operation facilities to the maximum.

There is another important reason as to why having a 'range' of forecast is desirable. The forecast should include various possibilities. There could be trends and events that have low probabilities of occurrence or probabilities one cannot quantify but if the event were to occur, it would have a disproportionately large impact. For instance, 9/11 was a much bigger surprise than it should have been, because airliners being flown into monuments were assumed to be the stuff of only Tom Clancy novels of the 1990s, despite the knowledge that the terrorists had a personal antipathy towards the Word Trade Centre.*

DIFFERENT SCENARIOS

Putting a forecast to use is also an art. Essentially, forecasting is nothing but a vast collection of data which is processed presenting various scenarios under assumed conditions. This being so, one can use a wealth of this data for specific planning purposes.

Sometimes weak or soft data is as important as strong, i.e. quantifiable data. There is a case of a squadron of ships steaming from San Francisco to San Diego that ran aground on the shores of central California on the fog-shrouded ill-fated evening in September 1923. All ships except one relied entirely upon the commander's dead-reckoning navigation despite the bearings obtained from a radio direction centre which differed. Only one of the ship's captain took the doubts raised

* Saffo, Paul, "Six Rules for Effective Forecasting", Harvard Business Review, July-August 2007, pp.l122-131.

by his deck officers regarding their closeness to the shore a little more seriously and ordered a course correction averting the disaster.* This ship was saved while other ships met with the calamity.

Thus in forecasting, as in navigation, lots of weak information is vastly more trustworthy than a point or two of strong information. The traditional management habit is to collect strong information mostly leaving out weak information. Good forecasting should be a process of strong opinions but weakly held with a room for weak opinions.

PRECISION IN FORECASTING

Precision in forecasting is not as important as proper use of available data. A forecast or forecasts can go wrong. There is no point in looking for more and better data which may not be available. It is better that the best use of the available data is made according to the situational demands. It is not always necessary to have exact data, which is very difficult to get, because excellent results can be obtained by means of rough data. What is important is the proper use of the data that is available.

HISTORICAL INFORMATION

As mentioned several times earlier, a forecast should not rely too much on the recent past. One must look far enough into the past to find as to how "history repeats itself" or better still to find as to how history 'rhymes' as it may not repeat itself identically. The historical patterns, the turns and 'S-curves' are useful in forecasting the inflection points and turns in business in the future. The financial crisis that started in 2008 has parallels in the past. Untill 2008, many businesses worldwide were only looking at the linear growth in the economies that has characterised the last 10-15 years and are surprised by the sudden turn of events or the 'S-curve' that has hit them.

FORECASTING AND THE INDIAN SCENARIO

Some of the more creative and productive organisations in India are to be found among high technology organisations such as Atomic Energy Commission, Indian Space Research Organisation and Bharat Heavy Electricals Limited, and Defence Research and Development Organisation (DRDO). The participation of the private sector in the high technology area has been very limited. The high technology companies in India have been scanning for technology developments in the world and trying to develop indigenous equivalent products. And for this, they do forecasting, particularly that of technology, in some measure.

However, barring these few examples, by and large, other organisations have not been using forecasting in a scientific manner. The reasons could be many. One of the main reasons has been that they did not feel the need to survey the environment and forecast future business. The reason behind this has been the country's erstwhile closure to foreign participation, ensuring secure you could produce something, it could always be sold in a products-starved country. The situation has changed since the turn of the century, but old habits, beliefs and psychology take time to change. The emphasis, therefore, had been on producing rather than on real practive marketing. The environment-scan, of the business/industries stopped at that. Hence, forecasting had indeed been a neglected aspect of management.

* Ibid

Now, with the gradual opening up of the economy, the economic scenario has changed due to the increasing participation of the multinational corporations in various areas of business/industry, including infrastructure. The Indian economy is increasingly getting the characteristics of a buyer(s) market. The Indian businessman, therefore, has to be very alert about the rumblings in the gangways. Forecasting models, such as the causal models can now be used to forecast the effect of concessions in corporate tax, customs duty, excise, and other areas. Opinion-based methods such as Delphi techniques and consumer behavioural surveys have increasing relevance. Monopoly or oligopoly does not need forecasts; it is the competition that needs the forecasts. Indian industries and businesses are waking up to the fact that it is now a different game. They know that if they do not follow appropriate management basics such as forecasting, they risk the danger of being marginalised for a long time to come.

SOLVED PROBLEMS

1. Sales of Super Cool brand of motorbikes are being analysed. The monthly sales figures for the previous year are furnished below.

Month	*No. Sold (in '00)*
1	8
2	5
3	9
4	11
5	13
6	13
7	10
8	11
9	14
10	15
11	16
12	18

(a) Get a 3-month moving average for the various months of the year.
(b) Get a 3-month weighted moving average with weights of:
Current month: 0.5
Previous month: 0.3, and
Previous to previous month: 0.2
(c) Which method seems give a better fit? You may base your reply upon MAD calculations.

Answer

Sample calculations for the 3-month moving average are given below.
Moving average forecast for month 4 = (8+5+9) / 3 = 7.33
Moving average forecast for month 5 = (5+9+11)/ 3 = 8.33
In the same manner we, now, get the entire moving averages forecast.

Month	*3-Month Moving Averages Forecast*
4	7.33
5	8.33
6	10.00
7	12.33
8	12.00
9	11.33
10	11.66
11	13.33
12	15.00

Sample calculations for the 3-month weighted moving average are given below.
Forecast for month 4 = $(9 \times 0.5 + 5 \times 0.3 + 8 \times 0.2) = 7.6$
Forecast for month 5 = $(11 \times 0.5 + 9 \times 0.3 + 5 \times 0.2) = 9.2$
In the same manner we, now, get the entire weighted moving averages forecast.

Month	*3-Month Weighted Moving Averages Forecast*
4	7.6
5	9.2
6	11.6
7	12.6
8	11.5
9	11.1
10	12.3
11	15.0
12	15.3

(c) Compare the forecasts with the actual sales. On a cursory examination, the weighted moving average seems to give a better fit than the simple moving average. However, as suggested in this problem, let us compute the MAD.

Month	*Actual Demand*	*Simple MAvg Forecast*	*Deviation*	*Weighted MAvg Forecast*	*Deviation*
4	11	7.33	–4.67	7.6	–3.4
5	13	8.33	–4.67	7.2	–3.8
6	13	10.00	–3.00	11.6	–1.4
7	10	12.33	+2.33	12.6	+2.6
8	11	12.00	+1.00	11.5	+0.5
9	14	11.33	–2.67	11.1	–2.9
10	15	11.67	–3.33	12.3	–2.7
11	16	13.33	–2.67	15.0	–1.0
12	18	15.00	–3.00	15.3	–2.7
Total of Absolute Deviation:			27.34		21.0
Mean Absolute Deviation (MAD): 27.34 / 9 = 3.038				MAD = 21.0 / 9 = 2.333	

The MAD for the Weighted Moving Averages is smaller than that for the Simple Moving Averages. Hence, the former model, viz. Weighted Moving Averages, seems to be giving a better fit of the two.

2. Customer footfalls in 'Carnival' shopping mall are being analysed. The data for the last few weeks are given in the table below.

Week No.	*Number of Footfalls (in '00)*
1	85
2	95
3	110
4	100
5	115
6	130
7	150
8	145

Test the following forecast models for their performance.

(a) Exponential smoothing with $\alpha = 0.4$. Start with the forecast for week 1 at 8000 footfalls.

(b) 4-week simple moving average.

Answer

(a) Forecasts with the Exponential Smoothing model are made using the formula:

$$F_{t+1} = \alpha \cdot D_t + (1 - \alpha)F_t$$

Calculations are as follows.

Forecast for week 2 = (α)(Actual Footfalls for week 1) + (1 – α)(Forecast for week 1)

Forecast for week 2 = (0.4)(85) + (1 – 0.4)(80) = 82

Similarly:

Forecast for week 3 = (α)(Actual Footfalls for week 2) + (1 – α)(Forecast for week 2)

Forecast for week 3 = (0.4)(95) + (1 – 0.4)(82) = 87.2

Forecast for week 4 = (0.4)(110) + (1 – 0.4)(87.2) = 96.3

Forecast for week 5 = (0.4)(100) + (1 – 0.4)(96.3) = 97.8

Forecast for week 6 = (0.4)(115) + (1 – 0.4)(97.8) = 104.7

Forecast for week 7 = (0.4)(130) + (1 – 0.4)(104.7) = 114.8

Forecast for week 8 = (0.4)(150) + (1 – 0.4)(114.8) = 128.9

(b) Forecasts made with 4-month simple moving average are as follows.

Forecast for week 5 = (Total of actual footfalls for weeks 1,2, 3 and 4) /(4)

=(85 + 95 + 110 + 100) / (4) = 97.5

Forecast for week 6 = (Total of actual footfalls for weeks 2,3, 4 and 5) /(4)

$= (95 + 110 + 100 + 115) / (4) = 105.0$

Forecast for week 7 = (Total of actual footfalls for weeks 3, 4, 5 and 6) /(4)

$= 110 + 100 + 115 + 130) / (4) = 113.8$

Forecast for week 8 = (Total of actual footfalls for weeks 4, 5, 6 and 7) /(4)

$=(100 + 115 + 130 + 150) / (4) = 123.8$

Following table has arranged all the above results.

Week No.	*Actual Footfalls ('00)*	*Exp. Smooth. Forecast ('00)*	*Deviation ('00)*	*4-mon Mov. Avg. Forecast ('00)*	*Devn. ('00)*
1	85	80 starting	–5.0		
2	95	82	–13.0		
3	110	87.2	–28.8		
4	100	96.3	–3.7		
5	**115**	**97.8**	**–17.2**	**97.5**	**–17.5**
6	**130**	**104.7**	**–25.3**	**105.0**	**–25.0**
7	**150**	**114.8**	**–35.2**	**113.8**	**–36.2**
8	**145**	**128.9**	**–16.1**	**123.8**	**–21.2**
Total Absolute Deviation from week 5 to 8*:			93.8		99.9
Mean Absolute Deviation (MAD) =			23.45		24.98

* The two models are compared only for the weeks on which we have both the forecasts. These figures are shown in bold.

It is interesting to note that both the forecasting models seem to be giving results close to each other. This should be expected because an approximate relation was mentioned in this chapter earlier.

Accordingly,

$\alpha = (2) / (\text{No. of periods in the moving average} + 1)$

$= (2) / (4 + 1) = 0.4$

The present example seems to verify that relation well.

So far, both the forecasts appear to be lagging behind the actual footfalls significantly. There seems to be a heavy trend in the number of footfalls. An exponential smoothing model with trend correction might do a better job.

3. Sadia Syed has come up with the following forecasting model for the number of admissions to her *alma mater* Barkat School of Business in Lucknow:

$$Z = 290 + [360(Y/100)^{0.5} / \{1 + \log_{10}(C)\}]$$

Where Z = number of new students getting admitted

Y = percentage of graduating students placed in the current year

C = number of business schools in the city

(a) What will be Sadia's forecast for admissions this year if 90 per cent of the graduating students have been placed and the business schools in the city number 11?
(b) What will it be if only 40 per cent have been placed and the business schools in the city are 23?
(c) What will it be if the placements are 100 per cent and the number of business schools in the city are 30?
(d) What may be the maximum possible number of students getting admitted to Sadia's alma mater, as long as this forecast model holds good?

Answer

(a) $Z = 190 + [360(0.90)^{0.5} /(1 + \log_{10}11)]$

$= 190 + [341 / (1 + 1.0414)] = 190 + 162 = 352$

(b) $Z = 190 + [360(0.40)^{0.5} /(1 + \log_{10}23)]$

$= 190 + [227 / (1 + 1.3617)] = 190 + 96 = 286$

(c) $Z = 190 + [360(1.00)^{0.5} /(1 + \log_{10}30)]$

$= 190 + [360 / (1 + 1.4771)] = 190 + 145 = 335$

(d) Maximum number of students will be possible when the placements are 100 per cent and Barkat Business School is the only business school in the city (i.e. number of business schools in the city is 1).

Hence, $Z = 190 + [360(1.00)^{0.5} /(1 + \log_{10}1)]$

$= 190 + [360 / (1 + 0.0000)] = 190 + 360 = 550.$

4. Jaipur Cements Limited has observed that the demand for cement typically shows quarterly seasonal variations, while the total annual demand appears to be rather steady. The data regarding quarterly demand (expressed in thousand tons) for the past two years is as follows.

Year	*Quarter 1*	*Quarter 2*	*Quarter 3*	*Quarter 4*
1	46	28	37	55
2	42	30	43	57

(a) Find the seasonal indices for each of the quarter.
(b) If the total demand in Year 3 is forecasted to be 200,000 tons, what may be the expected demand for Quarter 2 of year 3?

Answer

When one uses Seasonality Indices, one is generally using a Decomposition Method to forecast demand. The underlying premise is that the demand can be separately and distinctly broken down into its components, viz. trend, cycle, seasonality and randomness. The demand is usually considered as a product of these components.

$$D = T \times C \times S \times R$$

Where, D = Demand, T = trend value, C = cyclical factor, S = seasonality as an index and R = randomness as an index.

When periodic seasonality is the only distinguishing factor, as mentioned in the present example, the seasonality index when multiplied by the average demand would give the forecast corrected for seasonality.

(a) Use of Average Percentage Method of finding seasonal indices will be illustrated, basing the illustration on the present example.

Step 1: Find the average quarterly demand for each of the years.

These are: Year 1: (46 + 28 + 37 + 55) / 4 = 41.5

Year 2: (42 + 30 + 43 + 57) / 4 = 43.0

Step 2: For each year, divide the demand during a quarter by the average quarterly demand for that year. Express the result as a percentage.

For example:

For Quarter 1 of Year 1 : 46 / 41.5 = 1.1084 = 110.8 per cent

For Quarter 2 of Year 1 : 28 / 41.5 = 0.6747 = 67.5 per cent

Similar computations are made for the other quarters and the following table is the result. The table also shows the mean values of the percentages for each quarter over the given two years (e.g. for Quarter 1 of the two years, the percentages are 110.8 and 97.7 giving a mean of 104.25 or 104.3 for a single decimal precision).

Year	*Quarter 1*	*Quarter 2*	*Quarter 3*	*Quarter 4*
1	110.8	67.5	89.1	132.5
2	97.7	69.8	100	132.5
Mean	104.3	68.7	94.5	132.5

The total of mean values (in the above table) is adding to 400 exactly. This is good. Had it been, say 405, then each quarterly mean value would have had to be given a correction i.e. multiplied by (400/405).

Each of the mean values, in the above table, is the seasonality index for the corresponding quarter. This is shown below.

Quarter	*Seasonality Index*
1	104.3
2	68.7
3	94.5
4	132.5

(b) Total forecasted annual demand for Year 3 is 200. If there was no seasonality, the quarterly forecast would have been 200 / 4 = 50.

This average quarterly demand of 50 has to be given seasonal correction as follows:

Forecast for a quarter = (average quarterly demand) × (Seasonal Index for that quarter / 100)

Computations:

For Quarter 1 of Year 3 the corrected forecast = (50) × (104.3 / 100) = 52.1

For Quarter 2 of Year 3 the corrected forecast = (50) × (68.7 /100) = 34.4

For Quarter 3 of Year 3 the corrected forecast = (50) × (94.5 /100) = 47.2

For Quarter 4 of Year 3 the corrected forecast = (50) × (132.5 /100) = 66.3
As per above computation, the demand forecast for Quarter 2 of Year 3 is 34400 tons.
Alternatively, one could have used the Centered Moving Averages method of finding seasonal indices. Readers may find a description of it in other books. (Refer to Bibliography.)

5. Indian Banking Software Ltd. shows the following revenues in Dubai during different quarters.

Year	*Quarter*	*Revenue (in million Dirham)*
1	1	50
	2	30
	3	40
	4	60
2	1	55
	2	35
	3	45
	4	70

Forecast the revenues for Quarter 1 of Year 2 (Q1Y2) through Quarter 1 of Year 3 (Q1Y3) using a trend and seasonality adjusted exponential smoothing model. For the Quarter 4 of Year 1 (Q4Y1), take the initial forecast of revenue at 60 (million Dirham), a forecast ratio of 1.00 and an initial trend of zero. Use the smoothing constant a of 0.2 for both the demand and the trend factor.

Answer

Arrange the quarterly values of *Y*1 as the Base Series which is used in finding the 'demand ratio'. The 'forecast ratios' follow from there. Computations of the values of demand ratio (i.e. observed revenue divided by the corresponding base series figure) for the period '*t*' (D_t), forecast ratio for the next period (FR_{t+1}) calculated in period '*t*', trend factor for the next period (T_{t+1}) calculated in period '*t*', revised forecast ratio for the next period (RFR_{t+1}) calculated in period '*t*', and the final forecast for revenue in period '*t*+1' are furnished below. Thus, we obtain the forecasts with trend and seasonality incorporated into them.
For Q4Y1 (henceforth abbreviated as 41):
Demand ratio (DR_{41}) = 60/60 = 1.00, FR_{12} = 1.00 and T_{12} = 0.00. We start the forecasting procedure with these values.
Hence, $RFR_{12} = FR_{12} + T_{12}\,(1 - \alpha) / (\alpha) = 1.00 + (0.8/0.2)\,(0.00) = 1.00$
Hence, the forecast of revenue for the next period: $FD_{12} = (50)(1.00) = 50$

For Q1Y2:
$DR_{12} = 55 / 50 = 1.10$
$FR_{22} = \alpha\,(D_{12}) + (1 - \alpha)(\,FR_{12}\,) = 0.2(1.10) + 0.8(1.00) = 1.02$
Hence, $T_{22} = \alpha\,(FR_{22} - FR_{12}\,) + (1 - \alpha)T_{12} = 0.2(1.02 - 1.00) + 0.8(0.00) = 0.004$
Hence, $RFR_{22} = FR_{22} + T_{22}\,(1 - \alpha) / (\alpha) = 1.02 + (0.8/0.2)\,(0.004) = 1.036$

Hence, the forecast of revenue for the next period: $FD_{22} = (30)(1.036) = 31.08$

For Q2Y2:

$$DR_{22} = 35 / 30 = 1.167$$

$$FR_{32} = \alpha (D_{22}) + (1 - \alpha)(FR_{22}) = 0.2(1.167) + 0.8(1.02) = 1.049$$

$$\text{Hence,} \quad T_{32} = \alpha (FR_{32} - FR_{22}) + (1 - \alpha)T_{22} = 0.2(1.049 - 1.020) + 0.8(0.004)$$

$$= 0.0092$$

$$\text{Hence,} \quad RFR_{32} = FR_{32} + T_{32} (1 - \alpha) / (\alpha) = 1.049 + (0.8/0.2)\ (0.0092) = 1.0868$$

Hence, the forecast of revenue for the next period is: $FD_{32} = (40)(1.0868) = 43.47$

For Q3Y2:

$$DR_{32} = 45 / 40 = 1.125$$

$$FR_{42} = \alpha (D_{32}) + (1 - \alpha)(FR_{32}) = 0.2(1.125) + 0.8(1.049) = 1.065$$

$$\text{Hence,} \quad T_{42} = \alpha (FR_{42} - FR_{32}) + (1 - \alpha)T_{32} = 0.2(1.065 - 1.049) + 0.8(0.0092)$$

$$= 0.01036$$

$$\text{Hence, } RFR_{42} = FR_{42} + T_{42} (1 - \alpha) / (\alpha) = 1.065 + (0.8/0.2)(0.01036) = 1.1065$$

Hence, the forecast of revenue for the next period: $FD_{42} = (60)(1.1065) = 66.39$

For Q4Y2:

$$DR_{42} = 70 / 60 = 1.1667$$

$$FR_{13} = \alpha (D_{42}) + (1 - \alpha)(FR_{42}) = 0.2(1.1667) + 0.8(1.065) = 1.0853$$

$$\text{Hence, } T_{13} = \alpha (FR_{13} - FR_{42}) + (1 - \alpha)T_{42} = 0.2(1.0853 - 1.065) + 0.8(0.01036)$$

$$= 0.00829$$

$$\text{Hence, } RFR_{13} = FR_{13} + T_{13} (1 - \alpha) / (\alpha) = 1.0853 + (0.8/0.2)(0.00829) = 1.11846$$

Hence, the forecast of revenue for the next period: $FD_{13} = (50)(1.11846) = 55.92$

The above results are expressed in the following table.

Period	*Observed Revenue*	*Base Revenue*	DR_t	FR_{t+1}	T_{t+1}	RFR_{t+1}	*Forecast*
Q4Y1	60		1.000	1.000	0.000	1.0000	
Q1Y2	55	50	1.100	1.020	0.004	1.0360	50
Q2Y2	35	30	1.167	1.050	0.0092	1.0868	31.08
Q3Y2	45	40	1.125	1.065	0.01036	1.1065	43.47
Q4Y2	70	60	1.1667	1.1085	0.01235	1.11846	66.39
Q1Y3		50					55.92

(Note: The observed, base series and forecasted revenues are in Million Dirham.)

QUESTIONS FOR DISCUSSION

1. Are the moving averages method and the exponential smoothing method of forecasting related? How and why?
2. Does exponential smoothing track a trend in the demand satisfactorily? What is the reason?
3. **(a)** What is the purpose behind the computations of demand ratios in taking care of seasonalities in demand?
   (b) Are base series always computed over the calendar year? Give reasons for your answer.
4. What are the criteria on the basis of which you assess the different forecasting methods? Would *root mean square error* be the criterion? Would 'error', whichever way measured, be the only criterion?
5. What are the limitations of: **(a)** Trend extrapolation, **(b)** Use of input-output tables, and **(c)** Delphi technique?
6. Read through the literature and find out what 'Technology Assessment' is? How is it useful to operations management?
7. What are the levels of aggregation in forecasting for a manufacturing organisation? How should this hierarchy of forecasts be linked and used?
8. Data on Product *X*'s price and the number of units sold is furnished below:

Price Rs./unit	*Sales units*	*Price Rs.*	*Sales units*
9.90	1143	16.50	410
19.60	361	13.70	605
14.50	532	11.20	910
10.80	997	18.70	360
17.40	390	10.20	1094
15.30	475	12.00	806
12.70	722	19.20	355

   (a) Use regression analysis to estimate the demand function.
   (b) The present price of Product X is between Rs. 13.20 and Rs. 15.10. Use this information for making a forecast for use in planning for production.
9. The history of the load on a work centre is furnished :
   (a) Use appropriate value of the smoothing constant (α) and forecast for February 2009. Do *not* consider seasonality.
   (b) Forecast for the load during April 2009. Explain the procedure.
   (c) In this chapter we used "smoothing" twice: once for the random component and secondly for the trend. Instead, use the following "second-order" system of smoothing which is claimed to give forecasts already corrected for steady trend in demand:

$$F_{t+1} = \alpha \cdot D_t + 2\,(1 - \alpha)\,F_t - (1 - \alpha)\,F_{t-1}$$

   For the same value of α, how does this system compare with the one you used in part

(a) of this question? Use a different value of α, and check the performance of this second order system.

Month		*Load (Machine hr)*	*Month*		*Load (Machine hr)*
2007	January	1190	2008	January	1420
2007	February	1220	2008	February	1340
2007	March	1240	2008	March	1445
2007	April	1250	2008	April	1490
2007	May	1200	2008	May	1610
2007	June	1230	2008	June	1575
2007	July	1290	2008	July	1605
2007	August	1325	2008	August	1590
2007	September	1370	2008	September	1665
2007	October	1330	2008	October	1730
2007	November	1350	2008	November	1695
2007	December	1390	2008	December	1775
			2009	January	1880

10. How would forecasting be useful for operations in a BPO (Business Processes Outsourcing) unit? What factors may be important for this industry? Discuss.

APPENDIX

TECHNOLOGY FORECASTING

Technology Forecasting as the name indicates, deals with the estimation of future growths/trends in technology. This purports to answer questions like **(i)** What may happen to Indian steel production in the year 2020 and 2030 **(ii)** What may be the transportation modes available in the country at that time? Technology forecasting is of recent origin and is useful for examining future choices and making current decisions (which may influence the future) for an extremely wide range of long-term planning processes, be it national or regional planning, or organisational planning such as corporate planning, or parts of it such as production planning and marketing planning.

Technology is an important change element, which brings about social and political changes in the world at large. Since long-range planning involves the consideration of national and international economic, political, social forces in the future to come, technology forecasting is a vital tool in the hands of planners even at the micro-level of corporate production planning. For instance, a corporation making heavy machines, or machine-tools, or heavy electrical equipment needs a long time-horizon for its planning purpose. It cannot plan for a year or two, but has to plan for a longer period. Unless long-range planning is done properly, the intermediate range or short-range planning will have only temporary and sometimes marginal beneficial effects. As we shall see in the later chapters, intermediate range planning has to fit into the framework of a long-range plan and short-range planning has to be done within the framework of the intermediate-range plan. For high technology products, which need a long preparation or gestation time to become productive, forecasting of long-range technology trends and developments is imperative.

USES OF TECHNOLOGY FORECASTING

Technology forecasting can give qualitative or probabilistic quantitative indications about future developments in technology. This part of technology forecasting is termed *Exploratory Technology Forecasting* and depends on the past and the present data for exploration of the things to come in the future. An interesting fact to note is that there is a definite relationship between the past, present and the future of technology developments, inspite of the so called 'breakthroughs' in the technology. In fact, many of the so-called breakthroughs are due to a deliberate and consistent research effort and corresponding expenditure of finance and manpower energies involved in the past. Many discoveries and developments in the field of atomic physics and space-research are really not breakthroughs in the real sense of the word because they follow the continuous research efforts planned and deliberately helped by national and international policies. This is borne out by the past continuous trends observed in the various technological developments in the world such as: the increase in the efficiency of illumination, increase in the use of artificial fibre as a substitute to natural fibre, the development of polymers, increase in the use of synthetic detergents as a substitute to soaps and various other such technological developments. For this reason, exploratory forecasting is of much use in understanding future technological developments, so as to be prepared with adequate production capabilities to cope with future developments. A few examples of such trends are shown in Figs. 8.4 and 8.5. The log-linear relationships in Figs. 8.4 and 8.5 exist despite the fact that there have been many randomly occurring 'imports' of technical know-how in the past.

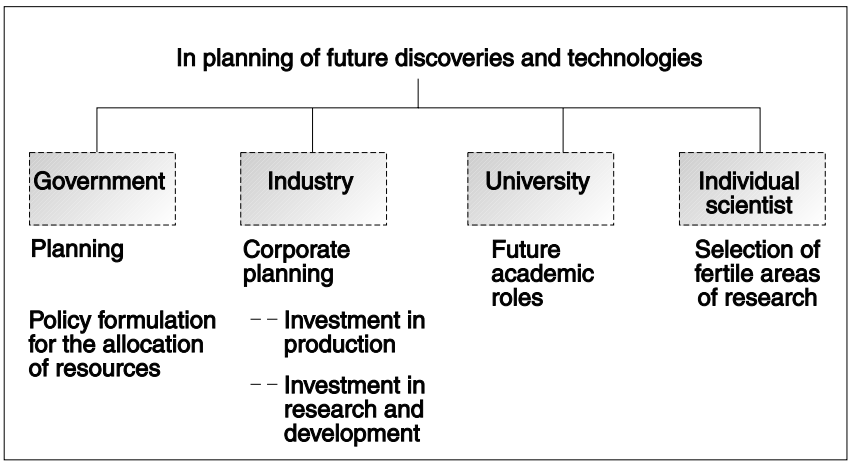


Figure 8.3 Uses of Technology Forecasting

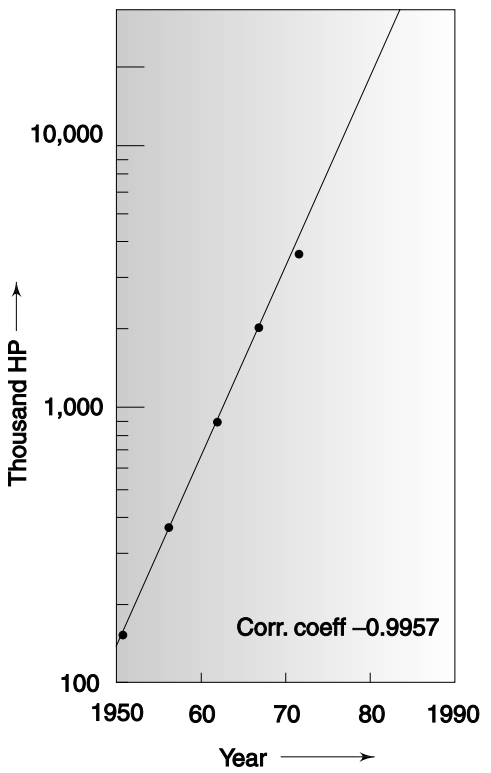


Figure 8.4 Trend of Electric Motor Production in India

Source : P.K. Rohatgi, K. Rohatgi and B. Bowonder, *Technological Forecasting*, That McGraw-Hill Publishing Co. Ltd. New Delhi, 1979

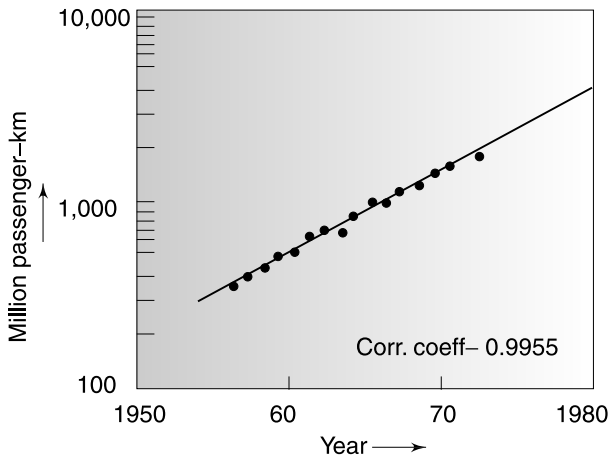


Figure 8.5 Air Travel in Indian Airlines

If the projection given in Fig. 8.6 is combined with the projections of hydel and thermal power availability and the availability from non-conventional sources of energy and conservation, it throws light on the necessity of nuclear power generation as well as various controversial issues such as the nuclear power plant at Kaiga, Karnataka.

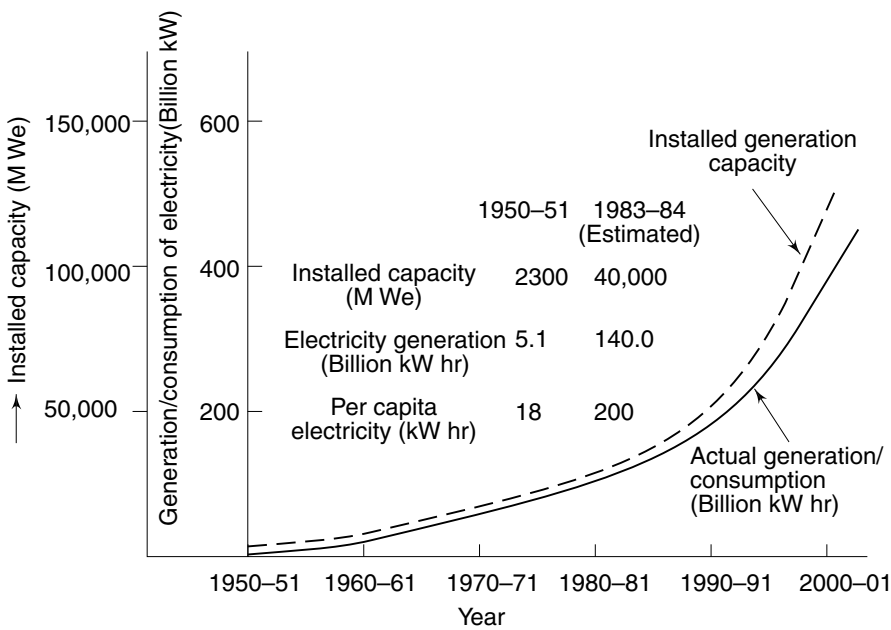


Figure 8.6 Past and Projected Growth in Electric Power Generation Capacity and Actual Generation/Consumption of Electric Power in India*

* D.P. Sen Gupta, ' There is no other option,' Deccan Herold, Oct. 22, 1985 p.8

Another aspect of technology forecasting is called *Normative Forecasting*. This follows from the long-term future backwards. For instance, one may project the requirements/objectives and goals of a nation, or of an organisation, and from this deduce what technology might be required to achieve these targets. From the very long-term future, we plan technological requirements for the long-term future, and for the intermediate-term future.

In short, one iterates between the 'needs' and the 'capabilities/capacities' in order to arrive at a decision for necessary current action. Figure 8.7 diagrammatically explains normative as also the exploratory forecasting modes discussed earlier. Table 8.6 shows the projections of demand, availability and deficit of energy up to the year 1990 for the State of Karnataka and this exploratory information can be used for normative purposes, i.e. action in the present. There is thus an 'interaction' between the two modes of forecasting and a proper matching of the two, one feeding back to the other, is necessary.

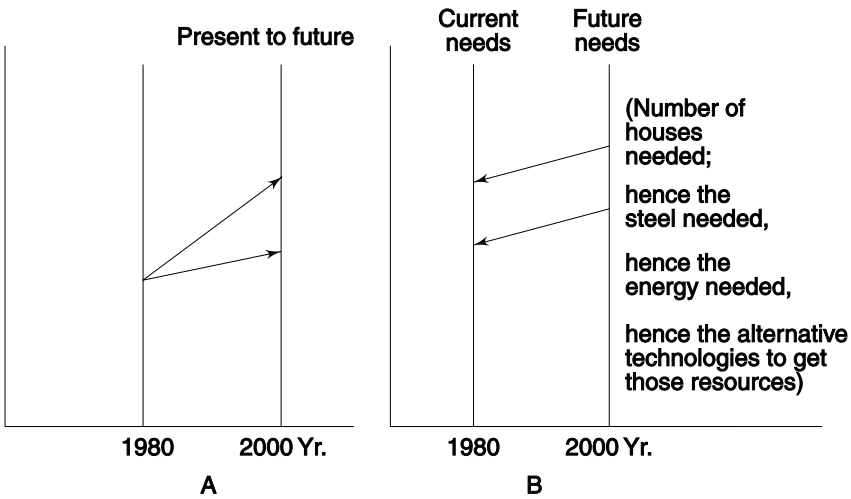


Figure 8.7 Two Aspects of Technology Forecasting: A–Explorative Forecasting; B–Normative Forecasting

Table 8.6 Power and Energy Demand, Availability and Deficit in Karnataka*

	1982–83 (base year)	*83–84*	*84–85*	*85–86*	*86–87*	*87–88*	*88–89*	*89–90*
Peak demand (MW)	1972	1974	2121	2272	2248	2614	2765	2908
Peak availability (net) (MW)	1569	1161	1220	1488	1837	2017	2142	2315
Deficit (MW)	–223	–813	–901	–784	– 611	–597	– 623	– 523
Energy requirement MU	9972	10987	11799	12637	13615	14539	15383	16174
Energy availability (net) (MU)	8273	7309	7772	8815	10613	12172	13560	14152
Deficit (MU)	–1699	–3669	– 4027	– 3822	–3002	–2367	–1823	–2022

*D.P. Sen Gupta, 'There is no Other Option', *Deccan Herald*, Oct. 22, 1985, p. 8.

The various methods of forecasting discussed in this chapter are useful for technology forecasting. For instance, one can use the techniques of: (1) trend extrapolation, (2) regression and (3) curve fitting. In fact, Figs. 8.4 and 8.5 were a case of simple regression involving two variables: time and a parameter measuring the technology development.

EXPERT OPINION GATHERING

When adequate past data about technology developments are not available and where the effect of a number of variables on technological development is not clear (the variables can be economic, political and social, and they can also be multi-disciplinary interactions within the scientific community) the technique of expert-opinion gathering, which is more of an intuitive method, can be quite effective. This technique is called the Delphi Technique. In this technique, a panel of experts, on a particular forecasting problem for technology development in the future, is formed. The names of the technical experts are not known to each other. A questionnaire to record the opinion of the experts is formulated and mailed to all the panel members, regarding various quantitative and qualitative aspects and the interactions of a number of variables. It is observed that many panel members do not respond to the questionnaires, and the drop-out rate of the panel members may be quite considerable. It is recommended that for reliable results from Delphi, which is a multi-round exercise, the number of panel members responding in the final round should be not less than 15. The first round of responses are pooled together, analysed and a second questionnaire made out which is intended to gather more detailed or insightful information on the problem under consideration. For instance, if in the first round the panel members are asked to give their opinions regarding what breakthroughs in technology are probable in the next 20–30 years, in the second round one may ask them about the chances (probabilities) of some of these events occurring. The second round responses are again pooled together, analysed, and the quantitative statistics or qualitative opinions again presented to the panel members for their third round of opinions. In this round one may present the statistics of the opinions gathered in the second round. The idea is to present different view points analytically so that the panelists can refine their earlier opinions, if found necessary to do so. In case the panelists have different opinions, they are asked to state reasons for their differing opinions. After the completion of the third round, one may proceed to the next round where, again, the analysed and processed opinions of the third round is fed to the panelists. There is really no restriction to the number of rounds administered, but when the opinions more or less stabilise, one may be said to have reached the final round of the Delphi. The outcome of the final round will be the forecast with probabilistic quantitative and/or qualitative indications regarding the future.

Some precautions in administering the Delphi Technique:

1. The questions should be precise, otherwise the answers may not be direct.
2. The Delphi expert panel members should be from various disciplines, so as to get a more integrated view of the future and to avoid any bias.
3. Questions should not be ambiguous.
4. The questions should be such as not to preclude any differing opinion. One should not close the door to a different point of view at the questioning stage.
5. The number of questions should be fairly limited and pertinent to specific areas of the respondents.

6. The Delphi technique, which is an opinion-gathering and analysing exercise in multiple rounds, can be supplemented if necessary and if feasible by other methods of technology-forecasting such as trend-studies, regression analysis, mathematical modelling and the like.

Dynamic Modelling

'Dynamic modelling' was made popular by J. W. Forrester. His book, *World Dynamics* inter-related many things such as internal resources, agriculture, population, pollution and industries. The dynamic models differ from the earlier given models. They can incorporate feedback information. There is always a relationship between input and output. Also, there is a definite lag or lead time for the effect of one variable over another. These relations, the interactions of the different variables and the time-relationship between them make the dynamic modelling process more advantageous than the static models.

THE INDIAN SCENE

Due to the importance of the technology forecasting in long-range planning (inclusive of production planning) many high technology organisations in India have shown active interest in it.

Bharat Heavy Electricals Limited has conducted the Delphi on future energy systems. Hindustan Machine Tools had earlier forecast the future of the machine tool industry up to the year 2000. (This work was done in collaboration with the Indian Institute of Science, Bangalore.) Besides these two corporate bodies, other organisations such as the Indian Railways, Steel Authority of India Limited, Bharat Aluminium Company, Jyothi Limited, Baroda, Bharat Electronics Limited, Bangalore, Electronics Commission, Atomic Energy Commission, do long-range planning and have carried out technology forecasting in their fields. Technology forecasting has also been encouraged by the Government of India which set up a Panel on Futurology under the auspices of the National Council on Science and Technology (NCST). This NCST panel has prepared various studies of future developments in India regarding food, housing, education, energy transportation and other areas. The results of the NCST panel study and collection of similar technology forecasting data from other organisations serve as useful inputs to the Planning Commission.

The impact of technology on long-range plan, and therefore on production planning as a component of it, will naturally be highest where the product or production is highly technology-oriented. Therefore, it has special relevance for high technology industries.

Technology forecasting and the related and more general science of futurology has applications even in other kinds of industries. Futurology includes not only projection of technology developments, but also social, economic and political developments in the long-term future.

SECTION III

Imperatives of Quality and Productivity

Chapter 9 Quality Management—I
Chapter 10 Quality Management—II
Chapter 11 New Quality Concepts and Initiatives, Total Quality Management and Six Sigma
Chapter 12 Product Design
Chapter 13 Maintenance Management—I
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Chapter 15 Work Study
Chapter 16 Job Evaluation
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Chapter 18 Job Redesign
Chapter 19 Productivity

In today's world, quality, cost and the availability of the product and the service on time have become the basic necessities. Customer needs a quality product/service at a competitive price. Having said that it is obvious that as to what constitutes 'quality' is determined by the customer. Gone are the days when the established firms could define the quality of the product and dictate the price. It is not true any more, even in an earlier government-controlled economy such as in India.

The world markets are getting more and more accessible and freer despite the efforts of some governments to build barriers to free trade by imposing one or the

other conditions to the import of goods and/or services into their country. For instance, during the year 2003-04, the US government decided to bring in legislation trying to put a cap on Business Process Outsourcing to countries such as India.Year 2009—with the financial crisis in the developed world—also faces a similar threat. But, in general, the economics of a free market prevail ultimately. It makes a lot of business sense to get a quality service at half the price.

Customer's requirements from a product/service can be captured in the specifications of the product. The production process can then be made to conform to the specifications. 'Conformance to specifications' has been a quality axiom since a long time. Not long ago the conformance to specifications could be within a few percentage points. The defectives rate of a single digit per hundred items was acceptable; a rate of a single digit per thousand items was considered excellent. During the past *three decades, particularly since the dominance of Japanese* products and the explosion of highly defect sensitive space and computer technologies, the tolerance levels of the customers of the products have come down drastically. Defects, if any, are tolerated at the level of parts per million.

This is one aspect of the change. What is even more complex for a production/operations system to handle has been the frequently changing tastes and preferences of the customers.

The product itself has to keep changing or, at best, keep evolving to suit these customer preferences that are in a constant state of flux and the expectations that are ever on the rise. Product design has, therefore, assumed great importance. The new/modified design of the product has to be made with the facilities that cannot be changed overnight. Therefore, Design for Manufacturability considerations are a necessity. A good product design that can be delivered with desired quality and at the desired time—with the available facilities and other infrastructure including the production plant and the supply/marketing channels—has become a necessary tool for success in a highly competitive market. If a company does not offer new/modified designs to meet the market needs, it is in danger of extinction. And, quality is an inescapable part of the 'design' of the product or service. It has to be 'designed in'.

Quality management is too important an aspect to be handed over to just one department—the Quality Control department—and forgotten. In the days of yore that might have been the case. But, now quality has to be incorporated at every function that the product interacts with. In today's parlance, Quality means 'total customer satisfaction' and this cannot come about unless the organisation's culture, its values, its processes, its employees, its business associates are all aligned to this quality objective. It has to be a 'total quality management' effort. It is needless to mention that a high level of leadership is called for.

Quality has developed several dimensions of 'service' since service is the ultimate goal. Product is no more just a physical entity. It is accompanied by several 'service' benefits to the customer. Therefore, 'service quality' is equally important for the physical products. Moreover, services by themselves constitute a very large proportion of the national and world economies. The need for services is growing rapidly. Service industry/business is as much—perhaps a shade more—in need of total quality management efforts as the manufacturing industry.

Since a customer pays for the products/services, these have to be available to her at the least possible price. Efficiency in terms of costs can never lose its importance. Whether the customer pays or not, somewhere somebody—an organisation or a society—has to pay the price. If it is not cost to the apparent customer, it may be cost to the society. Therefore, 'productivity' is another fundamental necessity. Usage of resources—material, energy, human intellectual—has to be done

in a 'productive' manner. Productive effort means meticulousness and focused work. Customer being the main object of focus, it is obvious that the efforts for productivity and quality would follow from each other. Without quality there cannot be productivity. Without the rigour of productivity, there cannot be quality.

Quality and productivity are the imperatives of production and operations management today. Most organisations, if not all, are trying to offer quality products/services with attention to productivity. These constitute the basic minimum for the survival of any company in the present competitive business world. Therefore, the differentiation between the competing organizations has to come from other aspects that add to the 'value' to the customer. But then, this additional 'value' will be realized only when the basics viz. quality and productivity are right.
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9 Quality Management–I

Quality is an important dimension of production and operations management. It is not enough to produce goods or services in the right quantity and at the right time; it is important to ensure that the goods and services produced are of the right quality. The consumer of the final product of a company needs a certain quantity of products of a quality appropriate to his needs. Without quality, the other dimensions of quantity and time have little relevance.

QUALITY AS A CORPORATE STRATEGY

Quality management, which includes ensuring proper quality for a company's output, is important not only for its survival in the market, but also to expand its market or when it wants to enter into a new product-line and various other marketing ventures. If a country' products are to make an impact in the international market, it is vital that the quality of its exports should be at par with, if not better, than similar products from other nations. Quality management is thus an important long-term marketing strategy as well. For developing countries, such as India, this aspect assumes greater importance since in the international market they have to compete with products of advanced countries with established brand names and brand loyalties. To make a dent on such a market, it might sometimes be necessary for our products to be one step better than the already established products of other advanced countries.

Looking at it from another angle, it is necessary that we try to improve the quality of our products and services for even domestic consumption, so that Indian consumers get better service in terms of improved products. This is the social aspect of quality.

WHAT IS QUALITY?

Although we have described the virtues of good quality, one basic question needs to be answered: What is quality and who decides what the quality should be?

1. Quality is the performance of the product as per the commitment made by the producer to the consumer.
   The commitment may be explicit such as a written contract or it may be implicit in terms of the expectations of the average consumer of the product.
   'The performance of the product' relates to the ultimate functions and services which the final product must give to the final consumer. For instance, a watch should show accurate time or a ball point pen should write legibly on a piece of paper or the paper should be capable of retaining the pen-or-pencil marks made on it. Quality may be measured in terms of performance tests. A product is called a quality product only when it satisfies various criteria for its functioning for the consumer. In addition to the physical criteria, there is also a service and time dimension to quality. The same quality of physical performance should be available over a reasonable length of time. Thus, time is also an essential aspect of quality.
2. Quality is either a written or non-written commitment to a known or unknown consumer in the market. Since the market or the target-market itself is decided by the company, that is to which type of consumer or customer to cater to, quality is a strategic marketing decision taken by the company itself at the outset. We may broaden this concept by saying that the quality of products to be produced by a corporation is a corporate level decision. It is a decision based on various marketing considerations, production constraints, manpower or personnel constraints, and equipment or technology constraints. The decisions regarding quality are not really in the realm of one functional manager as this involves overall strategic decisions for the running of the business of a corporation.
3. Once such a strategic decision regarding the quality is taken, it is the job of all functional managers, including the production and operations manager, to see that such strategic objectives and goals are implemented. In this, the purchasing department has as much contribution to make to the quality as the production department that produces the goods, and the warehousing department that stores the goods, and the transport department that ensures the proper shipment of the goods to the customers. Quality implementation is also a 'total organisation effort'.

STATISTICAL METHODS

Statistics and quantitative methods are helpful in the implementation of quality. Though these quantitative and statistical methods are not a panacea for the problems of quality implementation, they are nevertheless helpful in this implementation process.

We may say, that there are three aspects of assuring quality, as shown in Fig. 9.1.

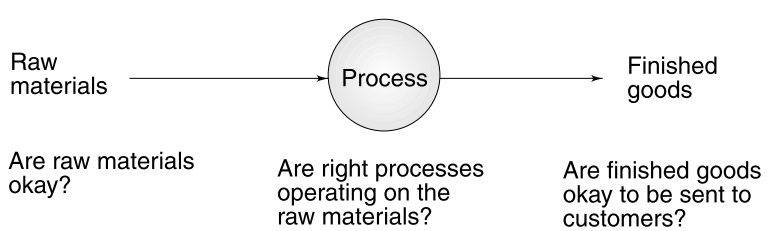


Figure 9.1 Basic Aspects of Assuring Quality

- Assurance of incoming raw material's quality.
- Assurance that proper processes are operating on the raw materials.
- Assurance of the quality of the outgoing finished goods.

Acceptance Sampling

The task of exercising control over the incoming raw materials and the outgoing finished goods is usually called 'Acceptance Sampling'. Here, one is concerned about accepting or rejecting the supplier's raw materials, and sending or not sending the finished goods out. This is why the control at the raw material and the finished goods point is called Acceptance Sampling. This is only one part of what is known as Statistical Quality Control.

Process Control

The control one exercises over the processes operating on the raw materials or the semi-finished goods is called Process Control. This is another aspect of statistical quality control. It is assumed that if controls are exercised at the above-mentioned three points, quality will be appropriately maintained.

Mass Production

At the outset itself we must be clear, that Statistics is a science of averages, and therefore, statistical methods are useful for mass-production and mass-purchase or procurement of raw materials and mass shipment of the finished goods. The statistical methods depend on a large population for their accuracy and relevance, and of course, being a science of averages, these methods have their own special drawbacks (which we need not elaborate at this point).

Sampling

Since in all the statistical methods we shall be dealing with small samples taken from a large population, these statistical methods are of a great help in ensuring adequate quality for the total population or mass of products by checking only a few. These methods, in addition to reducing the labour involved in the implementation of quality, also give us an adequate amount of confidence on a scientific basis. They tell us to what extent we might fail or succeed in our efforts to maintain quality. Quality management has been given a scientific basis with the advent of the statistical quality control methods.

STATISTICAL PROCESS CONTROL

In this chapter we confine ourselves to the control of the processes operating on raw materials. (Acceptance sampling will be discussed separately in Chapter 10.)

The premise in process control is that if the processes (chemical reactions, mechanical working by men and or machines) are operated within a tolerable range, the product produced will be of the desired quality. This assumes that the incoming raw materials are of the right quality to start with. The objective of process control is to set a proper procedure to work or shape the raw materials

into finished goods and then monitor the processes operating on the raw material frequently and any deviations from the said procedures should be corrected when required. Process control is nothing but the monitoring of the various physical variables operating on the materials and the correction of the variables when they deviate from the previously established norms.

Variations

But, we know that most things have a variable component to them. The processes which operate on the raw materials will also have variations due to causes inherent in them or otherwise. In any case, the causes responsible for the deviation of the processes from the established norms have to be rectified. The causes responsible for the deviation could be such that can be traced or spotted and, therefore, rectified and such that cannot be traced and rectified easily. In statistics, anything that we do not understand or we are not capable of understanding is called 'random'. The variations which are inherent in nature to a particular process and which are random since they are not traceable to any particular cause, are labelled to be due to 'random causes' or 'chance causes'. For instance, a machine filling toothpaste in tubes may not fill all tubes with exactly the same amount of paste; there will be some variations. This is due to the inherent nature of the process. In process control, we would be concerned only with those causes which can be rectified, i.e. the assignable causes. We can do nothing about the chance causes. But, anytime there is an assignable cause it is preferable to rectify it. The difficulty arising in this approach, of course, is to know when a particular deviation in the process is occurring due to the chance causes and when it is occurring due to assignable causes.

Monitoring the Process

We can control the process by **(a)** actually measuring the variables operating on the raw materials, or by **(b)** measuring the characteristics of the output product. When a number of variables are operating on the product, it becomes easier to monitor the processes by observing the quality of the product coming out of the processes, rather than monitoring the various variables operating. Moreover, we are interested in the final quality of the product rather than in the process variables operating on the materials. Therefore approach 'b', which is to monitor the output of the process and based on that to make inferences regarding the processes operating on the raw materials, is preferable. This is particularly so when a large number of variables are operating on the raw materials. The statistical process control would, thus, seek to monitor the output of the processes and thus control the processes by locating the causes for the deviations (if any) and rectifying the same.

Specification Limits for the Output

When the quality of a particular product is being described, one usually refers to the appropriate range of performance of this product. We do not say that the diameter of the shafts have to be 3 centimetres exactly. Rather we would say that it should be 3 centimetres plus or minus 0.002 centimetres. Similarly, we do not say that the pH of baby powder has to be 5.7 exactly. Rather we say that it has to be between 5.2 and 6.2. Every quality performance requirement is usually expressed within a certain range. This range, narrow or wide, of the performance requirement in terms of quality of a product is called the specification range or specification limits.

Control Limits

Naturally, in exercising process control by monitoring the product from the processes, we should not exceed these specification limits. In fact, we should exercise control over the processes before the product quality goes beyond the specification limits. Therefore, the limits for our process control purposes should be narrower than the specification limits. These limits should be such that when exceeded, a danger signal is given, but as yet it is only a signal, and the product is not harmed. This is the philosophy behind the design of control-limits vis-a-vis the specifications limits (which have been already set in the Quality planning process).

Cost Aspects in Designing Control Limits

In addition to the above, while designing the control limits or the danger signals one should keep in mind the cost aspects as well. There is no point in worrying over every small variation in the output and wasting our efforts in rectifying the processes operating on the materials. We must give the process its inherent free play as well. We must also allow for certain margin of error even if the error is assignable or locatable. Such should be the design of the process control limits.

Central Tendency and Dispersion Variations in any process can be described in general in terms of two parameters:

1. Central tendency, and
2. Dispersion.

The former has to do with accuracy and the latter with the precision. To understand these two concepts, let us consider the following example.

Example Suppose I weigh 150 pounds (lb). There are two machines and they show the following readings for my weight:

Machine No. 1	Machine No. 2
140, 151, 159 lb	139, 139.5 140 lb

Machine No. 1 gives an average of 150 lb and therefore, this is an accurate machine. Its central tendency does not show deviation, but it has a lot of 'dispersion'. Machine No. 2 is precise, but it is not accurate because, its central tendency is 139.5 lb which is far removed from the actual weight, whereas, its dispersion is quite low, ranging from 139 to 140.

The above example shows that in controlling errors one has to control not only the central tendency, but also the dispersion. Both controls are necessary. We need to control the mean and also amplitude of the variations. We need to check whether a process has gone out of control in terms of either the central tendency, or in terms of the dispersion, or both.

CONTROL CHARTS

In process control, we keep a check on both the above-mentioned aspects by a constant monitoring device; which is graphical; the graphs which are used for such monitoring are called control charts. Process control relies mostly on such graphical or visual representations, and monitoring thereby.

If we were to monitor the process by measuring the characteristics of output from the process, the continuous measurement will interfere considerably with the manufacturing activities. We

need to measure, but intermittently. Moreover if we were to continuously monitor the quality characteristics of the output of the process, the population of all such observations may not be amenable to easy statistical methods. If we were to plot distribution of the total population, it could be rectangular or it could be something else more abnormal.

Normal Distribution

The above told suggest that we resort to a sampling procedure for process control purposes. This has also another advantage by virtue of what is known as the Central Limit Theorem in statistics. The theorem states that the means of samples tend to follow a simple statistical distribution, viz. Normal distribution.

Therefore, the procedure will be: to take a few samples at a time; measure their quality characteristics; find the mean of the sample; measure the range of dispersion in the sample; and gather statistics for the ranges and the means of the various samples taken over frequent or regular intervals of time. These statistics, when plotted appropriately on a graph paper, will guide us as to when a particular process needs to be rectified and in what manner.

Statistical Relationships for Sampling

Based on the sample-size, there is a definite relation between the standard deviation of the population and the standard deviation of the sample means.

$$\sigma_{\bar{x}} = \frac{\sigma \text{ population}}{\sqrt{n}} \tag{1}$$

$$\mu_{\bar{x}} = \mu_{\text{population}} \tag{2}$$

where $\sigma \equiv$ Standard deviation

$\mu \equiv$ Mean

$x \equiv$ Value of the measured characteristic

$\bar{x} \equiv$ Mean of 'x' s observed of the sample (x_1, x_2, x_3, etc. individual values in the sample)

$n \equiv$ Sample size

The sampling distribution (of $\bar{x}$) being normal, the computation of $\mu_{\bar{x}}$, $\sigma_{\bar{x}}$ and Confidence Levels is quite easy.

$\bar{x}$-Chart

Now to keep a watch on the 'central tendency' we have to fix limits which are called 'control limits' for the values of $\bar{x}$. Any time the sample mean exceeds the control limits, we say that the process has gone out of control—that is, there are certain 'assignable causes' which should be looked into immediately. It may not be that every time the control limits are exceeded the process has really gone out of control. The overshooting may simply be due to chance causes; and when this is the case, our investigation into finding the assignable causes will mean an unnecessary burden of cost. Therefore we would like to limit the number of times we look for assignable causes for the variations. Depending upon the precision that is involved, we would be setting up the control limits on the + and the – side of the mean of the sample means. Usually $\pm 3\sigma$ limits are established. Since means of the samples are distributed normally, the 3σ limits will mean that when the process is

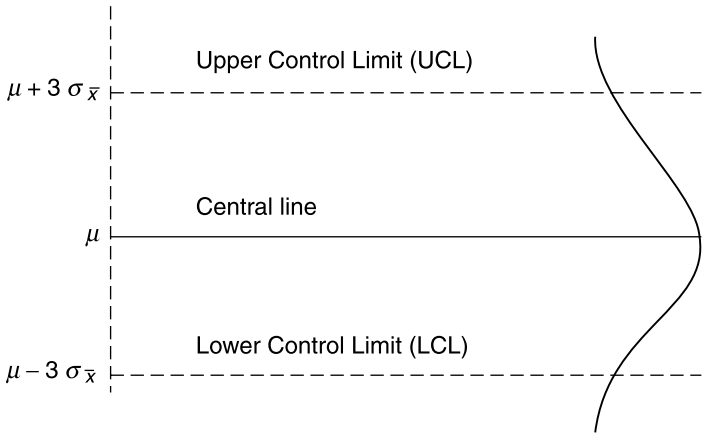


Figure 9.2 $\bar{x}$ -Chart for Process Control

under control we will investigate into the assignable causes 3 out of 1000 times. Incidentally, when we look for the assignable cause when none exists, it is called the Type 1 error; and when we are not looking for assignable causes, when these causes do exist, it is called Type 2 error. We would like to find a proper balance between the Type-1 and the Type-2 errors, and based on this particular balance we can fix the + and – control limits on the 'central tendency' (mean of the sample means). As we said, in many cases, we fix these limits at $\pm 3\sigma$ level. The control chart for the 'central tendency' is called the $\bar{x}$ -chart and is presented in Fig. 9.2.

Any time the sample-mean overshoots the upper control limit or undershoots the lower control limit, we give a red signal; that means, we look for assignable causes by checking the machine or equipment or process that is producing the particular product.

R-Chart

The chart in Fig. 9.2 is for keeping a control on the 'central tendency'. Now we look for the control for the 'dispersion'. The standard deviation as well as the Range will give an indication of the Dispersion. The range is the difference between the maximum value and the minimum value of the observations in a sample. We use the sample's range for controlling the 'dispersion' of the population as it is simpler to use. The distribution of the range for the samples is shown in Fig. 9.3.

$$\bar{R} = d_2.\ \sigma \text{ population} \tag{3}$$

where, d2 is a constant whose value depends upon the sample size n. The mean of the samples ranges or $\bar{R}$ will represent for σ_{pop} which is the standard deviation for the population. By maintaining $\bar{R}$ within limits we can maintain σ_{pop}. Although the frequency distribution of the sample's ranges appears as given in Fig. 9.3, it can still be approximated to a normal distribution and 3σ limits would be established for the upper and lower control limits. The resulting *R*-chart is presented in Fig. 9.4.

$$\sigma_R = \text{Standard Deviation of the Ranges} = d_3 \cdot \sigma_{pop} \tag{4}$$

where, d_3 is a constant whose value depends upon the sample size n.

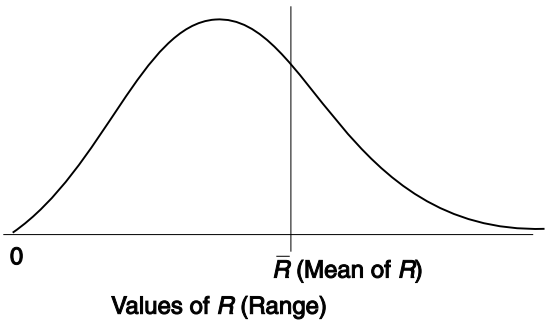


Figure 9.3 Frequency Distribution of Range

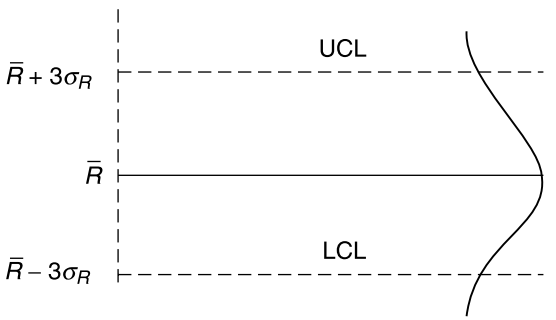


Figure 9.4 R-Chart for Controlling Dispersion

When the R values fall below the central line, it indicates that the process at that point of time is having less dispersion than the average values of the same. This may be desirable, and so we may ask the question why one should be concerned about the undershooting of the lower control limit in an R-chart. If the narrowing down of the dispersion is a permanent feature, it should be incorporated by having a revised R-chart. Moreover, we should ask whether this desirable result is due to some uneconomical methods which might have been employed, or whether it is due simply to the inspection error. These aspects need to be investigated, and hence the need for having a lower control limit even in R-charts.

Simpler Relationships for $\bar{x}$ - and R-charts

For $\bar{x}$ -chart: UCL and LCL

$$= \mu \pm 3\,\sigma_{\bar{x}}$$

$$= \mu \pm \frac{3\sigma_{\text{pop}}}{\sqrt{n}}$$

$$= \mu \pm \frac{3}{\sqrt{n}} \cdot \frac{\bar{R}}{d_2} = \mu \pm A_2 . \bar{R} \qquad (5)$$

where $A_2 = \frac{3}{d_2 \cdot \sqrt{n}}$; the values of A_2 can be read off from standard Statistical and Quality Control tables, corresponding to a sample size.

For R-chart: UCL and LCL $= \overline{R} \pm 3\sigma_R$

$$= \overline{R} \pm 3.d_3.\ \sigma_{pop}$$

$$= \overline{R} \pm 3.d_3.\frac{\overline{R}}{d_2}$$

$$= \overline{R}\left[1 \pm 3\frac{d_3}{d_2}\right] = D_4\overline{R} \text{ and } D_3\overline{R} \quad (6)$$

where $D_4 = 1 + \frac{3d_3}{d_2}$ and $D_3 = 1 - 3\frac{d_3}{d_2}$; the values of D_4 and D_3 can be read off from standard Statistical and Quality Control tables, corresponding to a sample size.

Thus, by looking for assignable causes which result in abnormal deviations in the means of the samples and in the ranges of the samples, we try to control the process and the quality level of a product.

Stable Values

But, to construct the $\overline{x}$ - and the R-charts we need to have information regarding the stable values of the mean of the sample means and the mean of the sample ranges. Unless these charts are constructed from a process which is statistically under control, they cannot be used as reference charts for control. Therefore, the procedure to determine the stable values is as follows:

1. Suppose we take 25 samples of a sample size $n = 5$.
2. We find the μ and the $\overline{R}$ for the above.
3. Read out A_2, D_4, D_3 values for $n = 5$ and compute UCL and LCL for both the $\overline{x}$ and R-charts.
4. Now the 25 sample points are plotted on the $\overline{x}$ - and R-charts.
5. Eliminate from your consideration those points which fall out of the control limits; and based on the screened data again calculate μ and $\overline{R}$.
6. Again fix the upper control limit and lower control limit values for the $\overline{x}$ - and R-charts.
7. Repeat the step of plotting the points on these $\overline{x}$ - and R-charts. Repeat steps 5 and 6 until the sample points fall within the new - and R-charts' control limits.

Cusum Charts

The $\overline{x}$ - and R-charts serve the purpose of locating or indicating the large sudden changes in the process, whereas, the cusum charts serve the purpose of noticing small step-by-step changes in the process under consideration. The theory of the cusum charts is as follows:

We define: $S_1 = \overline{x}_1 - \mu$

$$S_2 = (\overline{x}_2 - \mu) + (\overline{x}_1 - \mu)$$

$$S_3 = (\overline{x}_3 - \mu) + (\overline{x}_2 - \mu) + (\overline{x}_1 - \mu)$$

and so on, where $\overline{x}_1$, $\overline{x}_2$,…, etc. are means of sample numbers 1, 2,…, etc. (7)

These S's are the cumulative sum of the deviations of the sample means from the process mean (μ). If the process is stable, then the positive and the negative deviations should almost cancel each other out and therefore a plot of the S's versus the sample number (which increases as we go along in time) will be an almost horizontal line; whereas, if there is a gradual change in the process, it will be noticed in either gradually increasing or decreasing values of S's as you go along in time. This is depicted in Fig. 9.5.

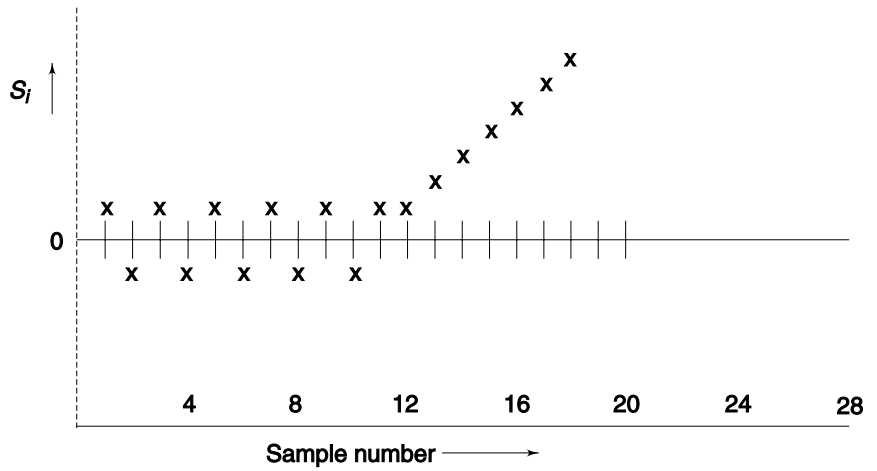


Figure 9.5 Cusum Chart

p-Charts or Fraction Defective Charts

So far, we have dealt with the control charts where measurements of the samples were taken in terms of the particular characteristic, for example, the diameters of the shafts being produced or the thickness of the plates being produced, etc. But, not in all cases can we describe the samples in terms of their measurable characteristics. Many a time, the inspection is of the go/no-go, or accept/reject type. In such a case, the particular sample is either defective or it is not defective. Control charts for such inspection procedures have been named p-charts where p stands for the fraction defective in a sample. The procedure of constructing the p-chart is as follows:

Suppose we take about 25 samples. We find the average fraction defective, $\bar{p}$. This is the central line. We assume normal distribution for the fraction defective data of these 25 samples. Note that though this is a typical case for the application of the Binomial distribution, we can approximate the distribution to a normal distribution when $np \geq 10$. If this requirement is met, then based on the normal distribution assumption, we set the limits for the upper and lower control:

$$\bar{p} \pm 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\left(\text{Note that the variance for the fraction defective is: } \bar{p}\,\frac{(1-\bar{p})}{n}.\right)$$

c-Charts or Number of Defects Chart

Many a time a part or product is considered defective not just based on one measurement like the go and no-go gauges would indicate, but on the basis of a number of defects present in a sample. For instance, a welded joint will have a number of defects all of which have to be taken into account before a decision to accept or reject it can be arrived at. Similar examples can be given of cloth produced which may have a number of defects per metre length. It is the total number of defects in the sample which would render a sample either acceptable or rejected. For process control measures in such situations where the number of defects is the criterion for acceptance or rejection, a special kind of chart called the *c*-chart is used. The procedure is to take a sample of fixed size, count the defects in the sample (suppose the number of defects are equal to *c*); then plot the distribution of *c*'s for all samples. The approximation of a Poisson distribution with a mean of $\bar{c}$ and a standard deviation of $\sqrt{\bar{c}}$ will be suitable. Therefore our control limits will be $\bar{c} \pm 3\sqrt{\bar{c}}$ and the chart would look as given in Fig. 9.6.

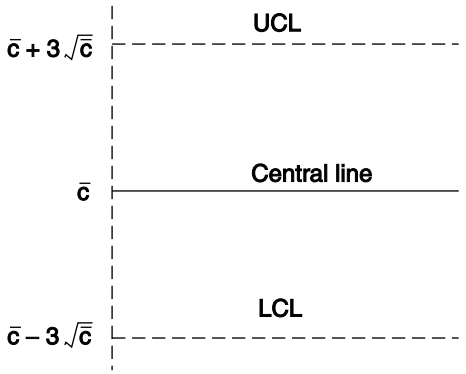


Figure 9.6 Control Chart for Defects

DIAGNOSTIC VALUE OF CONTROL CHARTS

It may not always be necessary for the sample point to cross the Control Limit in order to indicate trouble brewing in the process. Many a time the trend of the sample values provides diagnostic information regarding some real trouble in the process. If a series of successive points fall on the upper side of the control limits (Fig. 9.7), although within the band of control limits, it may mean a particular type of trouble in the process. If the successive points keep falling on alternate sides of the centre line, it may mean another kind of process problem. The upward or downward trend of successive points may mean a particular process change and sudden shift of the successive points on the chart may mean another category of process trouble. Such situations are depicted in Fig. 9.7.

PROCESS CAPABILITY

Mass production is controlled for quality by controlling the means operating on the raw materials entering into the process. By controlling the means of production it is assumed that the quality of the product will be controlled. The quality of the product will be as good as the ability of the process to produce the same. Based on the ability of the process or 'process capability' we can ensure by means of process control, as described above, only the capable (possible) stability of the processing system operating on the raw materials. The quality of the product will depend upon the capability of the stable system. The controls over the raw materials side will be described in Chapter 10.

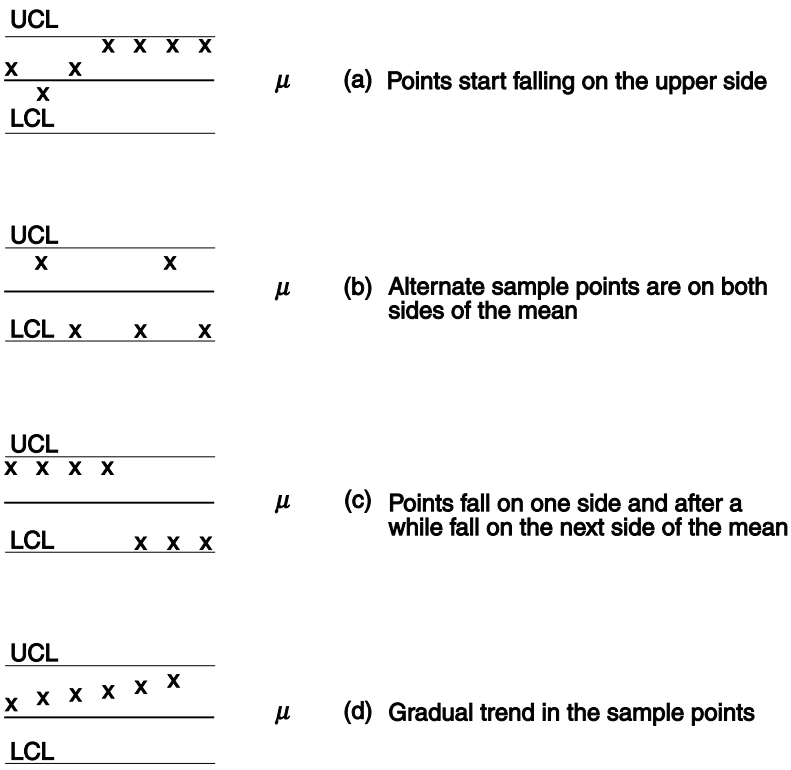


Figure 9.7 Behaviour of Control Charts and Diagnostic Information

USE OF STATISTICAL PROCESS CONTROL (SPC) IN SERVICES

Whether it is manufacturing or services, there are common concerns regarding costs, quality and effectiveness. Hospitals, other healthcare facilities, hotels and similar hospital industry, transport, tourism, banking, telecommunications, and other service industries need tools to help the service providers monitor and assess the quality of service being provided and guide them to make better decisions. Just as in manufacturing, the SPC helped in identifying the variation that needs to be

addressed, in service industry too the SPC can be quite useful in determining as to which aspect of service is out of control. Large deviation/s hint that an aspect is out of control, so that there is a need to determine the source/s of the variation and identify the best method of correction. The difference, in production and service situations, is mainly in the particular variable/s that is monitored.

Just as manufacturing/productions has a process, the service production also has a process. For instance, if it is a community health project, e.g. polio eradication, it has a process. In large hospitals with heavy patient load, the process aspect is quite evident. The quality of care delivered to the patients can have several measurable parameters. When these are in control, the service delivery can be expected to be of the desired quality. The statistical concepts of mean, standard deviation, range, and distributions like normal and poisson are equally applicable for several service situations. As long as there is a standardised process with identifiable and measurable variables, SPC can be a very useful tool for improving quality of the service outcomes or service delivery. The point to note is the requirement of a standardised process to be in a place. This requirement can be met in most service situations. The concept of 'special cause' and 'common cause' of variation is, then, of as much utility as in the manufacturing situation. $\bar{x}$ -chart, p-chart and c-chart can, therefore, be useful.

Process Control in Services is Possible

Service are different from manufacturing in that the customer actively participates in many service operations. While this is true, it need not come in the way of using process monitoring and control tools. Monitoring and control tools can be designed with customer participation included. Another difficulty expressed with regard to services is that different customers can have different expectations and definitions of service quality. This is also true. But, a service firm generally serves a 'niche' category of customers and hence even the customer expectations and the dimensions of service quality can be uniform and hence monitorable and controllable.

All 'tangible' process parameters and outcomes can be monitored and controlled for providing consistent service quality or for improvement in service quality. In fact, no organisation—competitive or otherwise and profit-making or non-profit—that intends to provide good service to its customers can leave many things in the realm of intangibility. Even services imparting supposed 'intangible' actions/ processes to people and/or things would try to bring a large number or part of the actions in the realm of tangibility, measurability, standardisation and controllability.

Case of services in Hospitals

Therefore, the 'process' in the service provision should be found and standardised. Admitting a patient to a hospital in-patient ward is a 'process'. Shifting a patient from the ward to an Intensive care Unit (ICU) is a 'process'. Laboratory tests are another process. Billing is an other process. When a process is identified , standardised, and key quantifiable quality parameters identified, the process can be 'controlled' by using the SPC techniques.

In each of these afore-said processes, the 'customer' is different and the key quality parameters are different. These are mentioned in Table 9.1 below.

Table 9.1 Some Processes in Hospitals

Process	*Customer/s*	*Key Quality Parameter*
Admitting patient to the ward	Patient	Politeness, Promptness
	Doctor/ Surgeon	Timeliness (on the appointed date and time)
Lab tests	Doctor Patient	Accuracy of reports, Reliability, Timeliness Punctuality and Politeness
Billing	Patient	Accuracy and Comprehensibility of the bill

The surgeon or doctor is interested in having the patient admitted to the ward on time, so that the surgical operation can be carried out as per schedule. This is very important because a surgical operation involves the coordinated work of the anaesthetist, the surgeon, assisting doctors, nurses, technicians and other staff. There may be much complex equipment (lasers, ultrasound, special microscope, endoscopy equipment, etc.) to be kept ready and hence specialist technicians have to test and ready the needed equipment prior to the surgical operation. It is like an orchestra and hence timeliness in admitting the patient is important for the Surgen operating on the patient. Any delay in admitting the patient may cause a delay in making the patient ready for the operation and may throw the entire surgery schedule out of gear. The patient is interested in quickly completing the procedure to get admitted to the ward. He would like the interactions to be polite.

If the process of 'admitting a patient to the ward' is standardised, then its relevant parameters can be monitored and controlled so that the required key service quality parameter is delivered. 'Of course, not all service quality parameters are quantifiable. Promptness and timeliness are quantifiable and hence statistically moniforable; but 'poteness' is not easily amenable to quanitfication because it is in the realm of customer's 'perception'. In respect of other process mentioned above, accuracy, reliability and timeliness of lab reports can lend themseleves to quantification; however, 'comprehensibility' of the bill relates to customer perception. But, as one would notice, a significant fraction of the service characteristics is quantifiable and therefore controllable with the use of SPC. Somehow, the general perception has been that the service quality is an individual perception-based nebulous entity, that is not easy to control. Hence, many production and operations management techniques were kept away from service industry. This has to change.
SPC can be used in service industry if:

1. The process can be identified and standardised with all its activities and flow charts.
2. The (i) quantifiable key quality parameters and (ii) process variables are identified.

SPC for Computer Software Industry

Similar to the healthcare industry, the computer software industry can also use SPC, provided the software development process is clearly identified and standardised, and the key quality parameters and process variable are identified. It may be noted that about 40 per cent of total cost of software development relates to poor quality and resultant rework. Other cost is the projects getting delayed and some of them ultimately getting cancelled or dropped. Software industry generally experiences much pressure on schedules, creeping requirements and reduced profitability per project. In many cases, these may be manifestations of a lack of standardised process, poor definition of quality and resultant lack of control over the software development process. This

in turn, may lead to rework and schedules going haywire as also perceived creeping changes in requirements. A good SPC with a good control over the software development process, its inputs and its quality characteristics can alleviate many of these problems.

CMMI levels and SPC

Capability Maturity Model Integration (CMMI) Level evaluates the capabiltiy of a contractor to perform a softwate project. The origins of CMMI levels can be traced to the US Military software subcontractors who overran time and costs. It measures as to how mature is the firm to carry out the required project. There are five CMMI levels. From ad hoc uncontrolled processes (CMMI Level 1) it goes to a more or less perfect state of process optimisation and continual improvement (CMMI Level 5). CMMI Level 3 refers to state where there are several well defined and documented standard processes. At CMMI Level 4, the software development firms uses statistical tools in the management of processes and projects. Threshold values are established for various processes. Variations from threshold values are assigned to either common causes or special causes. CMMI Level 5 firms are at a stage of continuous process improvement. Certification of the CMMI level spurs the software firms to improve themselves. However, it must be added that being CMMI complaint or at a high level does not guarantee that a project will be successful; it could increase its probability of success.

Correct the Processes, Not the People

Service organisations that do not have processes in place instead tend to blame people for the organisation's inefficiencies. For instance, a boss who does not identify the 'process' and its variables in typing work done by his secretary (variables like his own speed of dictation, the acoustics or noise in his office room, and the quality of the PC and software given to his secretary) will tend to blame the secretary for the lack of quality in her typing. He may not have even clearly defined as to what constitutes 'quality'.

Similarly, take an example of pest control services or domestic appliance services or a service such as the medical claims for senior citizens. It may be the experience of some customers that the telephone calls do not get answered up promptly and repeated telephone calls are necessary to register one complaint—the complaint being repeatedly narrated (in addition to repeating one's customer identification number, name, address, date of the Annual Maintenance Contract, etc.) to different persons answering the telephone. Actually a telephone call be a customer may be a chance to revalidate the positive service characteristics of the firm. This opportunity is lost. When an unhappy customer complains to the top boss of the firm, the reaction may many a time be to punish the field staff or to give the customer a free repeat service. Ironically, the customer complaint is seldom viewed as a deficiency in the business process. The management action that is generally needed is a rectification of the deficient business process. If the process was right, the variations in the service quality would not have occurred and the customer complaints would have drastically reduced. And, if the variations are occuring, there should be a mechanism to monitor and control these. Standardising the process and using SPC effectively would be a solution.

Use of Process Capability Studies in Service Industry

Process capability studies are equally relevant in service industry. If a service process is not capable to deliver a certain level of servce, it may mean that a redesign of the process is needed in order to meet the desired service quality. Cusomer expectations or industry expectations may change with time, necessitating improvement in the process capability. Process control can only be effectged within the limits of process capability. Once the redesigned capable process is in place, SPC can be used to monitor and control quality of the outcomes.

SOLVED PROBLEMS

1. Shubha & Company (SAC) is an automobile ancillary and manufactures piston rings amongst several other products. Since quality is very important in a highly competitive market, SAC wants to introduce statistical quality control on its shop-floor. Sample checks on the diameter (critical dimension for quality) of the piston rings are taken as they are produced. Samples are taken in a bunch of five items, i.e. five rods produced would constitute one sample. The results on 20 such samples yield the following:

$$\mu = 0.2244 \text{ cm} \quad \text{and} \quad \bar{R} = 0.0023 \text{ cm}$$

What should be the control limits for the process control charts?

Answer

$\bar{x}$-chart:

For the $\bar{x}$ chart the control limits are:

UCL= $\mu + A_2.\bar{R}$ and LCL= $\mu - A_2.\bar{R}$

Now, the value of A_2 corresponding to a sample size of 5 can be read off from the Appendix (Factors for Computing Control Chart Lines). It is:

$$A_2 = 0.577$$

Hence, UCL = 0.2244 + (0.577)(0.0023) = 0.2244 + 0.0013 = 0.2257 cm

and LCL = 0.2244 – (0.577)(0.0023) = 0.2244 – 0.0013 = 0.2231 cm.

R -chart

For the R-chart, the control limits are:

$$\text{UCL} = D_4.\bar{R} \text{ and LCL} = D_3.\bar{R}$$

Again, the values of D_4 and D_3 can be read off from the same table. These are: $D_4 = 2.115$ and $D_3 = 0$

Hence, UCL for the R-chart = (2.115)(0.0023) = 0.0049 cm and

LCL for the R-chart = (0)(0.0023) = 0.0000 cm.

2. In the above company, if the sample size was 10 (i.e. if they were taken in a bunch of ten) how would the process control charts have been different?

Answer

The factors A_2, D_4 and D_3 would have been different.

The new factors would have been: $A_2 = 0.308$, $D_4 = 1.777$ and $D_3 = 0.223$
Hence,

UCL for $\bar{x}$ -chart =0.2244 + (0.308)(0.0023) = 0.2244 + 0.0007 = 0.2251 cm

LCL for $\bar{x}$ -chart = 0.2244 - (0.308)(0.0023) = 0.2244 – 0.0007 = 0.2237 cm

UCL for R -chart = (1.777)(0.0023) = 0.0041 cm and

LCL for R -chart = (0.223)(0.0023) = 0.0005 cm.

We observe that the process control limits in this case (sample size of 10) have become narrower compared to the previous one (when the sample size was 5). Why is it so?
The reason is that in the present case, even with twice the number of items (i.e. 10 instead of 5) in a sample, the mean range is the same (0.0023). The process is, therefore, tighter and hence the control limits also need to be tighter. A sample size is chosen with the rationale that the units within a sample have the greatest chance of being alike and the units between the samples have the greatest chance of being different. This being so, a larger sample size presumes that the variation is expected to be lower.

3. During the mechanised packaging of a drug into sachets, the net weight of the drug has to be a minimum of 20.0 gm. Process control charts are being used with a sample size of six each. The figures for the charts – both $\bar{x}$ and R charts are in control – have been as follows:
$\mu = 21.0$ and $\bar{R} = 1.2$
What is the ability of the process to meet the specification? As the Quality Control Manager what actions would you suggest?

Answer

The control limits for the $\bar{x}$-chart and R-chart are calculated. The relevant figures from the Appendix (Factors for Computing Control Chart Lines) for the sample size of 6, are:
$A_2 = 0.483$, $D_4 = 2.004$ and $D_3 = 0.000$
Hence, LCL = $\mu - A_2.\bar{R} = 21.0 - (0.483)(1.2) = 21.0 - 0.58 = 20.42$ gm
LCL is $3\sigma_{\bar{x}}$ removed from the centre-line. Hence, $\sigma_{\bar{x}} = 0.1933$
Which means, the specification limit of 20.0 is removed from the centre line (μ) by (21.0 –20.0) / 0.1933 standard deviations, i.e. 5.17 standard deviations. That means, the chances that a sample average will go below 20.0 is very low.
But, even this LCL will not tell us the entire story. It speaks about the sample averages (i.e. the sample of six sachets together and their average) and not about an individual sachet. Whereas, in order to meet the stringent quality specification, we ought to look at the individual sachet. For this, we need to obtain the $\sigma_{population}$.
$\sigma_{population} = (\sqrt{n})(\sigma_{\bar{x}}) = (\sqrt{6})(0.1933) = (2.4495)(0.1933) = 0.474$
Alternatively, $\bar{R} = 1.2 = d_2.\sigma_{population} = (2.534).\ \sigma_{population}$
Hence, $\sigma_{population} = 1.2 / 2.534 = 0.474$
Since the process is in control, we have to find cumulative probability of any individual unit containing less than 20.0 gm under a Standard Normal distribution of $\mu = 21.0$ gm and $\sigma = 0.474$ gm.
$z = (21.0 - 20.0) / (0.474) = 2.1097$

Hence, referring to the standard normal probability distribution table (Appendix II to Chapter 21) the area that goes below the specification limit of 20.0 gm is = 0.500 – 0.4825 = 0.0175 This means, there are chances of 35 sachets out of 2000 not meeting the specification. Therefore, as an abundant precaution, we may fix 6-sigma level. That is, the $\bar{x}$-chart's centre line should be 6-sigma removed from 20.0 gm, which amounts to 20.0 + (6)(0.474) = 22.844 or 22.8 (to the nearest single decimal). This should be the new centre line for the packaging process. Or alternatively, the packaging manager may reduce the Average Range of the process. Between 21.0 and 20.0, he has to fit in six sigmas. That is, the $\sigma_{\text{population}}$ should be below (1.0)/(6) or 0.1667. Which means, $\bar{R}$ should be down to $d_2.\sigma_{\text{population}}$ = (2.534)(0.1667) = 0.4225 or 0.4 gm approximately. This is less easy than the earlier alternative action of shifting the centre line. Because, here one is speaking about reducing the variation in a process, which is, of course, the ultimate goal in the control of quality.

4. In a production process of precision washers, a sample of 100 washers is checked every hour. The outer and inner diameters and the thickness are the three dimensions that are checked. However, after the check, the washer is categorized as either 'defective' or 'good'. The readings of this quality control process on particular day (24 hours) are as follows.

Hour No.	*Percent Defectives*	*Hour No.*	*Percent Defectives*
1	2	13	4
2	4	14	1
3	2	15	1
4	4	16	3
5	3	17	4
6	1	18	2
7	3	19	1
8	3	20	4
9	3	21	2
10	2	22	2
11	3	23	4
12	4	24	2

(i) Draw the control chart for the above.
(ii) Is the process currently in control?
(iii) If the Manager-Quality desires that there are no more than 5 per cent chances that percentage defectives in a sample exceeds 5 per cent, would the current process meet the Manager's desires?
(iv) If the Manager's requirement is not met, what should be the action plan to meet the requirement? Will the control chart be different?

Answer

(i) The above process calls for a *p*-chart or Fraction Defectives chart.
There are 24 hourly points and the average fraction defective is (0.64) / (24) = 0.0267
The variance of the fraction defective is = (0.0267)(1– 0.0267) / 100 = 0.0002599

Standard deviation is = √ (0.0002599) = 0.01612
The Upper Control Limit would be: 0.0267 + (3)(0.01612) = 0.0765 = 7.65%
The Lower Control Limit would be: 0.0267 – (3)(0.01612) = 0 = 0%

(ii) The process has not crossed the control limits during the 24 hours and hence it is in control.

(iii) 5 per cent or 0.0500 fraction defectives correspond to:
(0.0500 – 0.0267) / (0.01612) = 1.445 standard deviations.
Referring to the Standard Normal Distribution table, it corresponds to an area of 0.4258 between the mean (centre line) and the value of 0.05 per cent defectives.
That means, the point of 0.05 will be exceeded with a chance of (0.5 – 0.4258) (100) per cent = 7.42 per cent.
Current process does not meet the Manager's requirement (although it is 'in control'. Note that 'in control' only means that the process is functioning as usual).

(iv) If the Manager's requirements have to be met, then he will have to:

a) Investigate each of the variables, viz. outer diameter, inner diameter and thickness.

b) Investigate the reasons for the quality lapses in the variable/s that may be responsible for the lower quality. The reasons could be in the inputs or in the processes or in the measurement itself.

c) The detected reasons have to be attended to, i.e. have to be corrected.

d) The output quality has to be checked once again after carrying out the above corrections.

Basically, one has to reduce the average fraction defectives of the process by means of the above suggested actions. Hence, the centre line (average fraction defectives) and the control limits (+/- 3 std. deviations) will be different in the new statistical process control chart for fraction defectives.

5. Surgical tape is being coated in a coating range. The process is to continuously coat a surgical grade cloth with medicated masticated rubber solution and pass it through an oven in order to cure it. The cured tape is wound at the other end to be slit later into required sizes and rewound. The tape is inspected for a number of flaws such as black specs, loose threads, foreign particles, adhesive clots and uneven ends among others. Half-hourly quality checks are done on a random two meter length and the number of flaws is counted. The readings during a particular shift of 8 hours have been as furnished below.

Reading No.	*No. of Defects Detected*	*Reading No.*	*No. of Defects Detected*
1	10	9	5
2	2	10	12
3	9	11	14
4	14	12	3
5	12	13	10
6	1	14	4
7	10	15	2
8	10	16	10

What is the appropriate process control chart and what may be the control limits for the same?

Answer

The appropriate statistical process control chart for this process would be the 'number of defects'-chart or 'c'-chart.

Using the data given above, the total number of defects in the 16 readings is 128. The average number of defects = 128 / 16 = 8.

For a 'c'-chart, the centre line is the average number of defects $\bar{c}$.

Upper Control Limit UCL = $\bar{c} + 3\sqrt{\bar{c}} = 8 + 3\sqrt{8} = 8 + (3)(2.8284) = 16.49$

Lower Control Limit LCL = = $\bar{c} - 3\sqrt{\bar{c}} = 8 - 3\sqrt{8} = 8 - (3)(2.8284) = 0$

Note that since LCL is negative, it is taken as zero.

Check that the process is in control. We see that all the sixteen readings are within the UCL and LCL. Hence, the process is in control and we have a stable control chart.

6. In the previous problem, if the number of defects in Reading Numbers 11 and 13 had been 18 and 6, respectively, would the control chart have been different? If yes, what would be the centre line and the control limits?

Answer

The total number of defects for the 16 readings would have remained the same, i.e. 128. But, the Reading No. 11 would now fall outside the UCL of 16.49 and, therefore, it needs to be removed.

Now, for the remaining 15 readings, the total number of defects is 110, giving an average of 110 / 15 = 7.333. This is the centre line for the revised c-chart.

The UCL and LCL for the revised c-chart are as follows.

$$UCL = 7.333 + (3)(\sqrt{7.333}) = 15.457$$

$$LCL = 7.333 - (3)(\sqrt{7.333}) = 0$$

Now, all the 15 readings are within the revised control limits and hence, the revised control chart is a stable chart.

7. Nagarjun Works Limited makes precision turnings on a mass scale for the trawling industry which is booming. One of the main products made at Nagarjun has the following statistical process control parameters for the process means:

Mean: 3.4250 cm Upper Control Limit: 3.4258 cm and Lower Control Limit: 3.4242 cm.

The specification limits for this product are: 3.4263 cm and 3.4237 cm.

For the past one week, it is observed that the mean of the process has shifted to 3.4254 cm. However, the 'average range' of the prescribed sample consisting of 7 items has remained the same.

The company estimates that the cost of failure of the product is heavy at Rs. 250 per bad quality item since the costs of attending to customer complaints and its fallout are substantial. If 7,000 numbers of this item are being produced per day, what may be the estimate of cost savings (per day) in shifting the process mean to the original 3.4250 cm?

Answer

This problem deals with the $\bar{x}$ -chart.

Referring to the table for the factors, corresponding to a sample size of 7, the value of the factor A_2 is 0.419 and that of d_2 is 2.704.

Now $\quad UCL = \mu + A_2 \cdot \bar{R}$

Therefore, plugging in the available values: $3.4258 = 3.4250 + (0.419)(\bar{R})$

Therefore, $\bar{R} = 0.0008 / 0.419$

However, $\bar{R} = d_2 \cdot \sigma_{population}$

Hence, $(0.0008) / (0.419) = (2.704) \cdot \sigma_{population}$

Hence $\sigma_{population} = 0.000706$

Cost of Bad Quality in the Case where the Process Mean has Shifted

The fraction of items exceeding the specification limits can be found from the tenable assumption that the process is following a Normal distribution. The current mean is 3.4254. The upper specification limit (USL) is 3.4263 and is away from the mean by (3.4263 – 3.4254) / (0.000706) standard deviations (i.e. $\sigma_{population}$).

That is, $z = 1.2748$

Referring to the Standard Normal tables, this means, the USL will be overshot with a probability of 0.1012

The lower specification limit (LSL) is away from the mean by (3.4254 –3.4237) / (0.000706) standard deviations (i.e. $\sigma_{population}$).

That is, $z = 2.4079$

Referring to the Standard Normal tables, this means, the LSL will be overshot with a probability of 0.0080

Hence, every day the number of items overshooting the USL and LSL are:

$$(0.1012 + 0.0080) \cdot (7000) = 764.4$$

The cost of bad quality = (764.4) (Rs. 250) = Rs. 1,91,100

Cost of Bad Quality when the Process Mean has Not Shifted

That means, $\mu = 3.4250$

The USL and LSL are away from the Mean (μ) by (3.4263 – 3.4250) / (0.000706) standard deviations (i.e. $\sigma_{population}$).

That is, $z = 1.8414$

Referring to the Standard Normal tables, this means, the USL and LSL will be overshot each with a probability of 0.0326.

Hence, every day the number of items overshooting the USL and LSL are:

$$(0.0326 + 0.0326) \cdot (7000) = 456.4$$

The cost of bad quality = (456.4) (Rs. 250) = Rs. 1,14,100

The difference between Rs 191100 and Rs. 114100 is Rs. 77000 which is the amount saved per day on the given item if the process mean is restored to its original.

8. "Good Times" restaurant in the city of Patna has introduced quality control measures in running the restaurant. One such measure is to record the time of arrival and of the de-

parture of each guest (or the group of guests) on the bill. At the end of a day, five bills are randomly picked up and the "amount of time spent in the restaurant" for each of those bills (i.e. by the guests) is noted. For the last week, the following data were obtained.

Day	*Time Spent in Restaurant (minutes)*				
Sunday	55	63	73	84	75
Monday	46	41	88	53	59
Tuesday	82	89	65	77	37
Wednesday	30	48	27	43	77
Thursday	42	29	28	69	37
Friday	81	71	47	49	52
Saturday	87	59	92	81	95

(a) With these figures of the last week, construct the Sample Means ($\bar{x}$) and Ranges (R) charts.

(b) How will this quality control measure help Good Times restaurant?

Answer

(a) The last week's figures can be expressed in terms of the sample means and the sample ranges for the seven days of the week. We have the following:

Day	*Sample Mean ($\bar{x}$), minutes*	*Sample Range (R), minutes*
Sunday	70	29
Monday	57	47
Tuesday	70	52
Wednesday	45	50
Thursday	41	41
Friday	60	34
Saturday	84	34
Total	427	287

Therefore,

Mean of the Sample Means $\bar{\bar{x}} = 427 / 7 = 61$

Mean of the Ranges = $\bar{R} = 287 / 7 = 41$

For a sample size of 5, the factors are: $A_2 = 0.577$, $D_4 = 2.115$ and $D_3 = 0$

Hence, the $\bar{x}$ -chart will have UCL = $\bar{\bar{x}} + (0.577)\cdot\bar{R} = 61 + (0.577)(41) = 84.66$

LCL for the $\bar{x}$-chart is = $61 - (0.577)\cdot\bar{R} = 61 - (0.577)(41) = 37.34$

The R-chart control limits will be:

UCL for R-chart = $D_4\,\bar{R} = (2.115)(41) = 86.71$ and LCL = $D_3\,\bar{R} = 0$

We observe that the last week's figures are all within the control limits of the control chart

constructed above.

(b) It is indeed useful to know the average time a guest spends in the restaurant and what could be considered as a situation that warrants the restaurant manager's action. The manager of Good Times should also note that there is wide difference between the times spent by his restaurant's different customers. If it goes beyond the control limits of the ranges chart, he may have to look into it.

One may also look as to whether it will be okay to link the time spent by the guest and the bill amount, so that there is a financial angle brought into the picture. But, that depends upon the business model and the operations strategy employed by Good Times restaurant. One should note that the characteristics or determinants of 'quality' as defined by the management are a product of the organisation's strategy.

QUESTIONS FOR DISCUSSION

1. What is the role of statistics in quality control? Give examples of the situations where statistics is applicable and where it is not applicable.
2. How would you control quality in a job-shop situation (where one customer's order may be different from another's). How would you control quality in a bank ? In a restaurant ? Discuss.
3. How would you perceive the role of the Quality Control Manager in an organisation? In a manufacturing organisation Should the quality control function be separate from the line function of manufacturing? If yes, why? If no, why not? (Give an example as to where it need not be separate.)
4. What is the difference between the specification limits and the control limits?
5. What is the implicit assumption when we say 'the control limits fall within the range of specification limits'? When is this possible and when is it not?
6. For what kind of industries and products do you feel that statistical process control may not be quite applicable? Describe the different situations.
7. We have introduced a sampling procedure in order to simplify the statistical computations. Is it always possible to adopt such a sampling procedure in all industries?
8. What are the merits and demerits of 'narrow' band of control limits and of 'wider' band of control limits? Is it always necessary to use ± 3s limits for the control charts? (Why not ± 2s or just ± s ?)
9. Besides the examples given in this chapter, give examples of a few more situations where the *p*-chart and the *c*-chart can be used.
10. Under what conditions are the assumptions of a Poisson distribution valid for the *c*-chart?
11. Give an example of how quality planning is a part of the corporate planning process. Give an example from the service industry.
12. A particular equipment is quite old and gives wide fluctuations in quality. What can you do and not do to control quality in such circumstances?
13. In Vayuputra aircraft's landing gear assembly the defects are found as given in the table below.

Aircraft Number	*Serious "A"*	*Number of Defects Not so Serious "B"*	*Minor "C"*
1	–	–	5
2	–	1	4
3	–	1	–
4	1	–	2
5	–	2	1
6	–	–	3
7	–	–	3
8	–	–	9
9	–	1	6
10	–	–	1
11	1	–	3
12	–	–	1
13	–	2	–
14	–	4	2
15	–	–	–
16	–	1	4
17	–	1	6
18	1	1	3
19	–	–	4
20	–	–	2

If the weightages given for the different classes of defects are:

A	10
B	5
C	1

Construct appropriate stabilised control chart/charts for quality.

14. Following is the record of the defectives observed during the inspection process of an automatic machine producing small bolts of standard size.

Sample Number	*Sample Size*	*Number of Defective Bolts*
1	25	3
2	50	5
3	45	1
4	55	2
5	35	–

Contd.)

Sample Number	*Sample Size*	*Number of Defective Bolts*
6	40	1
7	50	9
8	65	2
9	30	3
10	25	2
11	55	5
12	40	4
13	50	3
14	25	2
15	40	2

(a) Find $\bar{p}$, UCL and LCL.
(b) Are the UCL and LCL constant?
(c) If not, what is the reason?
(d) Express the deviation from $\bar{p}$ (i.e. $p - \bar{p}$) in units of so many standard deviations. Draw the control chart.

15. The specifications for a product characteristic are: 0.3027 ± 0.008. The values given below are the last two figures of the dimension reading, that is, 23 means 0.3023. Sample Size n is 5.

Sample No.	$\bar{x}$	R
1	24	7
2	19	5
3	28	3
4	26	2
5	26	9
6	21	2
7	25	4
8	29	6
9	31	2
10	30	3
11	22	6
12	24	14
13	19	3
14	27	3
15	28	5
16	29	7
17	22	5
18	28	4
19	21	5
20	18	7

(a) Compute the trial control limits.
(b) Construct the stable control charts.
(c) Draw the specification limits on the chart and interpret your results. (Is the process able to satisfy the specifications?)

16. Bonnie Baby brand of baby powder is being packed in 400 g containers by an automatic filler. In order not to pack less powder into the container, the Bonnie Baby Powder Company sets a lower specification limit of 405 g. During the beginning of a packing run of 10,000 containers, the filling machine is set at 420 g. Twenty samples each of five containers were then collected, and the means and ranges for the samples were noted:

Sample No.	*Mean*	*Range*
1	414	10
2	408	12
3	418	9
4	415	8
5	407	9
6	405	3
7	411	3
8	413	10
9	413	5
10	419	7
11	425	12
12	421	8
13	416	8
14	410	6
15	414	5
16	419	3
17	422	11
18	415	10
19	410	2
20	405	5

(a) Is the initial setting okay? If not, what should it be? (Assume that the dispersion characteristics are not affected due to any change in the setting of the machine.) Set to the nearest 5 g.
(b) Suggest the control limits for this process. Explain your answer.



APPENDIX I

FACTORS FOR COMPUTING CONTROL CHART LINES

	Chart for Averages			Chart for Standard Deviations						Chart for Ranges						
Number of Observations in Sample, n	Factors for Control Limits			Factors for Central Line		Factors for Control Limits				Factors for Central Line			Factors for Control Limits			
	A	A_1	A_2	c_2	$1/c_2$	B_1	B_2	B_3	B_4	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
2	2.121	3.760	1.880	0.5642	1.7725	0	1.843	0	3.267	1.128	0.8865	0.853	0	3.686	0	3.276
3	1.732	2.394	1.023	0.7236	1.3820	0	1.858	0	2.568	1.693	0.5907	0.888	0	4.358	0	2.575
4	1.501	1.880	0.729	0.7979	1.2533	0	1.808	0	2.266	2.059	0.4857	0.880	0	4.698	0	2.282
5	1.342	1.596	0.577	0.8407	1.1894	0	1.756	0	2.089	2.326	0.4299	0.864	0	4.918	0	2.115
6	1.225	1.410	0.483	0.8686	1.1512	0.026	1.711	0.030	1.970	2.534	0.3946	0.848	0	5.078	0	2.004
7	1.134	1.277	0.419	0.8882	1.1259	0.105	1.672	0.118	1.882	2.704	0.3698	0.833	0.205	5.203	0.076	1.924
8	1.061	1.175	0.373	0.9027	1.1078	0.167	1.638	0.185	1.815	2.847	0.3512	0.820	0.387	5.307	0.136	1.864
9	1.000	1.094	0.337	0.9139	1.0942	0.219	1.609	0.239	1.761	2.970	0.3367	0.808	0.546	5.394	0.184	1.816
10	0.949	1.028	0.308	0.9227	1.0837	0.262	1.584	0.284	1.716	3.078	0.3249	0.797	0.687	5.469	0.223	1.777
11	0.905	0.973	0.285	0.9300	1.0753	0.299	1.561	0.321	1.679	3.173	0.3152	0.787	0.812	5.534	0.256	1.744
12	0.866	0.925	0.966	0.9359	1.0684	0.331	1.541	0.354	1.646	3.258	0.3069	0.778	0.924	5.592	0.284	1.719
13	0.832	0.884	0.249	0.9410	1.0627	0.359	1.523	0.382	1.618	3.336	0.2998	0.770	1.026	5.646	0.308	1.692
14	0.802	0.848	0.235	0.9453	1.0579	0.384	1.507	0.406	1.594	3.407	0.2935	0.762	1.121	5.693	0.329	1.671
15	0.775	0.816	0.223	0.9490	1.0537	0.406	1.492	0.428	1.572	3.472	0.2880	0.755	1.207	5.737	0.348	1.652
16	0.750	0.788	0.212	0.9523	1.0501	0.427	1.478	0.448	1.552	3.532	0.2831	0.749	1.285	5.779	0.364	1.636
17	0.728	0.762	0.203	0.9551	1.0470	0.445	1.465	0.466	1.534	3.588	0.2787	0.743	1.359	5.817	0.379	1.621
18	0.707	0.738	0.194	0.9576	1.0442	0.461	1.454	0.482	1.518	3.640	0.2747	0.738	1.426	5.854	0.392	1.608
19	0.688	0.717	0.187	0.9599	1.0418	0.477	1.443	0.497	1.503	3.689	0.2711	0.733	1.490	5.888	0.404	1.596
20	0.671	0.697	0.180	0.9619	1.0396	0.491	1.433	0.510	1.490	3.735	0.2677	0.729	1.548	5.922	0.414	1.586

Contd.)

	Chart for Averages			Chart for Standard Deviations						Chart for Ranges						
Number of Observations in Sample, n	Factors for Control Limits			Factors for Central Line		Factors for Control Limits				Factors for Central Line			Factors for Control Limits			
	A	A_1	A_2	c_2	$1/c_2$	B_1	B_2	B_3	B_4	d_2	$1/d_2$	d_3	D_1	D_2	D_3	D_4
21	0.655	0.679	0.173	0.9638	1.0376	0.504	1.424	0.523	1.477	3.778	0.2647	0.724	1.606	5.950	0.425	1.575
22	0.640	0.662	0.167	0.9655	1.0358	0.516	1.415	0.534	1.466	3.819	0.2618	0.720	1.659	5.979	0.434	1.566
23	0.626	0.647	0.162	0.9670	1.0342	0.527	1.407	0.545	1.455	3.858	0.2592	0.716	1.710	6.006	0.443	1.557
24	0.612	0.632	0.157	0.9684	1.0327	0.538	1.399	0.555	1.445	3.895	0.2567	0.712	1.759	6.031	0.452	1.548
25	0.600	0.619	0.153	0.9696	1.0313	0.548	1.392	0.565	1.435	3.931	0.2544	0.709	1.804	6.058	0.459	1.541
Over 25	$\frac{3}{\sqrt{n}}$	$\frac{3}{\sqrt{n}}$	–	–	–	†	*	†	*	–	–	–	–	–	–	–

Source: W.G. Ireson and E.L. Grant (Eds), *Handbook of Industrial Engineering and Management*, Prentice-Hall of India, New Delhi, 1977 (2nd edn.).

$$\dagger 1 - \frac{3}{\sqrt{2n}} \qquad * 1 + \frac{3}{\sqrt{2n}}$$

Note: $A = \frac{3}{\sqrt{n}}, A_1 = \frac{3}{c_2\sqrt{n}}, A_2 = \frac{3}{d_2\sqrt{n}}$

$$B_1 = c_2 - K, B_2 = c_2 + K, B_3 = 1 - \frac{K}{c_2}$$

$$B_4 = 1 + \frac{K}{c_2}, \quad \text{and } K = 3\sqrt{\frac{(n-1)}{n} - c_2^2}$$

$$D_1 = d_2 - 3d_3, D_2 = d_2 + 3d_3,$$

$$D_3 = 1 - 3\frac{d_3}{d_2} \text{ and } D_4 = 1 + 3\frac{d_3}{d_2}$$

The different factors are used for different situations as given below:

For x-chart: UCL_x and $LCL_x \equiv \bar{x}_{pop} \pm A \cdot \sigma_{pop}$ where $\bar{x}_{pop}$ and σ_{pop} are the mean and std. devn. of the population of individual observations,

For $\bar{x}$ -chart: $UCL_{\bar{x}}$ and $LCL_{\bar{x}} \equiv \bar{\bar{x}} \pm A_1 . \bar{\sigma}$ where $A_1 = 3/\sqrt{n}\ c_2$ and $\bar{\sigma} = c_2 \cdot \sigma_{pop}$; also,

$UCL_{\bar{x}}$ and $LCL_{\bar{x}} \equiv \bar{\bar{x}} \pm A_2 \cdot \bar{R}$ where $A_2 = 3/\sqrt{n}\ d_2$ and $\bar{R} = d_2 \cdot \sigma_{pop}$

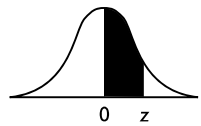
For σ-chart: $UCL_\sigma = B_2 \cdot \sigma_{pop}$ and $LCL_\sigma = B_1 \cdot \sigma_{pop}$; also, $UCL_\sigma = B_4 \cdot \bar{\sigma}$ and $LCL_\sigma = B_3 \cdot \bar{\sigma}$; central line is $\bar{\sigma}$.

For R-chart: $UCL_R = D_2 \cdot \sigma_{pop}$ and $LCL_R = D_1 \cdot \sigma_{pop}$; also, $UCL_R = D_4 \cdot \bar{R}$ and $LCL_R = D_3 \cdot \bar{R}$; central line is $\bar{R}$.

APPENDIX II

AREAS UNDER THE STANDARD NORMAL PROBABILITY DISTRIBUTION

Values in the table represent the proportion of area under the normal curve between the mean ($\mu = 0$) and positive value of z.



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2703	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3780	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990

Source: R.G. Schroeder, *Operations Management—Decision Making in the Operations Function,* McGraw-Hill, International Student Edn, 1985.

10 Quality Management—II

In Chapter 9 we discussed the control of the processes operating on input materials. In addition to these one also has to control **(i)** the incoming raw material quality, and **(ii)** the finished goods quality. This is done by means of the statistical procedure called 'acceptance sampling'.

ACCEPTANCE SAMPLING

This statistical sampling procedure purports to answer questions such as: **(i)** are the supplier's goods to be accepted or rejected? **(ii)** if accepted, what kind of risk do we incur in terms of bad quality? **(iii)** should the batch, which has been manufactured in our plant, be shipped outside to the customers or not? We are speaking about mass-scale procurement of raw material and of mass-scale shipment of finished goods, and hence the use of statistical sampling procedure in answering the accept/reject question.

Why it is not possible to check all items, instead of sampling? The answers are simple. **(i)** The cost of 100% inspection is prohibitive in most cases. **(ii)** Many of the acceptance tests require destructive testing of the item, and therefore a sampling procedure is a must in such cases. **(iii)** Also, 100% inspection does not necessarily ensure 100% quality. Inspection cannot be relied on to ensure that all accepted products are of good quality. The 'inspection-fatigue' with repeated inspection operations will very often limit the effectiveness of the inspection. In fact, total inspection (100% inspection) may lead, many a time, to less quality than if partial inspection were resorted to. **(iv)** The acceptance sampling procedure either accepts or rejects the incoming lot in total. Such an outright rejection of the lot by the consumer often results in remarkable quality improvements on the supplier side. This is an important motivational factor operating in acceptance sampling. **(v)** Less than 100% sampling makes the inspector carrying out the sampling inspection more responsible towards his job, because a mistake in calling an item good or bad may decide the acceptance or rejection of an entire consignment rather than that of only one item. This greater responsibility forces Inspectors to do a better job of inspection. Of course, the earlier mentioned factor of less inspection-fatigue in a sampling procedure also helps in improving the quality of the inspection procedure itself. These are some of the advantages of the sampling procedure.

One must, however, add that in certain types of products 100% inspection is unavoidable. For instance, Nuclear Power Plant equipment and accessories to the smallest valve or conduit need

to be inspected for quality on a 100% basis. We cannot afford to take a sample and based on that accept a consignment, because, however tight a sampling procedure, there is still, a chance that few defective items might enter into the nuclear power plant. Only a 100% inspection, with due consideration to the fatigue problem can ensure the requirements of a nuclear power plant. We can also quote instances from the pharmaceutical industry, where in many cases 100% inspection of the drug items becomes essential.

Figure 10.1 illustrates the case of 100% sampling where the lots are rejected if the proportion of defectives is greater than 3%.

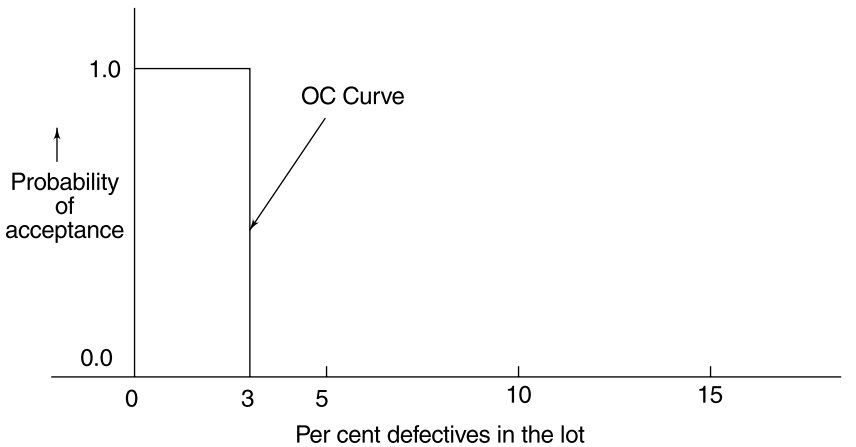


Figure 10.1 Operating Characteristics (OC) Curve for 100% Sampling

When the fraction defectives is less than 0.03, the probability of acceptance is 1.00, and if it is more than 0.03, the probability of acceptance is 0 (zero). Such a diagram, which represents the probability of acceptance with respect to the proportion of defectives in the lot, is called the Operating Characteristics Curve.

ACCEPTANCE SAMPLING PLAN

Such a clear-cut acceptance or rejection of the lot (i.e. probability of acceptance of 1.00 or 0) is not possible when we resort to a sampling procedure. The sampling procedure consists of taking a small sample comprising n number of items from a consignment of N number of items and accepting the consignment only if the number of defective items in the sample is less than or equal to a cut-off number c or else rejecting the consignment. The acceptance sampling plan is therefore expressed as: (N, n, c). The number c is called in technical language as the 'acceptance number'. In using the acceptance sampling plan, there is a finite probability that the lot may be accepted even if the quality is not really good; also, conversely, the lot may be rejected even if the quality is actually good. The first type of risk is called the "consumer's risk" and the second type of risk is called the 'producer's risk'. In the operating characteristics curve (hereafter abbreviated as OC curve) for 100% sampling these risks were each zero, whereas, for any other sampling procedure, there exist finite quantities of both these risks.

An OC curve is typical of a particular sampling plan. Different sampling plans give rise to different OC curves. Figure 10.2 shows an OC curve for the sampling plan indicated therein.

The sampling plan, which generates the corresponding OC curve, is a negotiated plan, i.e. an agreement explicit or implicit is reached between the vendor and the buying company. The producer's risk corresponding to an Acceptable Quality Level (AQL) is what the vendor is interested in. The consumer's risk corresponding to another target—the Lot Tolerance Percent Defective (LTPD)—is what the buying company is interested in. An appropriate sampling plan is one which satisfies both these conditions. Figure 10.2 shows these risks and the corresponding AQL and LTPD points.

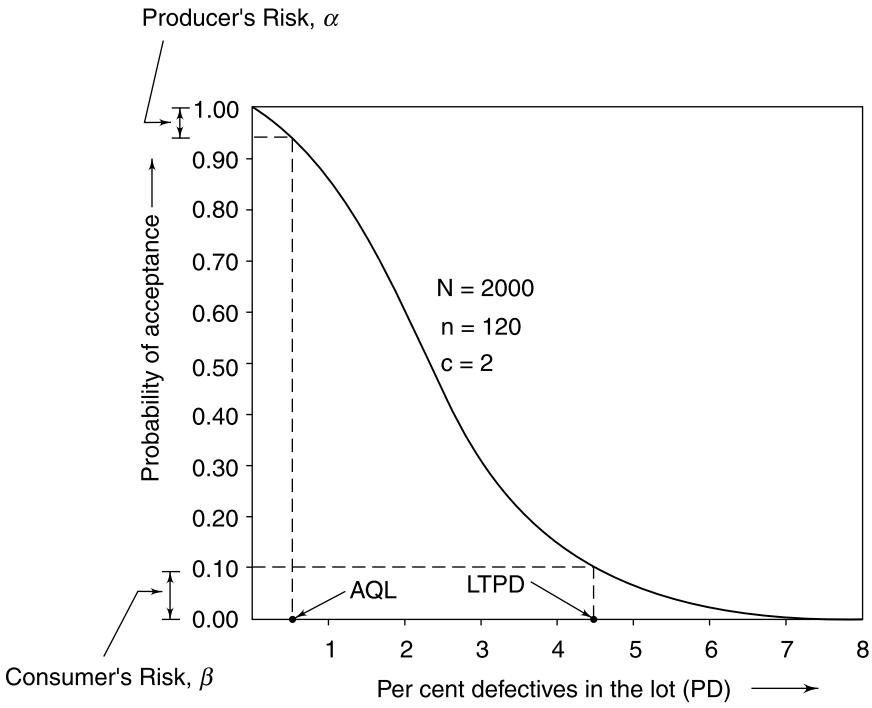


Figure 10.2 An OC Curve

In judging a particular acceptance sampling plan, it will also be necessary to know its performance over a length of time for various possible actual quality levels in the incoming consignment of materials. The OC curve provides us with a complete picture of the various probabilities of acceptance vis-a-vis the possible quality levels of the incoming materials. For any given fraction defective in a lot, the OC curve indicates the probability that such a consignment will be accepted under the given sampling plan. The OC curve indicates, therefore, what percentage of the submitted lots will be accepted 'in the long run of time' if a large number of lots of a particular quality were submitted for quality inspection.

Example Let us illustrate the construction of the OC curve by means of the following example. Suppose the consignment or lot consisted of 100 items with a percentage defective of 3%; let us

have a sample size of 10 items and a decision rule that the lot will be accepted only if the number of defective items in the sample is 1 or less than 1 defective item. We can calculate the different points on the OC curve by taking recourse to the probability theory. The probability of acceptance of the consignment will be

$$P\ (0 \text{ or } 1 \text{ defective}) = P(0) + P(1)$$

Now, in general, we have

$$P(b) = \frac{C_b^B C_g^G}{C_n^N}\ , \text{where } C_b^B = \frac{B!}{b!\left(B-b\right)!}$$

where B = Number of defective items or bad items in the lot

G = Number of good items in the lot

b = Number of bad items in the sample

g = Number of good items in the sample

N = Lot size or the number of items in the lot

n = Sample size or the number of items in the sample.

Therefore for our example, we get

$$P\ (0) = \frac{C_0^3 C_{10}^{97}}{C_{10}^{100}} = 0.7265$$

and

$$P(1) = \frac{C_1^3 C_9^{97}}{C_{10}^{100}} = 0.2477$$

Therefore, $P\ (0 \text{ or } 1) = 0.7265 + 0.2477 = 0.9742$

By such calculations for different values of the proportion of defectives in the lot, the corresponding values of the probabilities of acceptance can be arrived at. If these values are plotted against each other, we get the Operating Characteristics Curve for the sampling plan (100, 10, 1).

For different sampling plans there will be different OC curves. If the acceptance number c is smaller, then the OC curve will be tighter, which means there will be more rejections of the lot for the same percentages of defectives in the lot. If the sample size n is more, again the OC curve is tighter, because, we should expect a better insight into the quality of the lot based on a larger sample. Even sampling plans with the same ratio of n: c, will show a steeper slope of the OC curve (i.e. greater ability to discriminate between the consignments of different qualities) with larger values of the sample size. Figure 10.3 illustrates this.

In choosing an appropriate sampling plan corresponding to the negotiated consumer's and producer's risks, we need to locate the OC curve passing through the two AQL—producer's risk and LTPD—consumer's risk points. For this, the procedure indicated earlier (using hyper-exponential distribution) is quite cumbersome. But fortunately, the Poisson Distribution provides a good approximation where the lot size N is very large, the sample size n is also large, the per cent defectives is near zero and sampling is done without replacement. Most of the practical situations can satisfy this requirement fairly well.

Let us apply this approximation to the example worked out earlier. The problem is to compute the probability of finding 1 or less defectives in the sample. The Poisson occurrence is about the number of defectives in the sample, the mean value of which is np where p is the average fraction

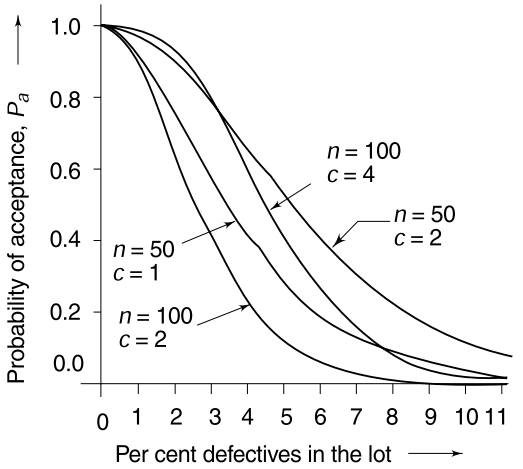


Figure 10.3 Effect of Parameters on the OC Curve

defectives in the lot and n is the sample size. The mean value in our example is: $10 \times 0.03 = 0.3$. As per the Cumulative Poisson Distribution table, the probability of 1 or less number of defectives in the sample is given as: 0.963.

Comparing this with the earlier answer of 0.974, poisson distribution gives a fairly acceptable fit. We can, therefore, construct the OC curve by making use of the cumulative poisson distribution tables. Different assumed sampling plans (n, c combinations) can be checked to see if any one passes through both the points of negotiated risks. That one would be the appropriate sampling plan. Please note that under this approximation, it is not necessary to mention the lot size in the Sampling Plan as it is very very large and therefore irrelevant; value of n and c are sufficient.

Use of Tables

To simplify the procedure further and to eliminate the trial-and-error calculations, one may resort to the special tables constructed. An illustrative table is given in Appendix I to this chapter. The table gives np (sample size × fraction defectives) values corresponding to c values and typical Producer's and Consumer's Risks. We shall work out an example.

Example The negotiated consumer's and producer's risks, corresponding to LTPD of 10% and AQL of 1%, are 10% and 5% each. What sampling plan would achieve this result?

$$\frac{p_{0\cdot10}}{p_{0\cdot95}} = \frac{0.10}{0.01} = 10$$

Therefore, $c = 1$ gives the best fit.

Now, as per the table (Appendix I), the sample size can be calculated at the producer's risk point: $np_{0.95} = 0.355$

That is, $$n = \frac{0.355}{0.01} = 35.5 = 36$$

Answer: The sampling plan is (36, 1).

CONCEPT OF AVERAGE OUTGOING QUALITY LIMIT (AOQL)

Sometimes the risk to the consumer is viewed differently—in terms of the average percentage of defective materials entering into the consumer's company due to the sampling plan. We know that on the basis of a sampling plan a lot is either rejected or accepted. If rejected, it undergoes 100% inspection at the supplier's or the consumer's plant before its acceptance. The bad quality entering the consumer's plant due to rejection of a lot is zero. The real danger to the incoming quality is from the accepted lots. At any value of per cent defectives in the lot, there is a corresponding probability of acceptance of the lot. The defectives entering into the plant, due to the acceptance of the lot, are:

(Probability of Acceptance, P_a) × (Per cent Defectives in the lot, p)

This is the Average Outgoing Quality (AOQ) in technical language. For each possible value of p there is a corresponding AOQ value. Since we do not know the quality of raw material the supplier may supply us, we are interested in knowing the maximum value of AOQ, which is called the Average Outgoing Quality Limit (AOQL). This is the maximum risk the company (consumers) is exposed to under the given sampling plan.

Example The probabilities of acceptance of the lots (of uniform size), under an acceptance sampling plan, are given as follows:

Actual Per cent Defectives in the Submitted Lots	*Probability of Acceptance*
1.2	0.731
1.4	0.650
1.6	0.570
1.8	0.494
2.0	0.423
2.5	0.278
3.0	0.174
3.5	0.106
4.0	0.062
5.0	0.020
6.0	0.006

What maximum bad quality can enter the plant, under this sampling plan?

Solution: It is required to calculate the AOQL under this sampling plan because AOQL is the maximum limit of the bad quality entering into the plant.

The computations of Average Outgoing Quality (AOQ) from the given data are shown below:

Actual Per cent Defectives in the Submitted Lots (p)	*Probability of Acceptance (P_a)*	*Average Outgoing Quality ($AOQ = P_a \times p$)*
1.2	0.731	0.8772
1.4	0.650	0.9100
1.6	0.570	0.9120
1.8	0.494	0.8892
2.0	0.423	0.8460
2.5	0.278	0.6950
3.0	0.174	0.5220
3.5	0.106	0.3710
4.0	0.062	0.2480
5.0	0.020	0.1000
6.0	0.006	0.0360

Therefore, the Average Outgoing Quality Limit (AOQL) is 0.9120. This is the maximum risk to which the plant is exposed under the given sampling plan. The above figures are graphically shown in Fig. 10.4.

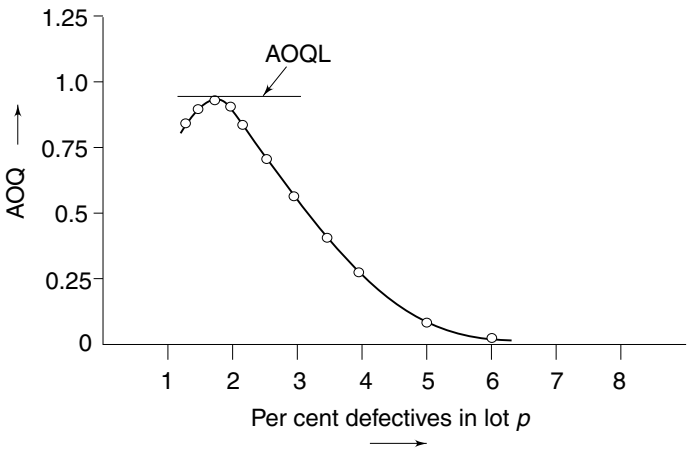


Figure 10.4 Average Outgoing Quality Limit for the Sampling Plan given in the Example

The AOQL values will be different for different sampling plans.

Dodge–Romig Tables for Acceptance Sampling

Dodge and Romig have constructed very useful Sampling Inspection Tables. Lot size, sample size *n*, acceptance number *c*, AOQL, average defectives in the lot (process average %), LTPD and consumer's risk are the different parameters. One set of tables have AOQL as constant and various sampling plans in that table give the same AOQL. In another set, the LTPD and Consumer's Risk values

are constant, and various sampling plans in that set correspond to the given LTPD—Consumer's Risk values. One important characteristic of the Dodge-Romig tables is that, these tables give sampling plans with minimum average total inspection. The average total inspection is given by: $n + (1 - P_a)(N - n)$. The probability of acceptance is different for various possible values of the per cent defectives in the lot. The values of the average total inspection under different sampling plans have been considered and the sampling plan giving minimum value is given in these tables.

These and similar other statistical quality control tables have simplified the computations considerably. Illustrative Dodge–Romig tables are presented in Appendices II to V of this chapter.

In the earlier discussion, the sampling procedure consisted of taking only one sample and making an acceptance/rejection decision based on that sample. There are other types of sampling plans where two or more samples may be taken in order to arrive at an accept/reject decision. These are called 'Double Sampling' and 'Sequential Sampling' respectively.

Double Sampling

The double sampling procedure consists of taking first a sample of size n_1 and inspecting it for defectives. If the number of defectives is less than or equal to cut-off number c_1 then accept the lot, if they are more than c_2, reject the lot. If the number of defectives are in between c_1 and c_2 then take another sample of a different size n_2. If the number of defectives in the combined sample of $n_1 + n_2$ is less than or equal to c_2, accept the lot; otherwise reject it. A diagrammatic representation of the double sampling plan is given in Fig. 10.5.

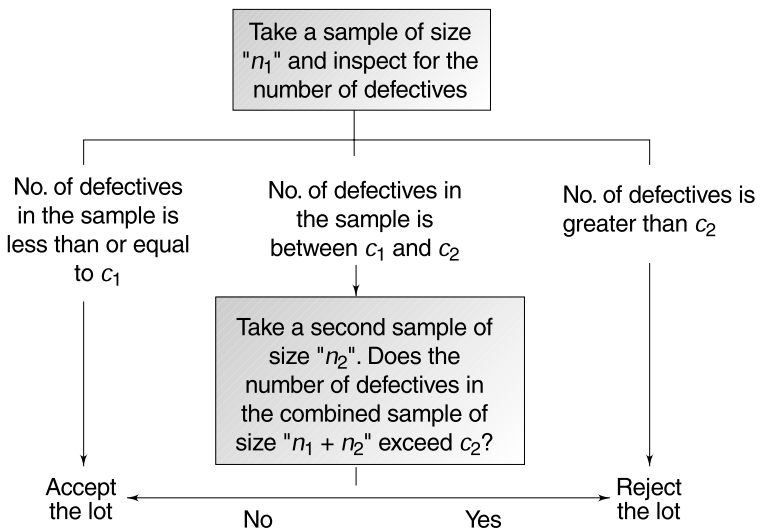


Figure 10.5 Double Sampling Procedure

Sequential Sampling

A natural extension of the doubling sampling procedure is sequential sampling. A sample of size n_1 is taken and, based on cut-off points, the decision alternatives are **(i)** to reject, **(ii)** to accept the lot, and **(iii)** to continue with one more sample. The samples are accumulated at each subsequent stage and based on different cut-off points at each stage a choice among the three decision alternatives is made. The procedure is continued till a decision to either accept or reject the lot is reached. For example, a sequential sampling plan could be as shown in Table 10.1.

Table 10.1 An Illustrative Sequential Sampling Plan

Lot Size	*Cumulative Sample Size*	*Acceptance Number*	*Rejection Number*
	40	0	5
	60	1	6
800 to	80	2	7
1299	100	3	8
	120	5	9
	160	9	10

The same table can be pictorially represented as shown in Fig. 10.6.

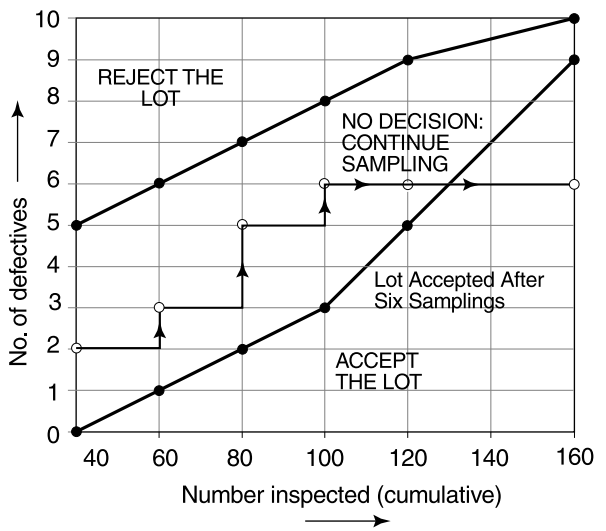


Figure 10.6 Sequential Sampling Plan (as given in Table 10.1) (Also depicts a lot being accepted after six samplings)

Merits of Sequential or Double Sampling Plans

One of the possible advantages in the double or sequential sampling procedures is that, if a lot is very bad or if it is very good, it can be either rejected or accepted with small initial sample/samples. Any lot which cannot be decided easily, can be examined further by means of additional sample/samples. Therefore, in some cases, the multiple sampling procedures provide short-cuts to the decision without jeopardising the incoming/outgoing quality of material. In such cases, obviously, the inspection load is reduced as compared to the single sampling procedure. But this may not always be true. If the process average of defectives in the lot supplied by the vendor varies considerably, the inspection load under the multiple sampling procedures might also vary appreciably. In such a case, the advantage claimed above for the multiple sampling procedures may no longer be valid, unless there is some other way of utilising the inspection manpower when the workload on inspection is low. There is one psychological advantage with the double or sequential sampling procedures—people may feel more secure with the idea of providing a second or third chance to the lot of material before it is rejected. Otherwise, for the incoming lots with per cent defectives level close to the acceptance quality level, the single sampling procedures may be more economical than double or sequential sampling.

Dodge and Romig have also come up with sampling tables for Double Sampling. These tables are of two categories: **(i)** providing protection in terms of AOQL, and (ii) LTPD with certain consumer's risk.

Dodge–Romig Tables for Double Sampling

In order to use the former (AOQL) table, one needs to know **(a)** the lot size supplied by the vendor, **(b)** the process average percentage of the defectives in the lots supplied by the vendor, and (c) the AOQL protection desired by the company for that material. Once these are known, the values of the recommended first and second sample size and the two different cut-off points as well as the corresponding LTPD protection available under the plan can all be read off from the tables. An example of a Dodge-Romig table for the AOQL protection is given in the Appendix to this chapter. For instance, if the maximum risk in terms of the AOQL is taken as 2%, the lot size is 1,500 items, and the process average of defectives is 1.5%, then the table recommends the following sampling plan:

$n_1 = 80$, $c_1 = 1$, $n_2 = 160$, $(n_1 + n_2) = 240$, and $c_2 = 8$

The value of LTPD corresponding to 10% consumer's risk can also be read off as 5.8.

The latter category of Dodge-Romig table can be used if one knows **(i)** LTPD with corresponding desired consumer's risk, **(ii)** the process average percent defectives, and **(iii)** the lot size as supplied by the vendor. An example of such a Dodge-Romig table for Double Sampling is also furnished in the Appendix to this chapter. Let us have LTPD = 5% and corresponding consumer's risk = 10%. Let the lot-size and process average be 1,500 and 1.5% respectively. The table gives the following sampling plan:

$n_1 = 90$, $c_1 = 1$, $n_2 = 185$, $n_1 + n_2 = 275$, and $c_2 = 8$

The corresponding AOQL protection available under the plan is 1.7%. The reader may check the similarity of values in the sampling plans for AOQL protection and LTPD protection as found in these paragraphs.

In addition to the Dodge-Romig tables other useful tables for acceptance sampling, such as MIL-STD-105 and Sequential Sampling Tables are available. These tables have simplified the working of acceptance sampling procedures.

So far, we have implicitly assumed that, other than a few exceptional cases, acceptance sampling procedures are a must. It is advisable to make some comparisons of costs of inspection and costs of reworking when the defective parts are incorporated into the finished or semifinished product. These comparisons can be utilised to decide whether we should go in for a 100% inspection, or no inspection, or a sampling inspection.

The earlier discussion focused on the use of statistical methods to control quality. Although statistical quality control is an important aspect of quality management, it is only a part of the comprehensive quality management function. It is one of the tools/techniques useful for quality management. Comprehensive quality management has to deal with organisation, costs, motivation, communication, planning, and monitoring aspects of the management function as well. Unless these various aspects of the quality management effort are properly attended to, the tools of statistical methods will have a limited effect on the functioning of the quality management process.

Acceptance Sampling for Services

Just as in production the materials are checked for acceptance (or delivery), there are service inputs (or outputs) that need to be checked for consistency of quality. While in the service context a rejection of a batch is not possible, a future rejection of such inputs or relevant rectification action on such inputs obtained from suppliers is very much in the realm of possibility. It helps in the management of suppliers. Acceptance sampling could be 'by variables' or 'by attributes (which monitors percent defeectives as discussed in this chapter)'. Since a statistical technique is being used, the service input monitored will be of a kind that is repeatedly provided by the supplier.

MANAGING QUALITY

Since each functional department has a contribution to make towards quality, it is imperative that the entire quality management effort be properly organised to coordinate the various contributing aspects to quality. Without such coordination, there may be chaotic situation, and although quality is everybody's business, it may become nobody's business. Therefore, quality management should be a separate function headed by a person quite high in the organisational hierarchy so as to facilitate the coordination of the various contributing functions to quality. And, not only should the Quality Manager belong to the top management, but the entire top management should be committed to quality.

Quality Planning

Just as in any management process, quality management also has three main components: **(a)** planning, **(b)** implementation, and **(c)** monitoring and control. The planning part of quality management, "quality planning" should deal with the following aspects:

1. To set quality objectives and targets and take into account customers' wants and the marketability of the products, etc.
2. To carry out pre-production process capability or quality deliverability studies (to find out whether the company is capable of producing and marketing the products of certain quality).
3. To establish the relative importance of the quality characteristics and specifications, and communicate it to the production line people as well as to the vendors supplying the raw materials. Specifications and drawing *per se* can never communicate what that particular specification stands for and why.
4. To look after various vendor quality control aspects such as examining new vendor facilities, their procedures and systems, setting up of the vendor rating scales and periodic performance evaluation of the vendors.
5. To establish statistical control techniques, charts and sampling plans.
6. To establish training programmes for various personnel in the company so that quality consciousness gains a firm ground in the organisation.

In short, designing the desired and deliverable quality standards is the job of quality planning.

Quality Implementation

The implementation part of quality management deals with:

1. Performing laboratory tests and analysis on the raw materials, finished products, and the semi-finished products for acceptance/rejection or for process control.
2. Maintaining quality control equipment (Process, Laboratory and Inspection).
3. Advising and providing assistance for the clarification and solution of quality management problems in manufacture.

Quality Monitoring and Control

The monitoring and control function deals with:

1. Appraising the quality plan vis-a-vis the problems of production and the problems of vendor quality, so that appropriate action is taken to correct the initial planning errors.
2. Appraising quality planning vis-a-vis the actual quality which has reached the customer and what the latter's reaction is regarding the product quality; how such reactions can be set right by modifications to the original quality plan.
3. In addition to performing quality audits, monitoring the costs of quality and providing such information to the quality-planners so that they take appropriate action for the future.

Integration of Planning, Implementation and Control Feedback

The organisation for quality should ensure that the planning, implementation, monitoring and control feedback cycle is properly facilitated. This is an important point. Since quality control is everybody's business, the organisation for quality should be so structured that in making quality everybody's concern it does not lead to a chaotic situation. In spite of the fact that many functional departments are involved in the maintenance of quality, the integrity of the management feedback

cycle should be maintained for effective quality management. One may delegate certain quality management tasks to particular departments. For instance, one may assign the urgent in-process testing and inspection work to the shopfloor people. But certain important considerations must predominate to make this decentralisation effective enough, e.g. **(a)** the quality management personnel should periodically check the degree or strictness to which the in-plant quality control procedures are being followed; **(b)** they should also check periodically or continuously the finished-product quality; **(c)** the quality management department should provide competent technical support to the shopfloor people in helping them to solve day-to-day quality problems; and **(d)** the inspectors on the shopfloor should have been trained sufficiently to perform their jobs. These are some of the precautions which need to be taken for the decentralization of the quality manageent effort. Whenever there is such delegation, a tight control by quality management is necessary.

Organisation

The organisation of quality management should be such that it is not a combination of bits and pieces of responsibilities assigned to different departments; rather, quality management should be a responsibility which is properly organised and which can be properly located. This leads us to the maintenance of a separate functional department for quality management, with its top man ranking high in the organisational hierarchy. The next in the hierarchy to the top man for quality management should subdivide the work along the specialised skills required in carrying out the jobs. Therefore, if it is the work of looking after different product-lines or if it is the specialised work of looking after different functional specialists within the organisation, these special tasks should be assigned to specialist personnel. The organisation for quality management should, as far as possible, comprise a large span-of-control and few levels of hierarchy. This is necessary to maintain quick feedback of information.

A wide span-of-control is necessary, since a high degree of specialisation is very desirable in quality management.

The following points may be remembered in organising for quality.

1. To ensure that the integrity of the planning-implementing-monitoring and control feedback cycle is maintained in the total organisation for quality.
2. Wherever the responsibility of quality management is to be delegated to different departments, it should be done with many precautionary measures whereby the monitoring and control is in the hands of the quality management people.
3. To maintain high quality standards, it is necessary that quality management should have top-management support. Therefore the highest person in quality management should be of the same level or a level below that of the top-most management of the company.
4. The hierarchy structure of quality management should be kept to as few levels as possible. The span-of-control should be as broad as possible. The division of responsibility at the second or third level of quality management organisation should be based on the needs of specialised skills, either productwise, functionwise, or techniquewise. Figure 10.7 is an example of an organisational structure for quality management in a large organisation with a number of product-lines.

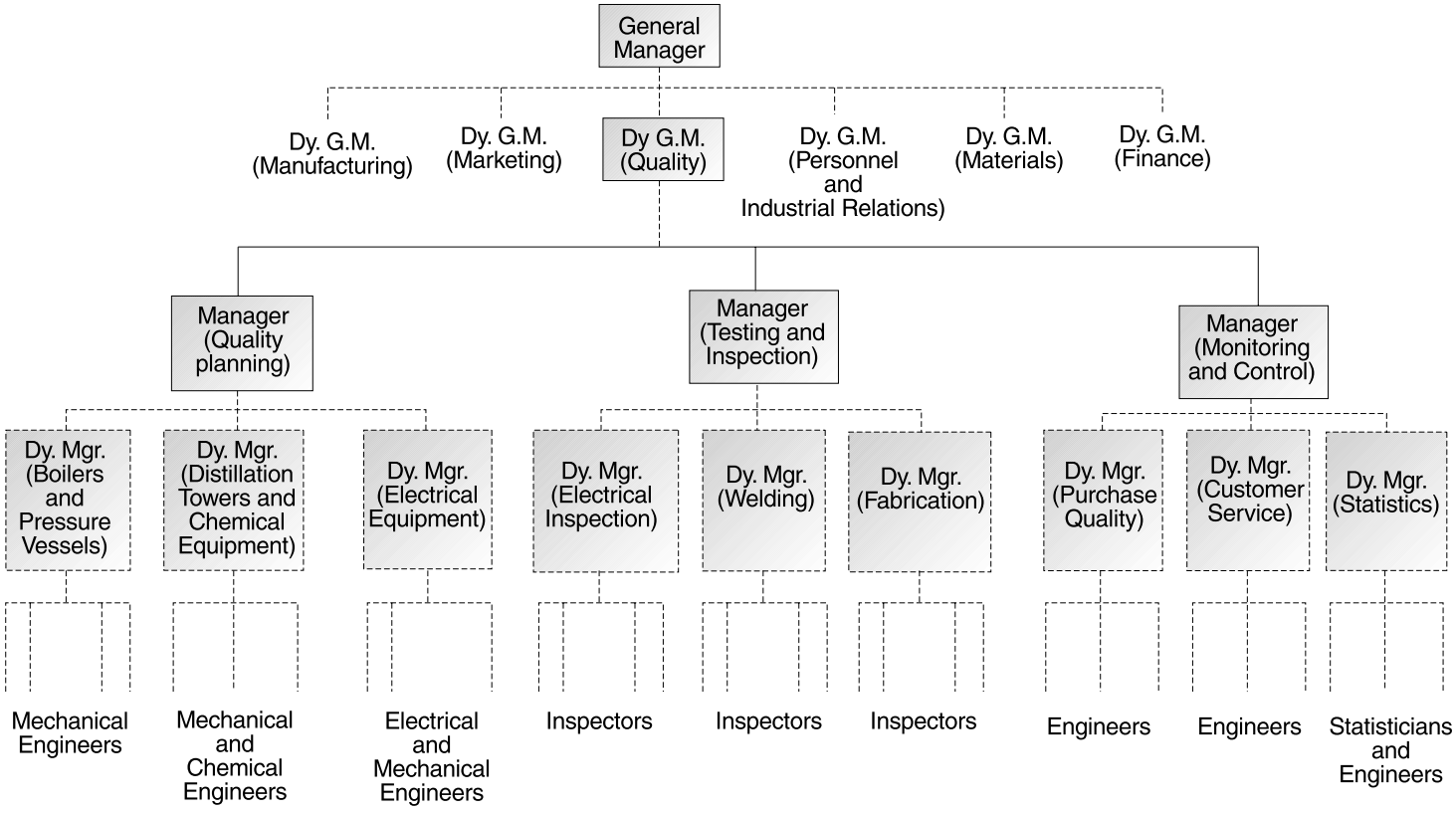


Figure 10.7 Organisational Structure for Quality Management for a Large Company Manufacturing Boilers, Pressure Vessels, Chemical Equipment and Electrical Equipment at One Single Location (Only for illustrative purposes)

Managing Quality in Services

Quality planning, quality implementation and quality monitoring and control are no different in services. All the three components are necessary. Since quality is more 'fragile' in services and since it is 'not inventoryable', quality planning assumes great importance in management of quality in services. If quality planning is done properly, more than half the job of quality is done. Quality planners in services have to think hard at the outset as to what can go wrong and, in order that it does not go wrong, what needs to be done right in the beginning itself. Much emphasis may have to be laid on the training of the employees in requisite skills, knowledge, orientation and attitude in addition to empowering them. In some cases, customer being a player in the process, training of customers becomes essential. When customer training is not paid adequate attention, the service quality tends to suffer. For instance, in a business school, if the student (i.e. customers) are not adequately trained in case analysis and presentation, the teaching by means of the case method tends to suffer however brilliant the teacher (i.e. service provider) may be. Even in a starred hotel, the htoel staffer spends a couple of minutes for the benefit of the customer explaining as to how the equipment in the suite may be operated. The intention is to enable the customer (who is also an operator) to use the service facilities fully and thus enhance the service quality. When safety is an important part of the service, hotels may sometimes conduct fire safety and other drills; airlines take pains to demonstrate all safety measures to the passengers on board.

Since service quality depends upon several 'moments of truth', all these moments or service enocounters have to be planned for qutlity experience. These 'moments' have also to be regularly and frequently monitored; they need to be corrected/controlled when found unsatisfactory.

Quality depends significantly on the 'leadership' provided in the organisation. A 'fragile' quality and a 'less definable' qualtiy—which are the characteristics of many services—call for much forethought in organising for quality. Communication flows within the organisation and the swiftness of the organisation in taking corrective actions have a premium in the service industry.

COSTS OF QUALITY

Quality management is not only concerned with maintaining the quality characteristics of a product but also with doing the same at least cost. There are basically three categories of cost of quality:

Costs of Appraisal

These are costs of inspection, testing, and such checking operations as are necessary to maintain the product or service quality. This includes the costs of the implementation of quality, and also the costs of monitoring and control.

Costs of Prevention

These are the costs to prevent the production of bad quality output. These include costs of activity such as quality planning which tries to ensure that proper precautions have been taken to avoid wrong sampling plans being made or bad quality of raw material entering into plant or improper methods and processes being followed in the plant.

Costs of Failure

In spite of prevention and appraisal, there will still be losses due to rejects, rework, spoilage, etc. to some extent. These, as well as the costs of attending to customer complaints and providing product service, are included under the category of costs of failures.

The costs of quality can be analysed in two different ways:

1. *Category to category comparison* Comparing the relative amounts spent on each of the above mentioned cost categories, i.e. how much is spent on prevention? how much on appraisal? and, how much on failure?
2. *Time to time comparison* For instance, comparing one quarter's operation with the previous quarter's operation.

Analysis of Quality Costs

When the latter type of analysis is to be performed, care should be taken to relate the total quality costs to the levels of organisational activity in that period. For example, if the manufacturing activity is increased considerably in the present quarter, it is meaningless to compare straightaway the present quality costs with the previous quarter's quality costs. Therefore, it is suggested that quality costs should be related to a base. The base could be: **(a)** number of units produced in a time period, or, **(b)** the net sales for that period, or, **(c)** the total direct labour cost for that period, or, **(d)** the value added (net sales minus the direct material cost). Unless a base is selected, the comparison of quality costs from one time-period to the other will be meaningless or baseless. The selection of the base to be used depends upon the particular product characteristics of the organisation. For example, 'value added' is preferred to the 'net sales' when the materials cost is a large part of the sales volume and where the price-fluctuations of the materials would distort the 'net sales' base. Also, when there are a number of end products, the basis of 'number of units of products produced in a period' does not make much sense, because a change in the product-mix would distort the comparison of the quality costs in the two different periods. Similarly, the sales have to be properly related to the quality costs. The sales in one period may not have any relation to the costs of quality in that period. The sales lag the production, and therefore, the base of 'net sales' is to be used with a lot of care. Similar considerations are applicable in service quality.

After having selected the base, a comparison of the different products or product-lines could be made with respect to the components of the costs of quality. These comparisons for instance, may reveal that the company is spending a considerable amount on failure and on appraisal, and is spending very little on quality planning. In such a case, spending more on planning aspects might bring down the cost of failure as well as that of appraisal.

General Electric discovered that the company's cost of correcting a quality problem discovered before the product is manufactured is US $ 0.003 per unit, $ 30 if discovered during manufacturing, and $ 300 if discovered after it is sold to the customer. Thus, an ounce of prevention is worth a ton of cure. 'To do the job right the first time' is, therefore, a good principle to follow. This aspect will be discussed in the later pages under 'Zero Defects Programme'. Many instances of industrial disasters when this principle is not followed may be mentioned. In 1993, General Motors recalled about 500,000 cars built between 1987 and 1991, which had defective engine head gaskets. Chrys-

ler recalled 35,000 Dodge Rams 1991–93 models because of faulty fuel pumps. In 1996 Mitsubishi recalled 650,000 vehicles made between 1990 and 1994 that had faulty brakes. Recalls on such a massive scale will drastically cut into the company's profitability. Toyota spent US $ 124 million or 10.5 per cent of its net profit for the year 1994, while General Motors spent US $ 200 million in 1992 towards settlements.* The cost of quality due to failure can be devastating. While in India the costs of quality are not felt as acutely today, the inevitable integration with the global market will sooner bring home the reality.

Quality Management as a Total Organisational Activity

Quality management is a total organisational activity. One has to be quality-conscious at every step of the functioning of an organisation, if the organisation desires to ensure the quality of its products or services. Quality management is neither an activity involving any particular functional area nor is it an activity which ends with the control of the process and the proper selection of raw materials or other inputs. It is a process encompassing each and everybody in the company. It is like a symphony. Unless this is understood and imbibed, ensuring product quality may not be possible.

SOLVED PROBLEMS

1. Ebenezer Works is a supplier of parts to Sarabjit Singh and Company. The parts arrive in large lots of 5000 parts. Sarabjit Singh and Ebenezer have agreed to a sampling plan whereby lots with 10 per cent defectives stand a chance of acceptance of only 1 per cent and lots with a quality level of 1 per cent defectives are rejected only 5 per cent of the time.
   (a) What should be the appropriate sampling plan under this agreement?
   (b) Ebenezer's lots generally have a quality level of 2 per cent defective. What per cent of such lots can generally be expected to be rejected under this plan?

Answer

(a) A sampling plan consists of the sample size (n) and the cut-off point (c). If the number of defectives in the sample is more than 'c', then that particular lot is rejected. The plan can be arrived at by referring to the table given as Appendix I at the end of the present chapter.
As per our problem, the consumer's risk and the producer's risk corresponding to LTPD of 0.10 and AQL of 0.01 are 0.01 and 0.05, respectively. The lot size is 5000.
Let us note down the given values.

$$p_2 / p_1 = 0.10 / 0.01 = 10, \quad \alpha = 0.05 \text{ and } \beta = 0.01$$

Refer to Appendix I.
Corresponding to $\alpha = 0.05$ and $\beta = 0.01$ and p_2 / p_1 of 10.0, we find the value of 9.418 to be just less than 10.0.
Hence, the acceptance number $c = 3$.
Also, we find that $np_1 = 0.823$.
Since p_1 is known to be 0.01, $n = (0.823)/(0.01) = 82.3$ or 82.

* Rene T. Domingo, 'Let the Seller Beware', World Executive's Digest, Sept. 1997, pp. 36—41.

The sampling plan would, thus, be (82, 3). For administrative convenience, it can be made to (80, 3) with not too much of a deviation from the requirements.

(b) The chance that a lot of 2 per cent defectives is rejected can be arrived at by referring to the Table of Poisson distribution (Appendix to this chapter). The probability of acceptance corresponding to $\lambda = (80)(0.02)$ and $x = 3$ is 0.921.
Hence, the average lots of 2 per cent defectives will be rejected with a probability of (1.0 – 0.921) = 0.079, which means 7.9 per cent of the time.

2. For the previous problem, what would be the Average Outgoing Quality Limit (AOQL)? What does that mean?

Answer

Referring to the Table of Poisson distribution (Appendix to this chapter), for various assumed values of per cent defectives in the lot, the probability of acceptance under the given sampling plan can be read out. The values are given in the following table.
(Sample computation: 1% defective corresponds to $\lambda = (0.01)$(sample size) = (0.01)(80) = 0.8. Corresponding to $x = 3$ and $\lambda = 0.8$, the table shows a value of 0.991.)

Per cent defectives in the lot (p)	*Probability of acceptance (P_a)*
1.0	0.991
1.5	0.966
2.0	0.921
2.5	0.857
3.0	0.779
4.0	0.603
5.0	0.433
6.0	0.294

The average outgoing quality (AOQ) for each of the above may be computed and the maximum of the AOQ will correspond to the limit AOQL.

p	P_a	$p \cdot P_a$
0.01	0.991	0.00991
0.015	0.966	0.01449
0.02	0.921	0.01842
0.025	0.857	0.02143
0.03	0.779	0.02337
0.04	0.603	0.02412
0.0425	0.558	0.02372
0.045	0.515	0.02318
0.05	0.433	0.02165
0.06	0.294	0.01764

Obviously, the maximum point is at $p = 0.04$, i.e. 4 per cent defectives.

The AOQL is 0.02412, i.e. the maximum bad quality that can enter the plant is 2.412 per cent defectives. Such a lot of 5000 items from the supplier may have (5000)(0.02412) = 120.6 or 121 defective items. That is, at any point in time the maximum number of defective parts expected to get through would not be more than 121. AOQL puts a limit on the worst we can expect.

3. A sampling plan consists of a sample size of 100 and a cut-off of 2, i.e. if more than 2 items in the sample are tested defective, the entire lot will be rejected. A lot (shipment) consists of 4000 items.
Suppose the supplier is unethical and decides to send the rejected consignment right back to the customer company without any screening. The customer company is unaware of such a malpractice. The supplier hopes that under the random sampling plan, the re-sent lot may be accepted. What is the probability that a 3 per cent defective consignment will be accepted either on the first or the second round?

Answer

This is certainly not the thing to do. Businesses are run on mutual trust and integrity. These are fundamental or core values and the edifice of statistical or other quality control is built on the firm foundation of the fundamental values.
Coming to the mathematics of the problem, we have:
n =100 c = 2
Referring to the Poisson tables, corresponding to the defect percentage of 3.0, the probability of acceptance is 0.423. The rejection probability would be (1 – 0.423) = 0.577.
The rejected lot stands a probability of acceptance of 0.423. That means, (0.423)(0.577) = 0.244 would be the probability the second time over.
Hence, the total probability that the lot will be accepted at the first time or at the second resubmission time would be (0.423 + 0.244) = 0.667

4. Shekhawat Industries supplies electrical components to Rajashekhar and Co. in consignments of 6000 parts. Rajashekhar has decided on an average outgoing quality limit (AOQL) of 2.0 per cent and is using a single sampling plan. Shekhawat's consignments have an average of about 0.3 per cent defectives.
(a) Using Dodge-Romig tables get the desired sampling plan.
(b) Under this plan what per cent defective in a lot will have a 10 per cent probability of getting accepted?
(c) What would be the probability that a consignment of 1 per cent defectives gets accepted under this plan?

Answer

Refer to the Appendix II (Dodge-Romig AOQL Tables for Single Sampling. In this table, the AOQL is fixed at 2.0. Therefore, it meets the needs of this problem.)

(a) Corresponding to the process average of 0.3 per cent and lot size of 6000, we have n = 42 and c = 1. This is the sampling plan.

(b) The same table also shows that the LTPD corresponding to the consumer's risk of 0.10 is 9.3 per cent. Thus, the answer to this part of the problem is 9.3 per cent defective.

(c) Now refer to the Poisson table (Appendix to this chapter). Corresponding to λ = (42)(0.01) = 0.42 and c = 1, we note (after a little interpolation) a cumulative probability of 0.933 which is the probability of acceptance of a lot of 1 per cent defective under the present plan.

5. Poongavanam Selvan Pvt. Ltd. is a component manufacturer in Marimalainagar and supplies to Tamilarasi Business Machines which is a large multinational company with plants in Chennai. Tamilarasi desires to use a Double Sampling Plan. Poonagavanam's consignments of 8000 components have been known to have a defective percentage of 0.8 per cent.

(a) If a lot with a defective percentage of 5.0 should have a 10 per cent chance of getting accepted by Tamilarasi, what may be the acceptance sampling plan?

(b) Tamilarasi is concerned about the input quality and would like to have the average outgoing quality to be never more than 2 per cent. Will this requirement be met by the above sampling plan?

(c) Find the probability of acceptance of a lot with 3 per cent defective, right on the first sample of this double sampling plan?

Answer

The facts of the case are as follows:
Double Sampling Plan, LTPD of 5.0 for a consumer's risk of 10 per cent, Lot size is 8000, and Process average defective is 0.8 per cent.

(a) Refer to Appendix V of this chapter (Dodge-Romig Double Sampling Lot Tolerance tables). Corresponding to the above facts, the sampling plan reads as follows:

n_1	c_1	n_2	$(n_1 + n_2)$	c_2
90	1	190	280	8

The above describes the double sampling plan.

(b) Also from the same table, the corresponding AOQL is noted to be 1.9 per cent. Hence, Tamilarasi's requirement regarding AOQL is met by this sampling plan.

(c) For $n = 90$, $c = 1$ and $\lambda = (n)(0.03) = 2.7$ we have from the Table of Poisson distribution (Appendix of this chapter):
Probability of acceptance = 0.249 (after interpolation). This is the probability of acceptance of a lot with 3 per cent defective under this sampling plan.

6. Manjarekar Brothers is a medium size enterprise supplying copper connectors to Karnik Electrical Works, a large manufacturer of standard electrical equipment located in Bhiwandi near Mumbai. Manjarekar supplies in lots of 1500. As per the past data, the lots supplied have had average defectives of 1.9 per cent. Currently, a sampling plan of $n = 40$ and $c = 1$ is being used for accepting the lots.

(a) If the cost of inspecting the lots is Rs. 4.50 per unit and if the cost of allowing a bad unit into the plant is high at Rs 200 per unit, what is the cost of quality per unit?

(b) If the above sampling plan was to be changed to $n = 80$ and $c = 2$, will the cost of quality per unit be lower? What will it be?

Answer

(a) $\lambda = (n)(0.019) = (40)(0.019) = 0.76$
Refer to Table of Poisson distribution (Appendix of this chapter) for $\lambda = 0.76$ and $x = 1$. Interpolate, if necessary.
Probability of acceptance under this sampling plan will be 0.824
That means, (0.824)(0.019)(1500) = 23.484 bad items enter the plant of Karnik Electricals.
The cost of quality, as per the present case, is the total of the cost of bad quality plus the cost of inspection under the sampling plan. This will be: (23.484)(Rs. 200) plus (number inspected = 40)(Rs. 4.50) = Rs. 4696.80 + 180 = Rs. 4876.80
So, the average quality cost of input per unit = Rs. 4876.80 / (Lot size of 1500) = Rs. 3.2512 = Rs. 3.25 approximately.

(b) In the second case, $n = 80$ and $c = 2$
Therefore, $\lambda = (80)(0.019) = 1.52$ and $x = 2$
The probability of acceptance is 0.804
That means, the number of bad quality items entering the plant of Karnik is now = (0.804)(0.019)(1500) = 22.914
The cost of bad quality per lot = (22.914)(Rs 200) = Rs. 4582.80
The cost of inspection per lot = (Rs. 4.50)(80) = Rs. 360
Total of the cost of quality = Rs. 4582.80 + Rs. 360 = Rs. 4942.80
Per unit cost of quality = Rs. 4942.80 / 1500 = Rs. 3.2952 = Rs. 3.30 approximately. This is a bit higher than the first case and not lower.
The second sampling plan is tighter than the first and it is making the cost of failure smaller. But, the inspection load also has doubled in the second case.

7. Subroto Sen & Co. has a unique acceptance sampling plan. It is a double sampling plan wherein at first a sample of 4 items is taken from a lot of 80 and if none of the four is defective, the lot is accepted. If there are 2 or more defectives in this sample, the lot is rejected. But, if there is 1 defective in the sample, Subroto takes one more item and accepts the lot, if this additional item is good.
For a lot consisting of 10 per cent defectives, what is the probability of accepting the lot under this plan?

Answer

At first, calculate the probability of obtaining a sample of 4 items with no defectives from a lot that has 10 per cent defective. We have:

$$\lambda = n{\cdot}p = (4)(0.10) = 0.40$$

(Note: The lot of size 80 is considered to be large. This is an assumption.)
Referring to the Poisson distribution table (Appendix of this chapter), we have:
For $\lambda = 0.40$ and $x = 0$, probability is 0.670
This is the probability of obtaining a sample of 4 items with no defectives.
Again referring to the above table, the probability of finding 1 defective or less in a sample of 4 is: 0.938 for this given lot. Since the probability of finding 0 defectives in the sample was 0.670, the probability of finding 1 defective is:

0.938 – 0.670 = 0.268

The probability that the second sample (just 1 separate item – not to be combined with the first sample) is good is:

$1 - [(B - 1) / (N - n)] = 1 - [(8 - 1) / (80 - 4)] = 0.9079$

(Note: B is the total number of bad items in the lot, N is the lot size and n is the sample size)

However, under Subroto Sen's sampling plan, this is a conditional probability – conditional to having found 1 defective in the sample. Hence, the probability of the lot getting accepted after inspecting the second sample is:

$$(0.268) \times (0.9079) = 0.2433$$

Now, the probability of acceptance of the lot under Subroto Sen's double sampling plan would be an addition of the probabilities of accepting after the 1st sample and after the 2nd sample. This would be: 0.670 + 0.2433 = 0.9133

The answer is: 0.9133

QUESTIONS FOR DISCUSSION

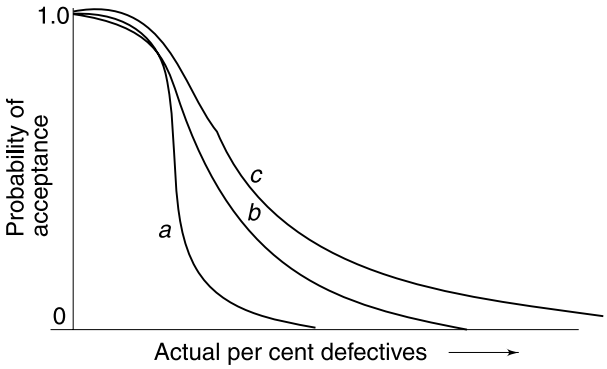
1. What is the difference, if any, between quality assurance and quality control as they are generally understood?
2. What could be the contribution of behavioural sciences to the management of quality?
3. What kind of an organisational structure for the purpose of quality management might you suggest for a manufacturing company having a number of divisions at different locations with different divisional managers heading the divisions?
4. How is organisational structure important in the management of quality?
5. Is the quality management job that of a policeman or that of an adviser? Explain. Is it one of these or both of these? If the latter is true, where will it be advisory and where will it be policing in your opinion?
6. What are the limitations of statistical quality can it be applied in service industry?
7. What information does the OC curve provide?
8. In this chapter an acceptance sampling procedure for attributes (defective/non-defective) was discussed. What could be the acceptance sampling procedure for variables (where you could measure the characteristics)?
9. What is the idea behind AOQL? Why is it required?
10. Do you think that the zero defects programme can be successful for an agricultural machinery manufacturing concern, where most of the parts are procured from outside? How can a ZD programme be implemented in a service organisation?
11. What are the interactions between quality control and purchasing?
12. Is it sufficient to mention AOQL and producer's risk for a sampling plan for quality control? Explain.
13. Do sequential or double sampling plans always produce cost economies in quality control as opposed to single sampling plans?
14. How are reliability and quality control related?
15. How might the quality management department delegate some of its responsibility to Manufacturing and yet retain the overall control?

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16. What is the meaning of AQL, LTPD and the corresponding probabilities of acceptance?

17. What is the effect of increasing the sampling size; what is the effect of decreasing the sampling size on the OC curve? If the sampling size is the same, what is the effect of increasing or decreasing the acceptance number?

18. Following is a diagram showing different OC curves. The OC curves and the three different sampling plans are separately indicated. Link a relevant sampling plan to each of these OC curves.



Sampling Plans:

(i) $n = 100$, $c = 2$: Is it curve (a), (b) or (c)?

(ii) $n = 300$, $c = 6$: Is it curve (a), (b) or (c)?

(iii) $n = 25$, $c = 4$: Is it curve (a), (b) or (c)?

19. Explain the utility of the Dodge-Romig tables.

20. When a product is being produced continuously, accumulating a batch of the products for acceptance or rejection later may not be a very good idea. For such a continuous production process, what kind of an acceptance sampling procedure do you suggest? Explain your rationale.

21. An ordnance factory gets brass tubings in lots of 15,000 units from a supplier whose performance in the past has been satisfactory, to the extent of finding 1 in 200 items to be defective on an average. The sampling plan had been $n = 70$ and $c = 2$, which was quite adequate, Of late, the supplies have been poorer in quality, i.e. there are more defective items than in the past. It is estimated that on average, the defectives have doubled, to the extent of 1:100 items. The supplier attributes this to the ageing of his machines and equipment. Being a reliable supplier otherwise, the ordnance factory would still like to retain him on their list but tighten up the quality control procedure so that the ordnance factory will, under any circumstance, have no greater than 2 per cent defectives in this input material to their factory—What sampling plan can the ordnance factory use for this supplier?

22. Lele Engineering Pvt. Ltd. has been a supplier to Hindustan Machinery Manufacturers Ltd. (HMML), a public sector Company. Lele supplies fasteners, mainly, and has been telling HMML that in spite of good quality being sent, HMML has been rejecting a number of good consignments causing much inconvenience and cost to Lele in terms of re-inspection, etc. Currently, HMML's quality department checks 100 items from Lele's consignments

which are in batches of 10,000 items or more and accepts the batch if there are no more than 2 defectives in the sample. Is it possible to suggest a sampling procedure for HMML which will substantially alleviate Lele's problem and yet not allow a worse than 2% bad quality to enter HMML's factory?

APPENDIX I

VALUES OF np'_1 AND c FOR CONSTRUCTING SINGLE SAMPLING PLANS WHOSE OC CURVE IS REQUIRED TO PASS THROUGH THE TWO POINTS $(p'_1, 1 - \alpha)$ AND (p'_2, β)†

	Values of p'_2/p'_1 for					Values of p'_2/p'_1 for			
c	$\alpha = 0.05$ $\beta = 0.10$	$\alpha = 0.05$ $\beta = 0.05$	$\alpha = 0.05$ $\beta = 0.01$	np'_1	c	$\alpha = 0.01$ $\beta = 0.10$	$\alpha = 0.01$ $\beta = 0.05$	$\alpha = 0.01$ $\beta = 0.01$	np'_1
0	44.890	58.404	89.781	0.052	0	229.105	298.073	458.210	0.010
1	10.946	13.349	18.681	0.355	1	26.184	31.933	44.686	0.149
2	6.509	7.699	10.280	0.818	2	12.206	14.439	19.278	0.436
3	4.890	5.675	7.352	1.366	3	8.115	9.418	12.202	0.823
4	4.057	4.646	5.890	1.970	4	6.249	7.156	9.072	1.279
5	3.549	4.023	5.017	2.613	5	5.195	5.889	7.343	1.785
6	3.206	3.604	4.435	3.286	6	4.520	5.082	6.253	2.330
7	2.957	3.303	4.019	3.981	7	4.050	4.524	5.506	2.906
8	2.768	3.074	3.707	4.695	8	3.705	4.115	4.962	3.507
9	2.618	2.895	3.462	5.426	9	3.440	3.803	4.548	4.130
10	2.497	2.750	3.265	6.169	10	3.229	3.555	4.222	4.771
11	2.397	2.630	3.104	6.924	11	3.058	3.354	3.959	5.428
12	2.312	2.528	2.968	7.690	12	2.915	3.188	3.742	6.099
13	2.240	2.442	2.852	8.464	13	2.795	3.047	3.559	6.782
14	2.177	2.367	2.752	9.246	14	2.692	2.927	3.403	7.477
15	2.122	2.302	2.665	10.035	15	2.603	2.823	3.269	8.181
16	2.073	2.244	2.588	10.831	16	2.524	2.732	3.151	8.895
17	2.029	2.192	2.520	11.633	17	2.455	2.652	3.048	9.616
18	1.990	2.145	2.458	12.442	18	2.393	2.580	2.956	10.346
19	1.954	2.103	2.403	13.254	19	2.337	2.516	2.874	11.082
20	1.922	2.065	2.352	14.072	20	2.287	2.458	2.799	11.825
21	1.892	2.030	2.307	14.894	21	2.241	2.405	2.733	12.574
22	1.865	1.999	2.265	15.719	22	2.200	2.357	2.671	13.329

Contd...

	Values of p'_2/p'_1 for					Values of p'_2/p'_1 for			
c	$\alpha = 0.05$ $\beta = 0.10$	$\alpha = 0.05$ $\beta = 0.05$	$\alpha = 0.05$ $\beta = 0.01$	np'_1	c	$\alpha = 0.01$ $\beta = 0.10$	$\alpha = 0.01$ $\beta = 0.05$	$\alpha = 0.01$ $\beta = 0.01$	np'_1
23	1.840	1.969	2.226	16.548	23	2.162	2.313	2.615	14.088
24	1.817	1.942	2.191	17.382	24	2.126	2.272	2.564	14.853
25	1.795	1.917	2.158	18.218	25	2.094	2.235	2.516	15.623
26	1.775	1.893	2.127	19.058	26	2.064	2.200	2.472	16.397
27	1.757	1.871	2.098	19.900	27	2.035	2.168	2.431	17.175
28	1.739	1.850	2.071	20.746	28	2.009	2.138	2.393	17.957
29	1.723	1.831	2.046	21.594	29	1.985	2.110	2.358	18.742
30	1.707	1.813	2.023	22.444	30	1.962	2.083	2.324	19.532
31	1.692	1.796	2.001	23.298	31	1.940	2.059	2.293	20.324
32	1.679	1.780	1.980	24.152	32	1.920	2.035	2.264	21.120
33	1.665	1.764	1.960	25.010	33	1.900	2.013	2.236	21.919
34	1.653	1.750	1.941	25.870	34	1.882	1.992	2.210	22.721
35	1.641	1.736	1.923	26.731	35	1.865	1.973	2.185	23.525
36	1.630	1.723	1.906	27.594	36	1.848	1.954	2.162	24.333
37	1.619	1.710	1.890	28.460	37	1.833	1.936	2.139	25.143
38	1.609	1.698	1.875	29.327	38	1.818	1.920	2.118	25.955
39	1.599	1.687	1.860	30.196	39	1.804	1.903	2.098	26.770
40	1.590	1.676	1.846	31.066	40	1.790	1.887	2.079	27.587
41	1.581	1.666	1.833	31.938	41	1.777	1.873	2.060	28.406
42	1.572	1.656	1.820	32.812	42	1.765	1.859	2.043	29.228
43	1.564	1.646	1.807	33.686	43	1.753	1.845	2.026	30.051
44	1.556	1.637	1.796	34.563	44	1.742	1.832	2.010	30.877
45	1.548	1.628	1.784	35.441	45	1.731	1.820	1.994	31.704
46	1.541	1.619	1.773	36.320	46	1.720	1.808	1.980	32.534
47	1.534	1.611	1.763	37.200	47	1.710	1.796	1.965	33.365
48	1.527	1.603	1.752	38.082	48	1.701	1.785	1.952	34.198
49	1.521	1.596	1.743	38.965	49	1.691	1.775	1.938	35.032

†Here p'_1 is the fraction defective for which the risk of rejection is to be α and p'_2 is the fraction defective for which the risk of acceptance is to be β. To construct the plan, find the tabular value of p'_2/p'_1 in the column for the given α and β which is equal to or just less than the given value of the ratio. The sample size is found by dividing the np'_1 corresponding to the selected ratio by p'_1. The acceptance number is the value of c corresponding to the selected value of the ratio.

Source: W.G. Ireson and E.L. Grant (Eds), Handbook of Industrial Engineering and Management, Prentice-Hall of India, New Delhi, 1977 (2nd edn). Reproduced with permission from Prentice-Hall of India, New Delhi.

APPENDIX II

EXAMPLE OF DODGE-ROMIG SINGLE SAMPLING LOT TOLERANCE TABLES

Lot Tolerance per cent Defective = 5.0 per cent; Consumer's Risk = 0.10

Process Average, %	*0–0.05*			*0.06–0.50*			*0.51–1.00*			*1.01–1.50*			*1.51–2.00*			*2.01–2.50*		
			AOQL,			*AOQL,*			*AOQL,*			*AOQL,*			*AOQL,*			*AOQL*
Lot Size	*n*	*c*	*(%)*	*n*	*c*	*%*	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*
1–30	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0	All	0	0
31–50	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49	30	0	0.49
51–100	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63	37	0	0.63
101–200	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74	40	0	0.74
201–300	43	0	0.74	43	0	0.74	70	1	0.92	70	1	0.92	95	2	0.99	95	2	0.99
301–400	44	0	0.74	44	0	0.74	70	1	0.99	100	2	1.0	120	3	1.1	145	4	1.1
401–500	45	0	0.75	75	1	0.95	100	2	1.1	100	2	1.1	125	3	1.2	150	4	1.2
501–600	45	0	0.76	75	1	0.98	100	2	1.1	125	3	1.2	150	4	1.3	175	5	1.3
601–800	45	0	0.77	75	1	1.0	100	2	1.2	130	3	1.2	175	5	1.4	200	6	1.4
801–1,000	45	0	0.78	75	1	1.0	105	2	1.2	155	4	1.4	180	5	1.4	225	7	1.5
1,001–2,000	45	0	0.80	75	1	1.0	130	3	1.4	180	5	1.6	230	7	1.7	280	9	1.8
2,001–3,000	75	1	1.1	105	2	1.3	135	3	1.4	210	6	1.7	280	9	1.9	370	13	2.1
3,001–4,000	75	1	1.1	105	2	1.3	160	4	1.5	210	6	1.7	305	10	2.0	420	15	2.2
4,001–5,000	75	1	1.1	105	2	1.3	160	4	1.5	235	7	1.8	330	11	2.0	440	16	2.2
5,001–7,000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	350	12	2.2	490	18	2.4
7,001–10,000	75	1	1.1	105	2	1.3	185	5	1.7	260	8	1.9	380	13	2.2	535	20	2.5
10,001–20,000	75	1	1.1	135	3	1.4	210	6	1.8	285	9	2.0	425	15	2.3	610	23	2.6
20,001–50,000	75	1	1.1	135	3	1.4	235	7	1.9	305	10	2.1	470	17	2.4	700	27	2.7
50,001–100,000	75	1	1.1	160	4	1.6	235	7	1.9	355	12	2.2	515	19	2.5	770	30	2.8

Source: W.G. Ireson and E.L. Grant (Eds), *Handbook of Industrial Engineering and Management*, Prentice-Hall of India, New Delhi, 1972 (2nd edn.). Reproduced with permission from Prentice-Hall of India, New Delhi.

NOTE: The AOQL values are furnished assuming that all the rejected lots are screened. The average amount of inspection (considering inspection of samples and screening of rejected lots) is smallest for that plan which belongs to the range under which the actual process average falls.

APPENDIX III

EXAMPLE OF DODGE-ROMIG AOQL TABLES—SINGLE SAMPLING

Average Outgoing Quality Limit = 2.0 per cent

Process Average, %	*0–0.04*			*0.05–0.40*			*0.41–1.80*			*0.81–1.20*			*1.21–1.60*			*1.61–2.00*		
			p_t			p_t			p_t			p_t			p_t			p_t
Lot Size	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*	*n*	*c*	*(%)*
1–15	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–	All	0	–
16–50	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6	14	0	13.6
51–100	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4	16	0	12.4
101–200	17	0	12.2	17	0	12.2	17	0	12.2	17	0	12.2	35	1	10.5	35	1	10.5
201–300	17	0	12.3	17	0	12.3	17	0	12.3	37	1	10.2	37	1	10.2	37	1	10.2
301–400	18	0	11.8	18	0	11.8	38	1	10.0	38	1	10.0	38	1	10.0	60	2	8.5
401–500	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
501–600	18	0	11.9	18	0	11.9	39	1	9.8	39	1	9.8	60	2	8.6	60	2	8.6
601–800	18	0	11.9	40	1	9.6	40	1	9.6	65	2	8.0	65	2	8.0	85	3	7.5
801–1,000	18	0	12.0	40	1	9.6	40	1	9.6	65	2	8.1	65	2	8.1	90	3	7.4
1,001–2,000	18	0	12.0	41	1	9.4	65	2	8.2	65	2	8.2	95	3	7.0	120	4	6.5
2,001–3,000	18	0	12.0	41	1	9.4	65	2	8.2	95	3	7.0	120	4	6.5	180	6	5.8
3,001–4,000	18	0	12.0	41	1	9.3	65	2	8.2	95	3	7.0	155	5	6.0	210	7	5.5
4,001–5,000	18	0	12.0	42	1	9.3	70	2	7.5	125	4	6.4	155	5	6.0	245	8	5.3
5,001–7,000	18	0	12.0	42	1	9.3	95	3	7.0	125	4	6.4	185	6	5.6	280	9	5.1
7,001–10,000	42	1	9.3	70	2	7.5	95	3	7.0	155	5	6.0	220	7	5.4	350	11	4.8
10,001–20,000	42	1	9.3	70	2	7.6	95	3	7.0	190	6	5.6	290	9	4.9	460	14	4.4
20,001–50,000	42	1	9.3	70	2	7.6	125	4	6.4	220	7	5.4	395	12	4.5	720	21	3.9
50,001–100,000	42	1	9.3	95	3	7.6	160	5	5.9	290	9	4.9	505	15	4.2	955	27	3.7

Source: W.G. Ireson and E.L. Grant (Eds), *Handbook of Industrial Engineering and Management*, Prentice-Hall of India, 1977 (2nd edn). Reproduced with permisssion from Prentice-Hall of India, New Delhi.

NOTE: 'p_t' is Lot Tolerance Per cent Defective (LTPD) corresponding to consumer's risk of 0.10. All the sampling plans in this table have the same AOQL (2.0%), assuming that all the rejected lots are screened. The average amount of inspection is smallest for that plan which belongs to the range under which the actual process average falls.

APPENDIX VI

TABLE OF POISSON DISTRIBUTION

Values of: $\sum_{k=0}^{k=x} (e^{-\lambda} \cdot \lambda^k)/k!$

λ \ x	0	1	2	3	4	5	6	7	8
.02	0.980	1.000							
.04	0.961	0.999	1.000						
.06	0.942	0.998	1.000						
.08	0.923	0.997	1.000						
.10	0.905	0.995	1.000						
.15	0.861	0.990	0.999	1.000					
.20	0.819	0.982	0.999	1.000					
.25	0.779	0.974	0.998	1.000					
.30	0.741	0.963	0.996	1.000					
.35	0.705	0.951	0.994	1.000					
.40	0.670	0.938	0.992	0.999	1.000				
.45	0.638	0.925	0.989	0.999	1.000				
.50	0.607	0.910	0.986	0.998	1.000				
.55	0.577	0.894	0.982	0.998	1.000				
.60	0.549	0.878	0.977	0.997	1.000				
.65	0.522	0.861	0.972	0.996	0.999	1.000			
.70	0.497	0.844	0.966	0.994	0.999	1.000			
.75	0.472	0.827	0.959	0.993	0.999	1.000			
.80	0.449	0.809	0.953	0.991	0.999	1.000			
.85	0.427	0.791	0.945	0.989	0.998	1.000			
.90	0.407	0.772	0.937	0.987	0.998	1.000			
.95	0.387	0.754	0.929	0.984	0.997	1.000			
1.00	0.368	0.736	0.920	0.981	0.996	0.999	1.000		

(Contd.)

λ \ x	0	1	2	3	4	5	6	7	8
1.10	0.333	0.699	0.900	0.974	0.995	0.999	1.000		
1.20	0.301	0.663	0.879	0.966	0.992	0.998	1.000		
1.30	0.273	0.627	0.857	0.957	0.989	0.998	1.000		
1.40	0.247	0.592	0.833	0.946	0.986	0.997	0.999	1.000	
1.50	0.223	0.558	0.809	0.934	0.981	0.996	0.999	1.000	
1.60	0.202	0.525	0.783	0.921	0.976	0.994	0.999	1.000	
1.70	0.183	0.493	0.757	0.907	0.970	0.992	0.998	1.000	
1.80	0.165	0.463	0.731	0.891	0.964	0.990	0.997	0.999	1.000
1.90	0.150	0.434	0.704	0.875	0.956	0.987	0.997	0.999	1.000
2.00	0.135	0.406	0.677	0.857	0.947	0.983	0.995	0.999	1.000

λ \ x	0	1	2	3	4	5	6	7	8	9
2.2	0.111	0.355	0.623	0.819	0.928	0.975	0.993	0.998	1.000	
2.4	0.091	0.308	0.570	0.779	0.904	0.964	0.988	0.997	0.999	1.000
2.6	0.074	0.267	0.518	0.736	0.877	0.951	0.983	0.995	0.999	1.000
2.8	0.061	0.231	0.469	0.692	0.848	0.935	0.976	0.992	0.998	0.999
3.0	0.050	0.199	0.423	0.647	0.815	0.916	0.966	0.988	0.996	0.999
3.2	0.041	0.171	0.380	0.603	0.781	0.895	0.955	0.983	0.994	0.998
3.4	0.033	0.147	0.340	0.558	0.744	0.871	0.942	0.977	0.992	0.997
3.6	0.027	0.126	0.303	0.515	0.706	0.844	0.927	0.969	0.988	0.996
3.8	0.022	0.107	0.269	0.473	0.668	0.816	0.909	0.960	0.984	0.994
4.0	0.018	0.092	0.238	0.433	0.629	0.785	0.889	0.949	0.979	0.992
4.2	0.015	0.078	0.210	0.395	0.590	0.753	0.867	0.936	0.972	0.989
4.4	0.012	0.066	0.185	0.359	0.551	0.720	0.844	0.921	0.964	0.985
4.6	0.010	0.056	0.163	0.326	0.513	0.686	0.818	0.905	0.955	0.980
4.8	0.008	0.048	0.143	0.294	0.476	0.651	0.791	0.887	0.944	0.975
5.0	0.007	0.040	0.125	0.265	0.440	0.616	0.762	0.867	0.932	0.968
5.2	0.006	0.034	0.109	0.238	0.406	0.581	0.732	0.845	0.918	0.960
5.4	0.005	0.029	0.095	0.213	0.373	0.546	0.702	0.822	0.903	0.951
5.6	0.004	0.024	0.082	0.191	0.342	0.512	0.670	0.797	0.886	0.941
5.8	0.003	0.021	0.072	0.170	0.313	0.478	0.638	0.771	0.867	0.929
6.0	0.002	0.017	0.062	0.151	0.285	0.446	0.606	0.744	0.847	0.916

(Contd.)

λ \ x	10	11	12	13	14	15	16
2.8	1.000						
3.0	1.000						
3.2	1.000						
3.4	0.999	1.000					
3.6	0.999	1.000					
3.8	0.998	0.999	1.000				
4.0	0.997	0.999	1.000				
4.2	0.996	0.999	1.000				
4.4	0.994	0.998	0.999	1.000			
4.6	0.992	0.997	0.999	1.000			
4.8	0.990	0.996	0.999	1.000			
5.0	0.986	0.995	0.998	0.999	1.000		
5.2	0.982	0.993	0.997	0.999	1.000		
5.4	0.977	0.990	0.996	0.999	1.000		
5.6	0.972	0.988	0.995	0.998	0.999	1.000	
5.8	0.965	0.984	0.993	0.997	0.999	1.000	
6.0	0.957	0.980	0.991	0.996	0.999	0.999	1.000

λ \ x	0	1	2	3	4	5	6	7	8	9
6.2	0.002	0.015	0.054	0.134	0.259	0.414	0.574	0.716	0.826	0.902
6.4	0.002	0.012	0.046	0.119	0.235	0.384	0.542	0.687	0.803	0.886
6.6	0.001	0.010	0.040	0.105	0.213	0.355	0.511	0.658	0.780	0.869
6.8	0.001	0.009	0.034	0.093	0.192	0.327	0.480	0.628	0.755	0.850
7.0	0.001	0.007	0.030	0.082	0.173	0.301	0.450	0.599	0.729	0.830
7.2	0.001	0.006	0.025	0.072	0.156	0.276	0.420	0.569	0.703	0.810
7.4	0.001	0.005	0.022	0.063	0.140	0.253	0.392	0.539	0.676	0.788
7.6	0.001	0.004	0.019	0.055	0.125	0.231	0.365	0.510	0.648	0.765
7.8	0.000	0.004	0.016	0.048	0.112	0.210	0.338	0.481	0.620	0.741
8.0	0.000	0.003	0.014	0.042	0.100	0.191	0.313	0.453	0.593	0.717
8.5	0.000	0.002	0.009	0.030	0.074	0.150	0.256	0.386	0.523	0.653
9.0	0.000	0.001	0.006	0.021	0.055	0.116	0.207	0.324	0.456	0.587
9.5	0.000	0.001	0.004	0.015	0.040	0.089	0.165	0.269	0.392	0.522
10.0	0.000	0.000	0.003	0.010	0.029	0.067	0.130	0.220	0.333	0.458

(Contd.)

λ \ x	10	11	12	13	14	15	16	17	18	19
6.2	0.949	0.975	0.989	0.995	0.998	0.999	1.000			
6.4	0.939	0.969	0.986	0.994	0.997	0.999	1.000			
6.6	0.927	0.963	0.982	0.992	0.997	0.999	0.999	1.000		
6.8	0.915	0.955	0.978	0.990	0.996	0.998	0.999	1.000		
7.0	0.901	0.947	0.973	0.987	0.994	0.998	0.999	1.000		
7.2	0.887	0.937	0.967	0.984	0.993	0.997	0.999	0.999	1.000	
7.4	0.871	0.926	0.961	0.980	0.991	0.996	0.998	0.999	1.000	
7.6	0.854	0.915	0.954	0.976	0.989	0.995	0.998	0.999	1.000	
7.8	0.835	0.902	0.945	0.971	9.986	0.993	0.997	0.999	1.000	
8.0	0.816	0.888	0.936	0.966	0.983	0.992	0.996	0.998	0.999	1.000
8.5	0.763	0.849	0.909	0.949	0.973	0.986	0.993	0.997	0.999	0.999
9.0	0.706	0.803	0.876	0.926	0.959	0.978	0.989	0.995	0.998	0.999
9.5	0.645	0.752	9.836	0.898	0.940	0.967	0.982	0.991	0.996	0.998
10.0	0.583	0.697	0.792	0.864	0.917	0.951	0.973	0.986	0.993	0.997

λ \ x	20	21	22
8.5	1.000		
9.0	1.000		
9.5	0.999	1.000	
10.0	0.998	0.999	1.000

λ \ x	0	1	2	3	4	5	6	7	8	9
10.5	0.000	0.000	0.002	0.007	0.021	0.050	0.102	0.179	0.279	0.397
11.0	0.000	0.000	0.001	0.005	0.015	0.038	0.079	0.143	0.232	0.341
11.5	0.000	0.000	0.001	0.003	0.011	0.028	0.060	0.114	0.191	0.289
12.0	0.000	0.000	0.001	0.002	0.008	0.020	0.046	0.090	0.155	0.242
12.5	0.000	0.000	0.000	0.002	0.005	0.015	0.035	0.070	0.125	0.201
13.0	0.000	0.000	0.000	0.001	0.004	0.011	0.026	0.054	0.100	0.166
13.5	0.000	0.000	0.000	0.001	0.003	0.008	0.019	0.041	0.079	0.135
14.0	0.000	0.000	0.000	0.000	0.002	0.006	0.014	0.032	0.062	0.109
14.5	0.000	0.000	0.000	0.000	0.001	0.004	0.010	0.024	0.048	0.088
15.0	0.000	0.000	0.000	0.000	0.001	0.003	0.008	0.018	0.037	0.070

(Contd.)

λ \ x	10	11	12	13	14	15	16	17	18	19
10.5	0.521	0.639	0.742	0.825	0.888	0.932	0.960	0.978	0.988	0.994
11.0	0.460	0.579	0.689	0.781	0.854	0.907	0.944	0.968	0.982	0.991
11.5	0.402	0.520	0.633	0.733	0.815	0.878	0.924	0.954	0.974	0.986
12.0	0.347	0.462	0.576	0.682	0.772	0.844	0.899	0.937	0.963	0.979
12.5	0.297	0.406	0.519	0.628	0.725	0.806	0.869	0.916	0.948	0.969
13.0	0.252	0.353	0.463	0.573	0.675	0.764	0.835	0.890	0.930	0.957
13.5	0.211	0.304	0.409	0.518	0.623	0.718	0.798	0.861	0.908	0.942
14.0	0.176	0.260	0.358	0.464	0.570	0.669	0.756	0.827	0.883	0.923
14.5	0.145	0.220	0.311	0.413	0.518	0.619	0.711	0.790	0.853	0.901
15.0	0.118	0.185	0.268	0.363	0.466	0.568	0.664	0.749	0.819	0.875

λ \ x	20	21	22	23	24	25	26	27	28	29
10.5	0.997	0.999	0.999	1.000						
11.0	0.995	0.998	0.999	1.000						
11.5	0.992	0.996	0.998	0.999	1.000					
12.0	0.988	0.994	0.997	0.999	0.999	1.000				
12.5	0.983	0.991	0.995	0.998	0.999	0.999	1.000			
13.0	0.975	0.986	0.992	0.996	0.998	0.999	1.000			
13.5	0.965	0.980	0.989	0.994	0.997	0.998	0.999	1.000		
14.0	0.952	0.971	0.983	0.991	0.995	0.997	0.999	0.999	1.000	
14.5	0.936	0.960	0.976	0.986	0.992	0.996	0.998	0.999	0.999	1.000
15.0	0.917	0.947	0.967	0.981	0.989	0.994	0.997	0.998	0.999	1.000

λ \ x	4	5	6	7	8	9	10	11	12	13
16	0.000	0.001	0.004	0.010	0.022	0.043	0.077	0.127	0.193	0.275
17	0.000	0.001	0.002	0.005	0.013	0.026	0.049	0.085	0.135	0.201
18	0.000	0.000	0.001	0.003	0.007	0.015	0.030	0.055	0.092	0.143
19	0.000	0.000	0.001	0.002	0.004	0.009	0.018	0.035	0.061	0.098
20	0.000	0.000	0.000	0.001	0.002	0.005	0.011	0.021	0.039	0.066
21	0.000	0.000	0.000	0.000	0.001	0.003	0.006	0.013	0.025	0.043
22	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.008	0.015	0.028
23	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.004	0.009	0.017
24	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.003	0.005	0.011

(Contd.)

λ \ x	4	5	6	7	8	9	10	11	12	13
25	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.006

λ \ x	14	15	16	17	18	19	20	21	22	23
16	0.368	0.467	0.566	0.659	0.742	0.812	0.868	0.911	0.942	0.963
17	0.281	0.371	0.468	0.564	0.655	0.736	0.805	0.861	0.905	0.937
18	0.208	0.287	0.375	0.469	0.562	0.651	0.731	0.799	0.855	0.899
19	0.150	0.215	0.292	0.378	0.469	0.561	0.647	0.725	0.793	0.849
20	0.105	0.157	0.221	0.297	0.381	0.470	0.559	0.644	0.721	0.787
21	0.072	0.111	0.163	0.227	0.302	0.384	0.471	0.558	0.640	0.716
22	0.048	0.077	0.117	0.169	0.232	0.306	0.387	0.472	0.556	0.637
23	0.031	0.052	0.082	0.123	0.175	0.238	0.310	0.389	0.472	0.555
24	0.020	0.034	0.056	0.087	0.128	0.180	0.243	0.314	0.392	0.473
25	0.012	0.022	0.038	0.060	0.092	0.134	0.185	0.247	0.318	0.394

λ \ x	24	25	26	27	28	29	30	31	32	33
16	0.978	0.987	0.993	0.996	0.998	0.999	0.999	1.000		
17	0.959	0.975	0.985	0.991	0.995	0.997	0.999	0.999	1.000	
18	0.932	0.955	0.972	0.983	0.990	0.994	0.997	0.998	0.999	1.000
19	0.893	0.927	0.951	0.969	0.980	0.988	0.993	0.996	0.998	0.999
20	0.843	0.888	0.922	0.948	0.966	0.978	0.987	0.992	0.995	0.997
21	0.782	0.838	0.883	0.917	0.944	0.963	0.976	0.985	0.991	0.994
22	0.712	0.777	0.832	0.877	0.913	0.940	0.959	0.973	0.983	0.989
23	0.635	0.708	0.772	0.827	0.873	0.908	0.936	0.956	0.971	0.981
24	0.554	0.632	0.704	0.768	0.823	0.868	0.904	0.932	0.953	0.969
25	0.473	0.553	0.629	0.700	0.763	0.818	0.863	0.900	0.929	0.950

λ \ x	34	35	36	37	38	39	40	41	42	43
19	0.999	1.000								
20	0.999	0.999	1.000							
21	0.997	0.998	0.999	0.999	1.000					
22	0.994	0.996	0.998	0.999	0.999	1.000				
23	0.988	0.993	0.996	0.997	0.999	0.999	1.000			
24	0.979	0.987	0.992	0.995	0.997	0.998	0.999	0.999	1.000	
25	0.966	0.978	0.985	0.991	0.994	0.997	0.998	0.999	0.999	1.000

11 New Quality Concepts and Initiatives, Total Quality Management and Six Sigma

The earlier chapters on Quality Management explained the statistical quality control methods. There was also a short discussion on the organisation for such quality and related cost controls. As mentioned therein, the job of quality mangement is not just advising a sampling plan for the acceptance/rejection of the incoming materials and controlling manufacturing process conditions; it is, in fact, a job at every step of the company's activities.

QUALITY IS EVERYBODY'S JOB

Quality management is a company-wide activity and various functional departments contribute to its success. The marketing department, specifically market research, have information about: what quality characteristics the customers desired and to what extent? This is a valuable input for planning quality. Also the information regarding the quality of the manufactured products needs to be presented to the customers. This is also done by the marketing department. Product design write the specifications for the product, raw materials, bought-out parts, and the contracts with the customers. The purchasing department makes contracts with the suppliers of raw materials, selects the vendors, develops the vendors, keeps track of the performance of the vendors. Naturally, product design and purchasing have much to contribute to the quality of the final product. Production engineers select the processes, methods, and equipments for the manufacture of the product and can provide valuable information regarding the anticipated difficulties in implementing a certain product quality specification. The contribution of manufacturing line is obvious. They are responsible for the actual production, and therefore the final product quality depends much upon their skills, motivation to work, and their interpretation of the specifications. Since the finished product may take as much as one year before it reaches the final consumer, the product quality depends upon the design of the packaging and the method for storage in the warehouses. The quality depends also on how the product is shipped. The purpose of good product quality is to create a good feeling for the company in the minds of the customer and this feeling should be sustained. Therefore the company has to attend to the complaints from customers and provide periodic services to the customers. The quality control laboratory which inspects a batch of raw materials, or semi-finished goods or finished goods or finished products and

approves or rejects them has much to contribute to quality. Many a time, the quality control job is misunderstood because of this last function alone. The product quality has inputs from various angles and a total quality control programme should consider all the different aspects contributing to quality. It is stated by many that "quality is everybody's job in a business". When we take a look at the organisations whose products are of top quality, we always notice that in such organizations all the company employees at all levels and in all functions are motivated to contribute to the total quality establishment effort.

Customer service is at the heart of quality Of late, the perception as to what constitutes quality has undergone a metamorphosis. The traditional view as mentioned in the earlier chapter still holds good. Quality is regarding the performance of the product as per the commitment (written or unwritten) made by the producer to the consumer. It does indeed concern itself regarding the control of defectives in a manufacturing environment and/or complaints in a service environment. However, the scope of quality as a concept has expanded beyond its conventional definition. Defining quality as only the lack of non-conforming product/service would be taking a very limited view. The prevailing new paradigm for world-class quality is: total customer satisfaction. The customer expectations are, there fore, paramount. Customer service is at the heart of quality—for physical products as well as services.

The work on quality by several persons, as mentioned in the following pages, presents this transformation.

TAGUCHI PHILOSOPHY

Genichi Taguchi, a Japanese engineer, realised the importance of cost associated with poor quality and its impact on corporate profitability. Taguchi did not confine himself to the corporate losses alone but took into consideration the losses (due to poor quality) to the society. His principle states that for each deviation there is an incremental economic loss of geometric proportion. The cumulative effect of the functional variations of various products can be very great, although these products may just deviate only a little from the target value of a measurable quality characteristic. Our traditional view has been that there is no negative effect as long as the products/components are within their respective engineering specifications. The whole statistical quality control, with its percentage tolerances and the upper and lower control limits, is based on this traditional view. In our statistical process control so far, we have seen 3-sigma control limits and 'percent' defectives. As long as the process is within these limits, the process was considered to be 'in control' or 'normal' and it was not to be disturbed. Taguchi, however, (contrary to this view) says that the point to consider is the cumulative impact of the deviations from the target value. Using the Taylor Expansion Series, Taguchi developed a mathematical model in which loss is a quadratic function of the deviation of the quality of interest from its target value. The Taguchi Loss Function is shown in the following figure (Fig. 11.1).

Taguchi methods of quality control, therefore, involve the on-line and off-line methods. On-line methods include the use of statistical process control charts amongst others so that the aspect of reducing deviations about the target value are taken care of as far as the process or manufacturing is concerned. The off-line methods involve market research, product design and development, and process development.

The tolerances, the key process variables and the overall system need to be so designed that the variations in the end product are minimised. For Taguchi, the variations from the target

values are very important, and these variations are to be reduced as much as possible. While it is necessary to be 'accurate', it may be better to be 'precise while being inaccurate' than to be 'accurate but imprecise'. For example, between the two hits on the dartboard as shown in Fig. 11.2 and Fig. 11.3, the former should be preferred; because, although the darts have missed the bull's eye, with a correction in the direction of hit, most of the darts will hit the bull's eye. This cannot be said of the more variable process.

Thus, in Taguchi philosophy, the definition of quality is changed from 'achieving conformance to specifications' to 'minimising the variability while achieving the target'. An important aspect of Taguchi philosophy is its linking of the quality of a manufactured product (total loss generated by the product) to the society. If these variations are to be minimised then one has to resort to the Design of Experiments (DOE) in order to identify the factors which are responsible for the variation, to find the relative impact of the factors on the variability and hence to suitably select a combination of input parameters to achieve the result.

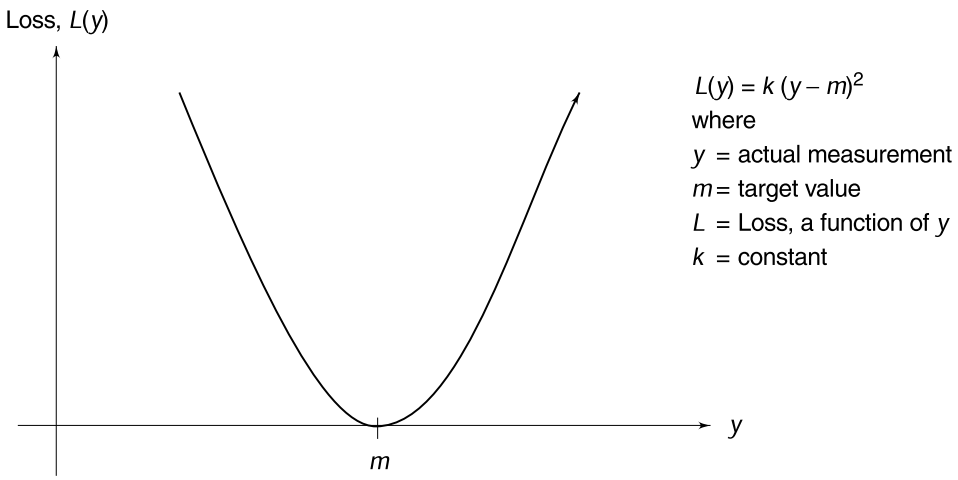


Figure 11.1 Taguchi Loss Function

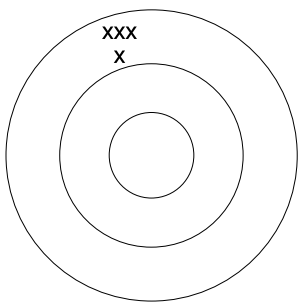


Figure 11.2 Less Accurate but Less Variable

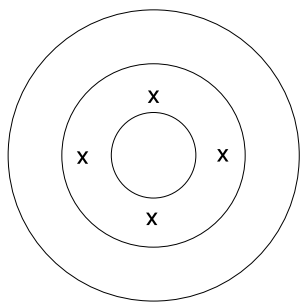


Figure 11.3 More Accurate but More Variable

DESIGN OF EXPERIMENTS (DOE)

DOE is a structured method and is not a hit-or-miss experimentation where input parameters are adjusted randomly hoping to achieve process improvement. Taguchi method uses the orthogonal array in order to express the relationship among the factors under investigation. For each level of any one factor, all levels of other factors occur an equal number of times. This way the experiment is balanced and permits the effect of one factor under study to be separated from the effects of other factors. The design of an orthogonal array does not require that all combinations of factors be tested. Thus, the experiment is cost effective.

If suppose the number of factors is 3 and the levels considered within each factor are 2, then the number of experiments (runs) required are $(\text{levels})^{\text{factors}} = (2)^3 = 8$. The following simple matrix (Table 11.1) depicts one such experiment. The levels chosen are 'high' (1) and 'low' (–1); the factors are *X*, *Y* and *Z*.

Table 11.1 Orthogonal Array

Run	*X*	*Y*	*Z*	*P (output observed)*
1	–1	–1	–1	352
2	–1	–1	1	340
3	–1	1	–1	326
4	–1	1	1	362
5	1	–1	–	404
6	1	–1	1	417
7	1	1	–1	493
8	1	1	1	432

If the objective is to maximise the output *P*, then the run 7 provides a combination of *X*, *Y* and *Z* which would give the desired result. The above experiment also reveals that the factor *X* is very significant since its change from –1 to + 1, in runs 5 to 8, has increased the output *P* considerably. Thus, factor *X* must be very closely controlled while running the production process. The relevance of Taguchi's design of experiments is that we can find a best combination of factors (variables) with only a handful of experiments.

ROBUST DESIGN

DOE indicates that varying the factors can affect the product and/or process adversely. Some of the factors may not be within our control, e.g. weather. The challenge before quality engineering is to see that the product performs consistently. This is called 'Product Robustness'. The goal is to reduce the sensitivity to uncontrollable factors so that the external variation affects the product performance as minimally as possible. A toffee manufacturer noticed that their product solidified to a rock hard condition at temperatures below 40°F and became almost soupy above 80°F. Using DOE, and appropriately selecting/designing the input process parameters, led to a product that was satisfactorily hard in this temperature range. If these kinds of actions towards a 'Robust Design' are not taken, there may be failures due to the external 'noise'. For instance, the 'O' rings which

became brittle and failed at low temperature on NASA's Space Shuttle Challenger is an example of a non-robustly designed product.* Robut design Concepts can also be extended to services—service that will not fail despite variations in the incontrollable factors.

ISHIKAWA DIAGRAM

DOE is one of the ways, albeit a very effective way, of optimising a process and reducing the causes of variations and defects. An older method of cause identification (or identification of important input parameters) is the Cause and Effect Diagram or Ishikawa Diagram (after the inventor of the method). It is also called as Fishbone Diagram. It shows the possible causes for a quality deviation. An example is given in Fig. 11.4 below.

As seen in the figure, there are main factors, the subfactors causing the main factors, the further sub-subfactors causing the subfactors and so on. Thus, by such branching, one can get to the root of the quality problem that is, the deviation in a quality characteristic. It also provides a good understanding of the various cause-effect dependencies which helps in controlling quality. It can also provide useful input to the DOE though it fails to provide an exact diagnosis as in the Design of Experiments. While using Ishikawa diagrams, one has to address all the root causes with equal attention.

Whereas, the DOE will point to a select one or two causes which, when attended to, will produce a major improvement in quality. Ishikawa diagrams help in systematically listing the factors that could possibly cause the variations in the desired quality characteristic. In fact, the factors (parameters) to be evaluated in a DOE can be obtained from Ishikawa diagrams. Cause and effect diagrams are as useful in service industry as they are in manufacturing industry.

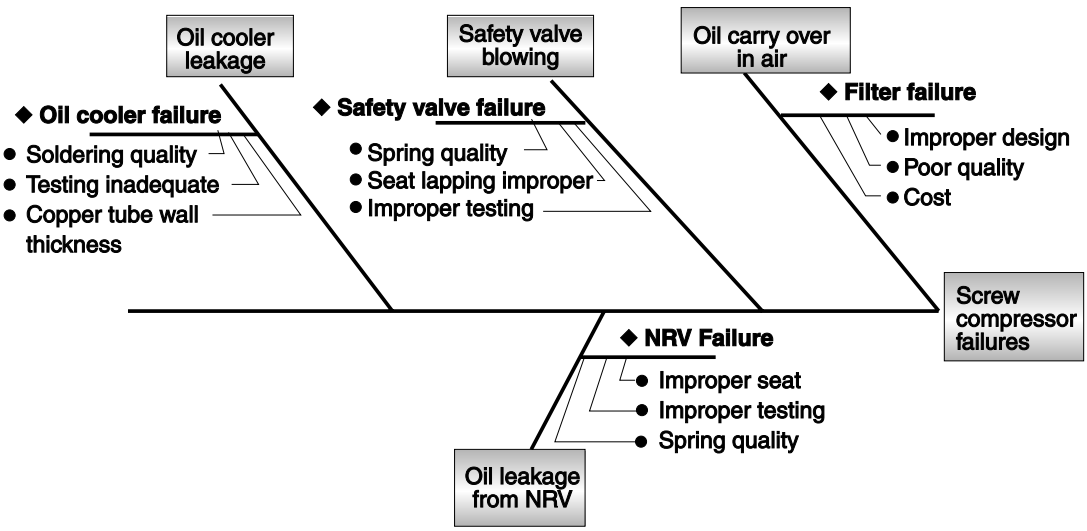


Figure 11.4 Cause and Effect Diagram

Courtesy: Kirloskar Pneumatic Co. Ltd., Pune

* Khory, Noshir, 'Introduction to Experimental Design in Manufacturing', *Motorola Automotive and Industrial Electronics Group*, Northbrook, Illinois, USA, Dec. 1997.

QUALITY FUNCTION DEPLOYMENT (QFD)

Cause-effect diagrams and Taguchi methods of DOE are good for ensuring the consistency of delivery of the quality as already decided upon by the organisation. But, the question to be asked is: How do we decide as to what quality characteristics are to be incorporated into the product? How do we decide as to which component of the product/service should provide which part/ aspect of the quality? That is, how do we plan to incorporate the quality characteristics into the product? Quality Function Deployment (QFD), which is a customer-driven planning process, answers these 'What' and 'How' questions. It does this by capturing the voice of the customer, breaking down quality into tangible, manageable, technical and operational actions—which may be design and/or process actions—so as to ensure that the customer's wants, needs and expectations are met to the maximum extent possible. QFD is the deployment of the quality functions/characteristics desired by the customer into the design of the product and the processes producing the product. While QFD is very useful for the design of new products, it can also be useful in improving the existing products. Thus, following are the elements of QFD:

1. Find out what are the Customer Requirements For instance, product should be durable, it should not come apart, it should work well with different materials, it should be heat resistant, it should be environmentally friendly, its cost should be low and the like. These are some of the 'customer voices' obtained through a survey of the target market through questionnaire responses, interviews. Express this customer's voice in distinct actionable requirements from the product/ process/service. Give customer importance ratings to these requirements, i.e. importance from the customer's point of view. These ratings range from 1 (least important) to 10 (most important).

Customer requirements

Broad classification	Detailed requirements	Importance rating
		9
		7
		8
		8
		9

2. Translate these Quality Requirements into Technical Requirements For instance, temperature rise, pressure difference, break force, absorption rate, porosity, biodegradation life, cycle life of the product, etc. could be some of the technical requirements. Without our intending so, it would happen very frequently that some technical requirements have relationship to more than one quality requirements. In order to highlight those technical requirements that have major relationship to customer's voice, all the relationships are, therefore, weighted as a strong relationship (weightage 9), moderate relationship (weightage 3) or a weak (weightage 1) relationship (symbols: ◎strong, ○ moderate, Δ weak). This helps us in determining as to which technical requirement needs our special attention. These relationships can also be given arrow symbols (↓↑) to denote whether more/bigger is better or less/smaller is better; '○' would mean meeting a definite target is best for customer satisfaction.

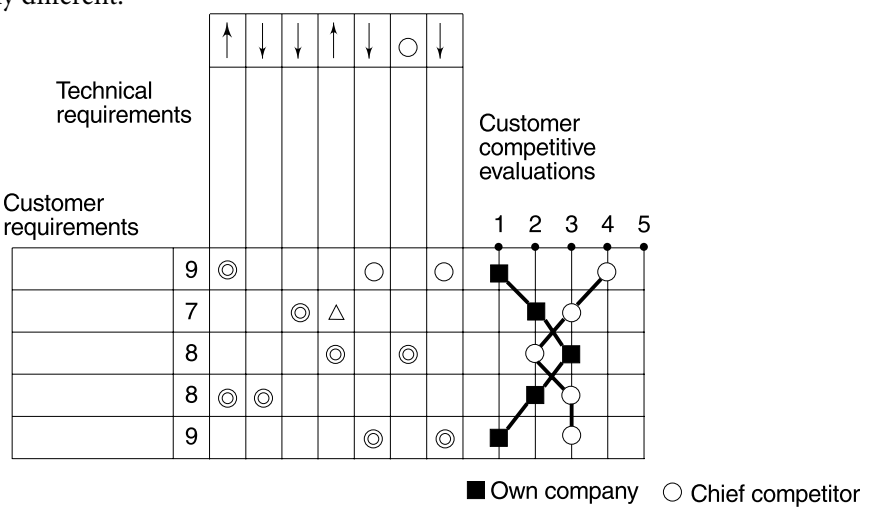
The customer requirements are placed in rows, while the technical requirements are placed in columns (one technical action can meet one or more customer requirements and one customer requirement may require more than one technical action in some cases), thus forming the QFD matrix. It should be noted that the technical requirements are very important because organisations do not, generally, work on the customer's voice directly. They work on technical requirements that are the translations of the customer's voice.

Customer requirements		↑	↓	↓	↑	↓	○	↓
	9	◎				○		○
	7			◎	Δ			
	8				◎		◎	
	8	◎	◎					
	9					◎		◎

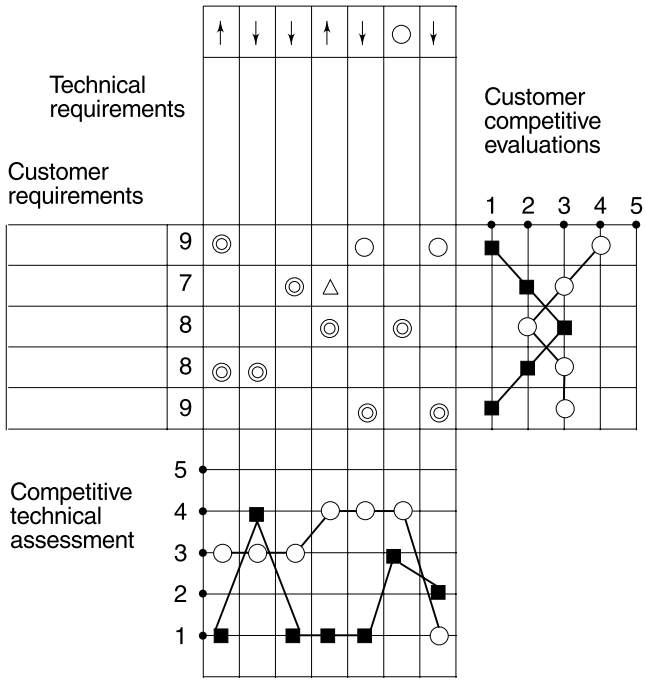
3. The Operational Targets for these Technical Requirements are Determined For example 80°C temperature maximum, 5 kg/sq cm minimum pressure difference, zero fluid loss, etc. targets appear at the bottom of the QFD matrix, below the competitive technical assessment (which is discussed in point no. 5 which follows in this section). The targets could change after performing the following analyses.

4. Our Product and Competing Products are Evaluated, on a 1 to 5 Scale, for Meeting the Various Customer Requirements This will reveal some vital information helpful in further fine-tuning the 'customer requirements', and therefore, the technical requirements. These evaluations are plotted. These plots appear on the right hand side of the QFD matrix.

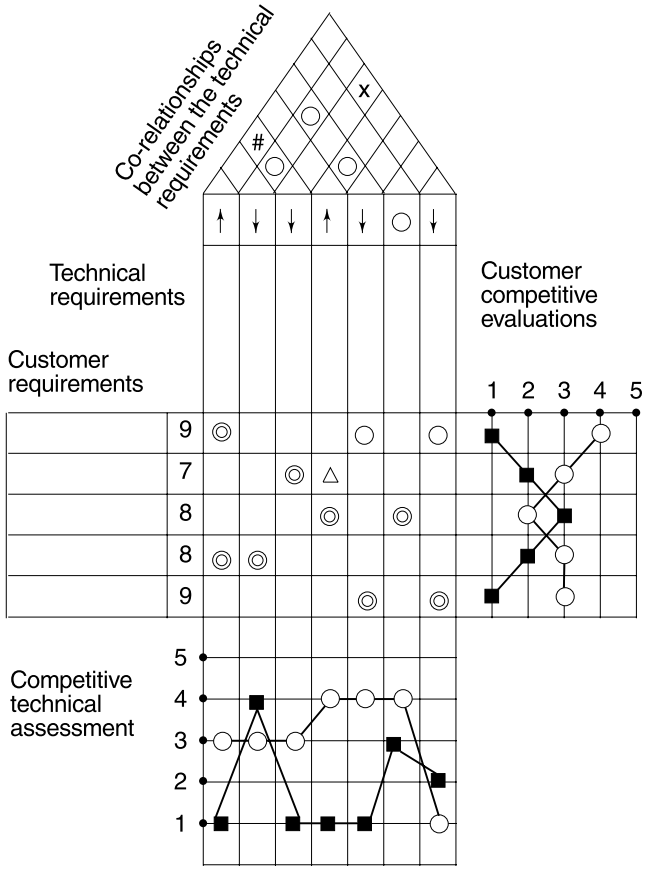
For instance, if our product—a bathing soap–is judged as 1 and the competitor's soap is judged as 4 on the customer requirement of 'good lathering', then we must take appropriate technical action of increasing the alkali content from 0.05 per cent to 0.10 per cent (which is what the customer's soap contains). But, despite this increase in alkali content, if our company's soap still languishes at only 2 on the customer's evaluation, then there is more to it than just 'alkali content' or more to it than just 'lathering'. There could be a parallel technical condition that needs to be satisfied. Or, by 'lathering' the customer may be describing some other experience such as a smooth fine oily film deposited on the skin by the soap. In which case, the technical requirements are entirely different.



5. Similarly, our Product and the Competing Products are Evaluated, on a 1 to 5 Scale, for Meeting the Various Technical Requirements This, in conjunction with the above evaluation, will help in fine-tuning the technical requirements. The plots are graphically depicted at the bottom of the main matrix.

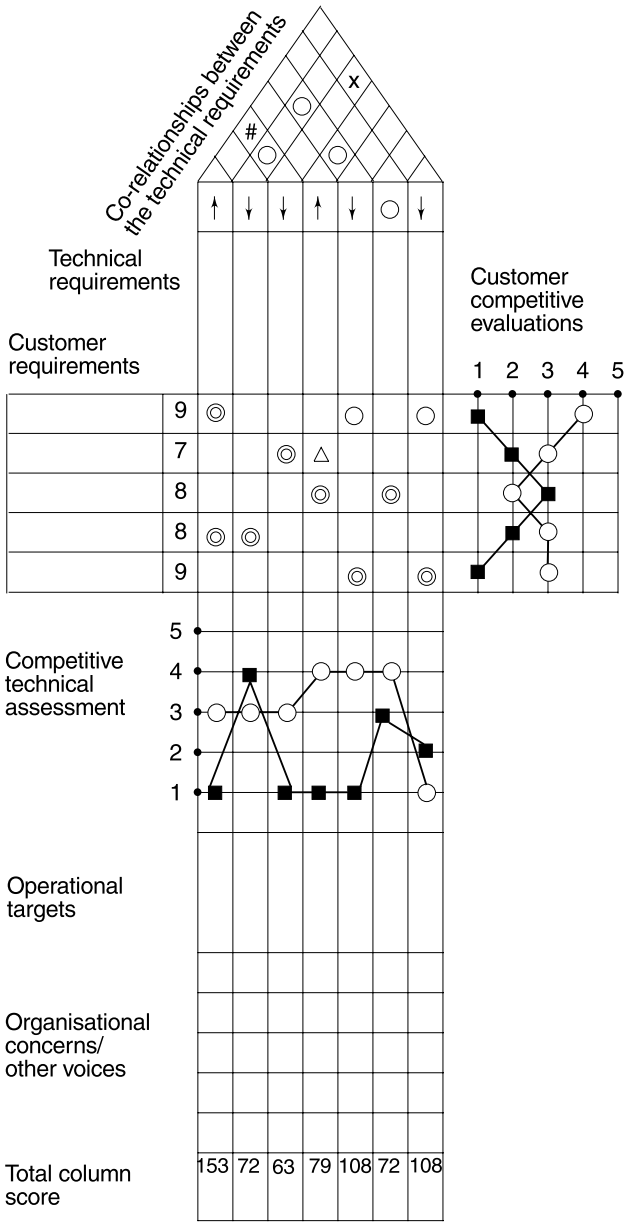


6. Many Technical Requirements may have Co-relationships which Need to be Identified Enhancing one may harm another or may have beneficial results. For instance, a technical requirement of improving km. per litre of petrol may reduce the pick-up (i.e. acceleration) of the vehicle. To mention another example: the technical action to increase the durability of the material of construction of a consumer-item may in some cases negatively affect the technical requirement of an environmentally degradable (biodegradable) item. Whereas, fire-resistance and sweat absorption characteristics of cotton-based garment could simultaneously improve with the same technical action viz. increasing the proportion of cotton fibres in the blend. This is a positive co-relationship. These co-relationships, particularly the negative co-relationships, dictate the trade-off between conflicting technical actions. These are indicated on the top of the technical requirements in a diagonal matrix. (symbols: # strongly negative, × negative, ○ positive).



7. There may be Concerns/voices other than that of the Customer which also Need to be Attended to For instance: government regulations, IS (Bureau of Indian Standards) specifications, standards of importing countries (for example, DIN standards of Germany, BS standards of UK, UNI/EN standards of Italy, SS of Singapore and ANSI of USA), environmental considerations and the like. All these are also indicated in the QFD, immediately below the operational targets. These are intentionally kept separate from the customer's voice, so that they will not diffuse the voice of the real customer.

8. Technical Requirements may Need Prioritization The customer importance rating and the corresponding number (weightage) for the strength of relationship to the related technical requirement are multiplied to obtain a score. The scores in a column (i.e. corresponding to a technical requirement) are totalled and indicated at the bottom-most row of the QFD. For example, the total score for the first column is: $(9 \times 9) + (8 \times 9) = 153$; similarly, the score for the fourth column is: $(7 \times 1) + (8 \times 9) = 79$. Columns with high total scores are the actions that are very important for the consideration of the product/quality planner. Such prioritisation also helps in the trade-off between the negatively co-related technical requirements (for example, in the trade-off between the technical requirements corresponding to the first and third column—scores of 153 and 63—in the adjoining figure).



9. Analyse all the above and Finalise the Technical Actions and their Respective Targets This is the crux of the matter or the final decision regarding the design of our product (which also could mean/involve service). This is the final result of our QFD exercise of capturing the customer's voice.

The QFD matrix diagram resembles a picture of a simple house with a sloping roof; hence, QFD is also called as the 'House of Quality'.

It will be appreciated that an organisation should not stop with only product planning; rather, it should lead to the planning of the component parts, which should lead to the planning of the process, then to manufacturing planning, which in turn should lead to maintenance planning, quality assurance planning, planning for the suppliers and so on. Quality function needs to be deployed at various levels in the organisation and its 'family'. It might interest the reader to know that QFD is yet another management process of Japanese origin.

Deviations from the designed quality can be caused due to following reasons, at a broad level:

(a) *Mechanical problem* Deterioration in the condition of the machinery or equipment.

(b) *Physical factors problem* Change in the quality of the input materials and changes in the physical environment.

(c) *System problem* Lack of or inadequacy of systems. Systems could also be improper.

(d) *Customer taste/usage changes problem* Change in the way the customer uses or would like to use the product/service. Customer's purpose, perception and mode of usage, if changed, would mean that the focus of quality itself has changed.

(e) *Human/Attitudinal problem* Lack of motivation amongst all or various levels of employees including managers.

The reasons (a) and (b) relate to process technology and could be attended to by suitable changes in the design of the process and/or the product. Design of Experiments and Robust Design combined with appropriate Total Productive maintenance and vendor arrangement should lead to improvements in quality. The reason (e) is concerned with motivational aspects which are referred to later in this chapter. Reasons (c) and (d) refer to the management system, its standardisation with respect to consistency, adequacy and verifiability, and appropriateness vis-a-vis the customer. One of the major attempts to bring in these improvements in the system is the ISO 9000, the system standards.

ISO 9000

ISO is the acronym for International Organisation for Standardisation located in Geneva, Switzerland. The term 'isos' is a Greek word meaning equal, homogeneous or uniform. That is precisely the idea behind ISO 9000 which is an attempt to bring in uniformity in the quality standards prevailing—each pertaining to a different country, for example, BSI or British standards, DIN or German standards, ASQC or American standards and MIL standards. The genesis of ISO 9000 began with the launch of Technical Committee 176 in the year 1979 and culminated in the ISO 9000 series which was issued in the year 1987. Different countries have now adopted ISO 9000 series under their respective national standards. India has adopted it as IS 14000 series, while United States of America has adopted it as ANSI/ASQC Q90 series (Q90, Q91, Q92, Q93 and Q94), and European Union as EN (European Norm) 29000 series.

The ISO 9000 standards, which consists of six parts viz. ISO 8402, ISO 9000, ISO 9001 ISO 9002, ISO 9003 and ISO 9004, stand for system standardisation and certification rather than product standardisation and certification. They do not replace but complement the product standards.

Content of ISO 9000

ISO 8402 deals with standardisation of quality vocabulary. ISO 9000 is actually a series of guidelines for selection and use of the appropriate systems standards of ISO 9001, ISO 9002 or ISO 9003. Thus, ISO 9000 is the road map to the entire series. ISO 9004 helps building up a quality system that can fit to a specific situation. It offers guidelines for interpreting the elements required in ISO 9001, ISO 9002

or ISO 9003. There are 20 chapters in ISO 9004, viz: (1) scope and field of application, (2) references, (3) definitions, (4) management responsibility, (5) quality system principles (structure of the quality system, documentation and auditing of the quality system), (6) economics (quality-related cost considerations), (7) quality in marketing, (8) quality in specification and design, (9) quality in procurement, (10) quality in production (process control), (11) control of production, (12) product verification (inspection and testing), (13) control of measuring and test equipment, (14) non-conformity (control of non-confirming product), (15) corrective action, (16) handling and post-production actions (storage, packing, delivery and after-sales service), (17) quality documentation and records, (18) personnel (training), (19) product safety and liability, and (20) statistical methods. After a company adopts ISO 9000, an independent official certifying body will assess the company. The assessor will check whether the company, desirous of the certification, has covered the basic quality elements pertaining to its industry, business, and customers. The firm then gets certified to either ISO 9001, ISO 9002, or ISO 9003.

ISO 9001 is the most difficult of the three standards to be chosen for certification, because it includes all the twenty elements. This comprehensive certification is desired by manufacturing organisations which design their own products. For ISO 9002 certification, two of those twenty elements are dropped viz. design and servicing, so as to focus more on manufacturing. ISO 9002 applies to firms which provide goods and/or services as per the design or specifications given by the customer. Many process industries used to opt for the ISO 9002 certification as they thought that their activities neither involve design nor servicing. However, now many of these firms are seeing the parallels between R&D and 'design' (under the ISO) and hence opting for the comprehensive ISO 9001 certification. The ISO 9003 standard drops most of manufacturing, leaving only final testing and inspection. ISO 9003 certification is generally desired by organizations like the testing laboratories which inspect and test the supplied products. This ISO standard is the least comprehensive of the three.

It may be worth repeating that ISO 9000 series is a system standard and not a product quality standard. If a firm gets ISO 9000 certification, it does not automatically mean that the firm's products/services are superior in quality to the other firm which has not opted for such certification. For instance, for a long time, Japanese firms producing excellent quality products have not bothered to obtain the ISO certification. This does not make their products and services inferior in quality:

Benefits from ISO 9000

There are many benefits of getting an ISO certification:

1. ISO 9000 certification has become the *de facto* minimum requirement for those wishing to compete globally.
2. All actions in preparing for ISO 9000 certification and in maintaining the certification would result in streamlining of the quality management system which may lead to improvements in product quality. The extent of improvement may vary from one firm to another. In any case, the formal documentation procedures which ISO 9000 demands, would minimise misinterpretations, manipulations and malpractices.
3. It can also lead to significant cost reductions through reductions in rework, warranty work, repair, scrap etc.
4. ISO 9000 lays stress on customer orientation. This would result in better overall results for the company in addition to improving customer relations.
5. There may be an impetus to improve employee relations, employee empowerment and organisational development.

Getting the ISO 9000 certification is not all. There are re-audits by the ISO registrars every three years and surveillance audits approximately twice a year in order to ensure continued compliance. ISO 9000 certification is valid for not more than three years. In order that the system standards translate to product/service quality, it requires that a strong commitment to quality continues to be present with the top levels of management and that there are attitudinal changes at all levels in the entire organisation. This takes time, training, and sustained management effort. After all, ISO 9000 certification can only be a part of the total quality management effort.

ISO 9000 Standards as Non-tariff Trade Barriers

Some countries, especially the developing ones, have feared that ISO 9000 could be used as a trade barrier (NTB) by the developed countries. 1992 was the year in which the European Community was to start asking for full compliance to ISO 9000 for imports from other countries; and the year 1992 was dreaded for that reason. However, such fears of ISO 9000 being a trade barrier do not hold much credibility. We in India should view these ISO 9000 standards in a positive light as an impetus to continuous improvement in our organizations, so that 'Made in India' products are sought after internationally and Indian companies become truly global players.

ISO 14000: GLOBAL ENVIRONMENTAL MANAGEMENT STANDARDS

Although the ISO 14000 series have no formal relationship with ISO 9000 series of standards, both the series are structured very much alike. The guiding intention behind ISO 14000 is to bring about global environmental consideration in all industrial and business activities, transcending narrow national or regional considerations. Since the environmental effects are global and, therefore, there are several transnational issues, it is felt that in this globalised world of trade a corporate should encounter a single/uniform environmental management system anywhere it would like to operate. The ISO 14000 certification is voluntary, just like ISO 9000, but it is likely to become an essential prerequisite for carrying out trade around the world.

KAIZEN

Kaizen, meaning 'continuous or ongoing improvement' in Japanese, is an inseparable aspect of the management of quality. There is an old saying in Japanese, which is very apt: 'If a man has not been seen for three days, his friends should take a good look at him to see what changes have befallen him.' Such is the Japanese belief in unending improvement.

In fact, continuous improvement is required in all activities of the organization, be it productivity improvement or new product development or labour-management relations or total productive maintenance (TPM) or Just-In-Time production and delivery system or customer orientation. All directly and indirectly productive or productivity generating activities of the organisation come under the umbrella of Kaizen (refer Fig. 11.5).

Kaizen has to basically do with small, step-by-step continuous improvements. While innovations or drastic improvements (mainly as a result of a large investment in new technology and/or equipment) are welcome for improving the function of the organization in terms of market reach, productivity and profitability, such innovations only happen once in a while and somewhat unpredictably. Smaller and continuous improvements are more realizable, predictable, controllable and acceptable. Various behavioural, cultural and philosophical changes are better brought about through small step-by-step improvements than through radical changes.

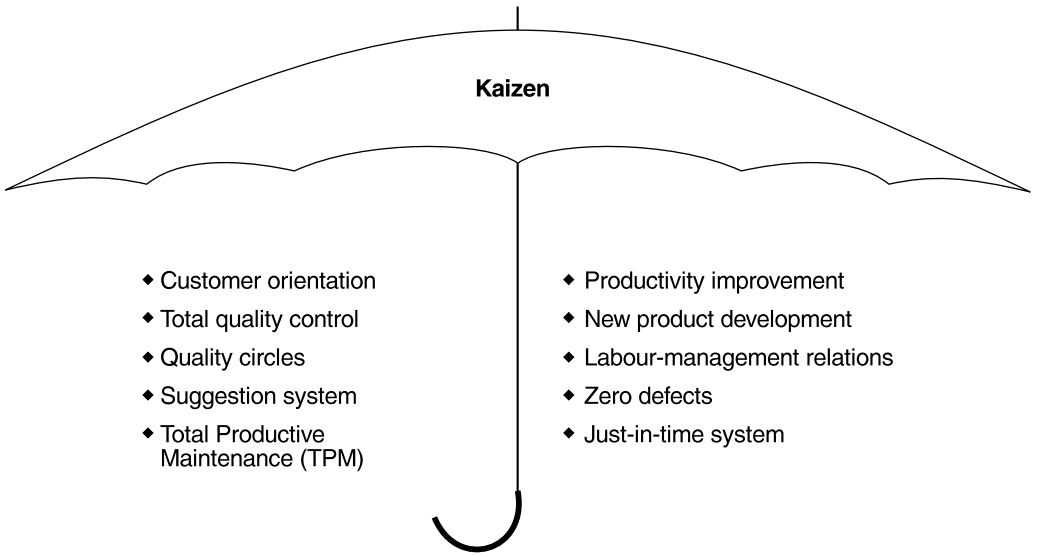


Figure 11.5 Kaizen Umbrella: Applications of Kaizen

Kaizen philosophy believes that people at all levels, including the lowermost levels in the organisational hierarchy, can contribute to improvement. This is possible because Kaizen asks for only small improvements. The Japanese and the Western (and, by their influence, our Indian) perceptions are presented in Fig. 11.6. A point to be noted is that Kaizen is to be performed at all levels, from the top management to the lower level employees.

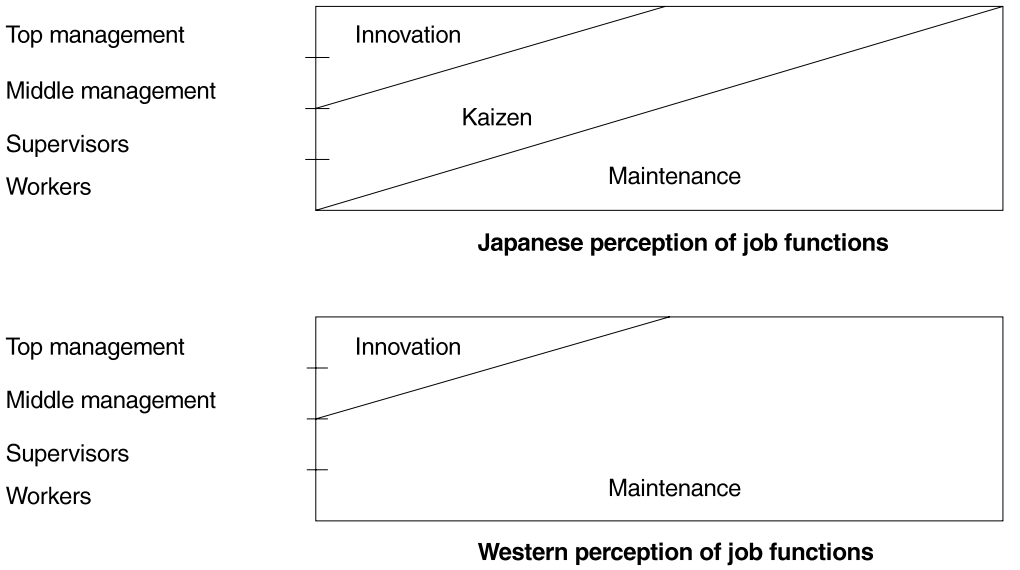


Figure 11.6 A Comparison of Japanese and Western Perceptions of Job Functions

Source: Imai, Masaaki, *Kaizen*, McGraw-Hill, Singapore, International edition, 1991.

Existence of Kaizen does not belittle the importance and necessity of innovations. Innovations should be supplemented by continuous improvement, so that the benefits of the innovation keep increasing over time instead of decreasing their utility due to constantly changing environment. Figure 11.7 depicts this succinctly.

The worst organizations are those that do nothing but maintenance. These organisations have no internal drive for either Kaizen or for innovation. Change is forced on management by the market conditions and competition, and the management is unaware where it wants to go. Unfortunately many of the Indian companies fall in this category. And then, they cry hoarse against liberalising the Indian economy, against more global participation and for a more 'level field' for the Indian organisations of their ilk.

Quality in products/services comes through:

(a) Physical standards	… … …	quantifiable standards
(b) System standards	… … …	methodology-oriented
(c) Behavioural standards	… … …	ways of interacting
and **(d)** Philosophical standards	… … …	ways of thinking or attitudes and motivational aspects

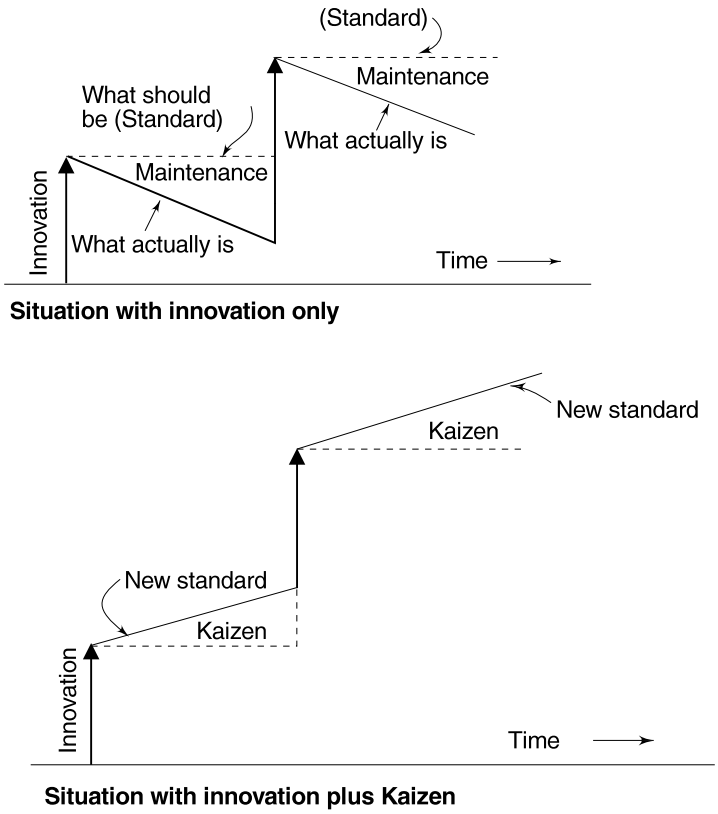


Figure 11.7 Effect of Kaizen

Source: Imai, Masaaki, *Kaizen*, McGraw-Hill, Singapore, International edition, 1991.

Kaizen has to do with the philosophy of, or strong commitment to continuous improvement. Without a philosophical basis, improvements can diminish and disappear over time; they may not even materialise.

CONTRIBUTION OF DEMING

W. Edwards Deming, an American quality expert, became a *Parama-guru* (Guru par excellence) in Japan because he preached the philosophical basis of quality and productivity which were accepted, absorbed and implemented with sustained positive results by the Japanese. The highest award in the Japanese industrial circles is the Deming Prize for Quality.

Referring to the process control charts, Deming pointed out that the removal of a special cause (assignable cause) of variation, although important, does not really amount to the improvement of the process. It only brings the system back to where it should have been in the first place. The important problems of improvement commence once you achieve statistical control. One of the aims of continuous improvements should be to shrink the spread between the control limits, that is, to minimise the variations. This concept is similar to Taguchi philosophy. Perhaps, it was the precursor to the latter. The whole effort is to improve the process capability and, more generally, the system or organisational capability. This requires that experiments be designed and performed in order to highlight areas for continuous improvement.

Dr Deming introduced the Plan-Do-Check-Act (PDCA) cycle to the Japanese decades ago. Briefly, a company plans a change, does it, checks the results and, depending upon the results, acts either to standardise the change or to begin the cycle of improvement again with new information. Continuous or never-ending improvement requires such a circular (cyclical) approach. Otherwise, we are used to doing projects in a linear fashion, with a beginning and an end. The Deming Cycle or the PDCA cycle is shown in Fig. 11.8.

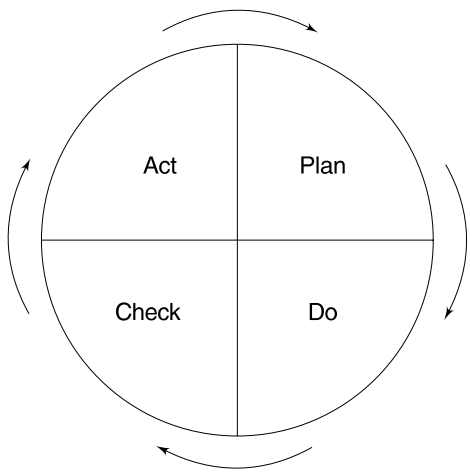


Figure 11.8 Deming Cycle

Dr Deming propounded 14 points for the transformation of business in Japan. These basic principles as given in Table 11.2 below are applicable globally and in any industry/business.

Table 11.2 Deming's 14 Points for Transformation of a Business

1. *Create constancy of purpose toward improvement of product and service* A company's role is to stay in business and provide jobs through innovation, research, education, constant improvement and maintenance, rather than pursuing the singular objective of making money.
2. *Adopt the new philosophy* A transformation is required in Indian organisations. A strong commitment to the philosophical basis of these 14 points is required.
3. *Cease dependence on mass inspection* Deming says that routine large scale inspection to improve quality is equivalent to 'planning for defects'. Why pay workers to make defects and then to correct them? Quality comes not from inspection but from improvement of the process.

(Contd.)

4. *End the practice of awarding business on the basis of price tag alone* The buyer company must change its policy from lowest initial cost of material purchased to lowest total cost. Buyers should seek the best quality in a long-term relationship with a single vendor for any one item.

5. *Improve constantly and forever the system of production and service* Deming stresses the importance of continuous improvement or what came to be known as Kaizen. Quality is built in through improvements in the design of the products, processes and systems.

6. *Institute training* There should be basic foundation of training for the management and the new employee. The greatest waste in India is in not using the abilities of people.

7. *Adopt and institute leadership* As Demanding put it: 'The job of management is not supervision, but leadership. Quality and productivity cannot come about in a leadership vacuum'.

8. *Drive out fear* In order to have improvements in quality and productivity, it is essential that people feel secure. Fear only gives rise to impaired performance, padded figures and lack of initiative. Fear makes people think only in short-term at the cost of long-term results.

9. *Breakdown barriers between staff areas* Various departments/units of an organization must work in unison as a team towards the organisational goal. Productivity and quality can come about only when there is this integration and synergy.

10. *Eliminate slogans, exhortations, and targets for the work force* As Goethe observed, 'Where an idea is wanting, a word can always be found to take its place'. Slogans, posters and exhortations are directed at the wrong people. The charts and posters take no account of the fact that the most trouble comes from the system for which the management is responsible. Also, numerical goals set for people, without a road map to reach the goal, have effects opposite to the effects sought.

11. *Eliminate numerical quotas for the work force and numerical goals for management* According to Deming, a quota is a fortress against improvement of quality and productivity. The job of management is to replace work standards by knowledgeable leadership.

12. *Remove barriers that rob people of pride of workmanship* People always want to do a good job and be proud of it—be they workmen or managers. However, in many organisations people–whether in management or the shop floor—have become, to management, a commodity.

13. *Encourage education and self-improvement for everyone*

14. *Put everybody in the company to work to accomplish the transformation*

The role of management in terms of providing leadership, designing and implementing appropriate systems and motivating people comes out clearly from the above discussion. Principles guiding management of quality are no different. The next section deals with the various movements taking cognisance of the motivational factor in quality.

MOTIVATION IN QUALITY MANAGEMENT

Zero Defects Programme

An illustration of the motivational aspects of quality management could be given by means of the relatively novel ideas generated by the Zero Defects Programme and Quality Circles. The philosophy behind Zero Defects is to negate the commonly held view that 'to err is human'. Instead, Zero Defects philosophy believes in total perfection or 'to do the job right the first time'. This idea first originated in 1961 in the Orlando Division of the Martin Company in USA which manufactured Missiles Systems. It was noticed in this company that failures in the Missiles System were caused, many a time, by small items costing as low as $1.50. The Zero Defects Programme reportedly paid rich dividends to this company.

Errors or defects are caused by two factors: lack of knowledge and lack of attention. While the former factor can be taken care of by imparting more knowledge, the latter is an attitudinal problem.

Modern Worker vs. Traditional Worker The main theme behind Zero Defects is that the worker should be positively motivated to achieve as much perfection in his job as possible. The modern worker, as opposed to the traditional worker, is alienated with the product, i.e. he has little pride in his work. The mass production of goods may be one of the causes responsible for this. Also achievement, enjoyment and responsibility is lacking significantly in modern workers. Thus, the modern worker resorts to complaints regarding his working environment, wages, and other things.

Motivating the worker to take pride in his job and to do his job as perfectly as possible the first time itself is the heart of the Zero Defects Programme.

Means for Motivation Motivation is achieved through various means: posters, publicity, voluntary pledges by workers, visits of customers to the plant, etc. The thrust is on each worker fixing his own defectives-reduction goal by himself (not by the supervisor, although the supervisor may help him in the process). Before such pledges and other motivational techniques, it is necessary to generate a good awareness about the product amongst workers, such as, what is the product, where is it used, etc. It is also necessary to generate an awareness of the performance of the product-quality in the past. Such an awareness campaign should precede the actual implementation of the Zero Defects Programme.

Organization of the ZD Programme The Zero Defects Programme should be a separate activity coordinated probably by an administrator with the help of a number of Zero Defects representatives working in various functional areas and manufacturing departments of the company. The Zero Defects Administrator may report to the Quality Manager of the organization. Top management support is absolutely essential for implementing a radical programme such as Zero Defects.

Removal of Errors For the actual implementation of the Zero Defects Programme, in addition to the positive motivation of the worker to do a better job, it is also essential to probe, by various means, the causes of the defects or errors. One such vital component of the Zero Defects Programme is the Error Cause Removal campaign. Suggestions are invited from all, in writing, as to how the errors are caused in his/her own work as well as in other areas of work in the company. Of course, not all the causes could be genuine. But the idea here is to encourage all suggestions, because some small things may be causing large errors. The Zero Defect administrator with the help of others might sift through these suggestions and implement only a few, but it is necessary that he give positive recognition to all the workers who have shown interest in the Zero Defect Programme; it could be a certificate, it may be some sort of publicity in the company's magazine, or it may simply be a pat on the back. But such feedback to the workers is important to keep up the tempo of ZD.

Criticism of the ZD Programme The Zero Defects Programme is, therefore, basically a motivational programme where the workers are made more responsible, more achievement-oriented and more proud of their work. It cannot be a short-term programme; it has to be a long-term programme. Because of this, some think that interest in ZD may be lost in the long-term. Such

apprehensions are not warranted, provided (a) the management (including the top management) is itself not demotivated towards ZD, and (b) provided that all the important precautions regarding implementing the Zero Defect Programme are properly taken care of. To explain the latter: if a company has a large component of brought-out parts in its final product, it goes without saying that the Zero Defects Programme should be applicable and operating in the vendor organizations also. Although many feel that it is conceptually impossible to have *zero* defects, nevertheless, benefits from ZD in terms of improved quality are substantial in the light of the cost associated with the Zero Defects Programme. In many organisations abroad, the benefits-to-cost ratio has been said to be as high as 70 to 1. In addition to the benefits in terms of better quality of product, there are many indirect benefits such as improved industrial relations, better plant utilization, etc. On the whole, the Zero Defects Programme, if properly applied, can produce results on a long-term basis.

Quality Circle

Whereas ZD promotes motivation individually and invites suggestions individually, Quality Circle is a collective effort where 3 to 15 volunteers from the workers form a group and meet regularly—weekly or bi-weekly for about an hour—in order to identify, analyze and search for solutions to work-related problems and the ways of implementing the solutions. The meetings, which are generally supervised (usually the Foreman), address themselves to technical problems and follow a strict problem-solving approach (workers and management are trained in it) so that the meetings do not fritter the time away and become forums to handle grievances.

The problems addressed are not limited to quality alone but deal with all "technical" problems that affect productivity.

Every department can have its Quality Circle and this should depend largely on the initiative of the workers themselves, with the support and encouragement from the management.

Quality Circles should encourage participation by all members and should foster creativity. The idea is to develop the talents of the people to develop leadership besides getting a bunch of good ideas to solve problems by tapping the collective intellect and creative genius of the working staff.

Philosophy behind Quality Circles Quality Circle is a philosophy of workers' direct involvement in solving problems that affect their work, their work output and their work place. It is also a philosophy of human resources development of nurturing and bringing out the human potential.

The results of Quality Circles could therefore, only be measured in the long-term although many organizations here and abroad have claimed significant benefits within a short period of time.

The successes of Quality Circles in Japan are striking and it is sometimes referred to as a Japanese management technique. The Circles can be effective here or elsewhere also, if the management commitment to the basic philosophies underlying the concept of Quality Circles is there. This philosophy and commitment takes time to permeate all levels of the organization. Of course this depends upon the already existing organizational climate and culture, and upon the social culture within which any organization has to function. In India, BHEL started its first Quality Circle at its

Hyderabad unit in 1980-81. The idea caught on in the entire corporation and in two years there were more than 200 circles with about 1800 members. Other companies also immediately followed suit. Some of these were Jyoti, Shriram Refrigeration, Kirloskars, Sundaram Fasteners. Cromption Greaves, Madura Coats, Bharat Fritz Werner, Essae Industries and Mangalore Chemicals and Fertilisers. The results of the experiment of Quality Circles in Indian industries are encouraging. The reasons for this, it has been said, can be seen in the firm commitment and continual supportive guidance by the top and senior managers to the Quality Circles Programme. A word of caution: Indian industries have still a long way to go before catching up with world-class quality. As our organizations are improving the quality of our products, the foreign competitors are also continuing to improve their product quality.

Indian Experience It should be noted that, Quality Circles cannot immediately be imposed on any unit and expect to yield results. Mutual trust, mutual concern for development, and cooperation, if not already existent in sufficient measure take time to build. Circles can help accelerate this building process but the introduction of this potent concept in any organization has to be gradual. Or else, with few initial failures, the zeal may not be sustained in the long-term.

Factors Influencing the Success of Quality Circles Quality Circles is a case where the leadership in bringing about changes is taken by workers themselves leaving the management with the new role of an advisor, a catalyst, a facilitator. The labour unions also have to change their traditional concept of leadership style. This change in attitude and in the style of leadership takes time. The management has to get over its phobia of losing the management prerogative of decision-making, and likewise unions have to rid themselves of the fear that management are trying to undercut their power through this new gimmic. These fears may be far-fetched, because Quality Circles address themselves only to technical problems. But it is also true that Quality Circles are not just a modified version of the old 'suggestion box'; far from it.

For the good work done by such Circles, some organizations believe in giving tangible recognition such as monetary incentives. Although 'recognition' is essential, monetary incentives pose tricky problems such as: How much of incentive and how to distribute it amongst the workers? Moreover, monetary incentives may be unnecessary. As a worker from BHEL has pointed out, in Quality Circles the work itself is a reward besides having a safer and improved work environment.

The concept of Quality Circles is also, reportedly, being experimented in various non-industrial sectors such as hospitals, banks, educational institutions, etc. in India. Professional bodies such as the National Institution for Quality Assurance and the Indian Association for Quality and Reliability have been helpful. The Quality Circle Forum of India has been active in the propogation of knowledge, gained from experience, about the methodology for starting and establishing Quality Circles in the Indian environment.

SERVICE QUALITY

Chapter 3 (Services) dealt with service quality to some extent. Table 3.5 mentioned the various determinants of service quality. The table is helpful in identifying the quality determinants most important to the customer segment of a firm. This identification provides focus for a quality improvement programme. Also in comparing quality delivered by the company vis-à-vis its competitors, the assessment can be based upon the key quality determinants.

Service Quality Model

One of the best models on service quality has been presented by the same three persons viz. Valerie A. Zeithaml, A. Parasuraman and Leonard L. Berry. (Fig. 11.9 furnishes the model.)

The gaps that are shown in Fig. 11.9 indicate the key discrepancies between the firm's perceptions and actions and the customer's expectations. These gaps need to be closed in order to improve the service quality. Given below is an explanation about these gaps.

Gap 1 This gap depicts that the management's perceptions of customer's expectations are different from what the customer actually expects. This could happen due to:

- Insufficient market research or inadequate use of the available market research information.
- Inadequate interaction with the customers.
- Communication gaps within the organisation due to various reasons, for example: too many levels of management.

Gap 2 This gap represents the extent to which the service quality standards have gone wrong. This can happen because of:

- Inadequate task standardisation.
- Absence of goal-setting.
- Inadequate management commitment to service quality.

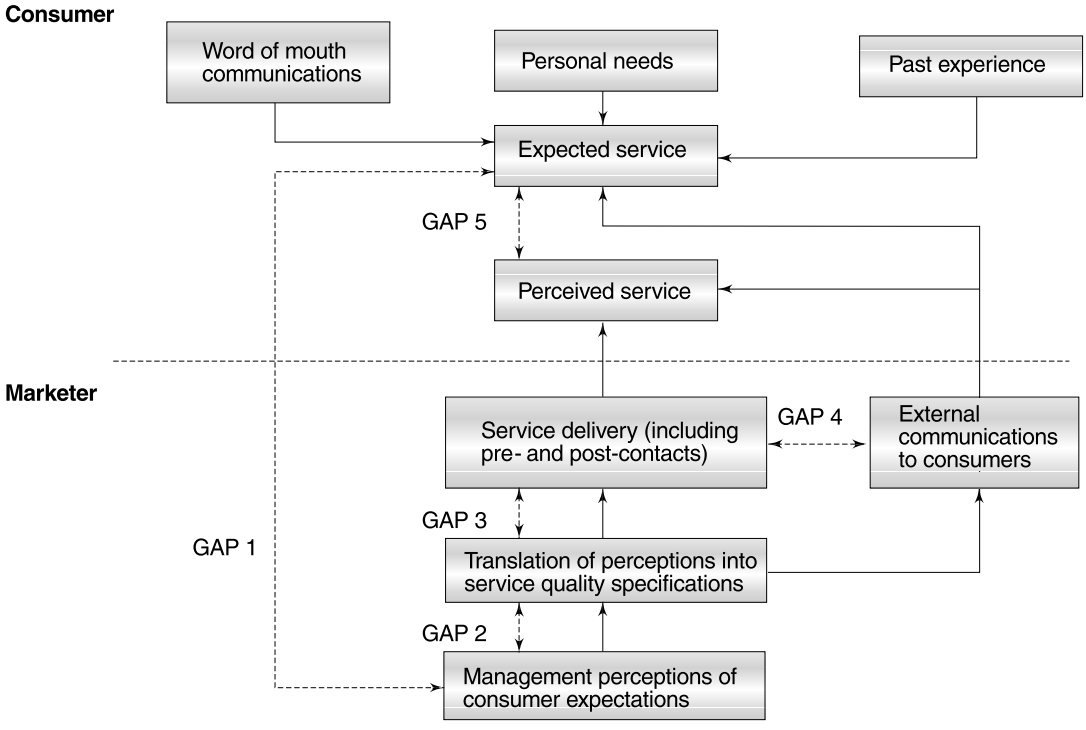


Figure 11.9 A Service Quality Model

Source: Parasuraman A., Valerie A. Zeithaml and Leonard L. Berry, 'A Conceptual Model of Service Quality and the Implications for Future Research', *Journal of Marketing*, Fall 1985, pp 41–50. American Marketing Association, Chicago, Illinois, USA.

Gap 3 This is the gap between what the specifications of the company call for and what is delivered. It may be called as the Service Performance Gap. This can happen because of:

- Ambiguity in the roles of the contact personnel. The job or the service task is not clear to the employee. He/She also is not clear about his/her range of discretion.
- Role conflict
- Poor Employee-Job fit
- Poor Technology-Job fit
- Lack of teamwork
- Inappropriate supervisory control systems

Gap 4 This is the gap or discrepancy between what has been communicated/promised to the customer and what is delivered to him. This can happen because of:

- Carelessness in terms of promising to the customer more than what can be delivered. This could be termed as dishonesty.
- Inadequacy in communication between the various departments of the service organisation. Hence, what one promises the other may not know or comprehend fully.

Gap 5 This is the result of all the other gaps. It indicates as to how the customer experiences the gap between what he expected and what he is perceiving as service received.

MANAGERIAL IMPLICATIONS

Some of the insights provided by the above and other researchers, into the managerial implications for service quality are as follows:*

1. Assurance of providing basic service

A hotel should provide a clean and secure room and treat you like a guest. This is the principal expectation of any customer from the hotel. Ostentations like a thick carpet, fancy lamps, colourful wallpaper, etc. cannot compensate for a soiled bedsheet or a cockroach found in the corner of the bathroom.

Similarly, an airline should transport you to the desired destination punctually and safely. No amount of treatment like a so-called 'Maharaja' can compensate for a delayed or cancelled flight and missed appointments.

2. Reliability of what you promise to deliver

Reliability is extremely important, particularly in services because services have a large component of intangibility and probable variability attached to them. Service is not a product; it is performance. Service operations are less of 'physical' operations; they are more of 'social interactions'. Therefore, trust and credibility are very important.

A physical product is described by dimensions of length and diameter, etc. However, a service product consists of sensual and psychological benefits also. Since the latter two aspects cannot be exactly described in measurable terms, it is possible for a careless or unethical salesperson to overpromise the service bundle. A beautiful brochure with more beautiful drawings of a hotel should not end up as an empty promise. The actual decor, aesthetics, comforts and conveniences

* B.P. Lingaraj, A.R. Karim and S.N. Chary, 'Services and Quality', *Management and Labour Studies*. Vol. 18, No. 4, Oct. 1993, pp 207–215.

should be the same as what the customer has been led to believe and expect. Let there not be a gap between customer's expectations and perceived service.

In many service situations the expectations are pretty simple. For instance, a prompt settlement of the insurance claim in an accident goes a long way in building the 'quality' of the automobile insurance company.

A service product includes who delivers and how he delivers the service. It is a cumulation of all the 'moments of truth' as the customer interacts with service personnel. If this service product is to be good, it goes without saying that all the contact personnel should be seen as honest and trustworthy besides being competent.

3. Foster two-way communication

The customer should know what to expect. This can only come about through communication. Even if there is a defect in service or if there is a limitation on the part of the service-provider, these should be communicated to the customer. This helps in building trust and, therefore, even better quality of communication between the service company and its customer.

For example, if a surgery is going to involve a probable complication, the same needs to be explained to the patient and his family prior to the surgery.

Needless to say, without good communication, the service company would never get to know its customer's needs and changing expectations. This knowledge is crucial to continue to retain its customers and to add on more customers. Half of a service company's market research information can be generated through communication with the existing customers.

4. Customer Relationship

Service quality is, after all, in the perception of the customer. A *daal-chapati-rice* meal cooked with a homely taste could be several times superior than a dinner in a 5-star hotel. This is not just a question of habit. It has that relationship component to it. The taste of homely meal is not just in the food.

Customer goodwill is very important in services. It makes the customer more tolerant when service problems occur. A service as mentioned earlier, is a social interaction. Relationships are the foundation stones on which the edifice of service is built. The more personalised a particular service, the more important it is to build this relationship. However less personal certain services may sound, they cannot be devoid of the emotional content. Even an ATM, which apparently involves no human interface, is used by the customers on trust and dependability of the people in the Bank if anything were to go wrong. The customer operates it backed by the trust he places on the Bank i.e. its people.

SERVICE QUALITY FOR RETAIL STORES 11.1

Worldwide, the study of quality management of retail operations has gathered momentum in the recent years. In India, since the government has initiated some amount of liberal policy measures — particularly with respect to the participation of foreign direct investment — the possible globalization of retail operations has generated much interest in the management circles. In this country, the retail operations are undergoing a rapid change with the appearance of malls and supermarkets in the metros and other cities and towns. The competition in retail operations in hotting up.

Differentiation through service has always been an effective competitive measure an in retail operations it is of considerable importance. It is, therefore, essential to measure a retail store's service quality as against that of its competitors. A good way to measure the service quality is through measuring the customer's perceptions of quality.

SERVQUAL

In fact, one of the pioneering measuring scales has been that SERVQUAL developed by Parasuraman et al. * It has five dimensions as briefly mentioned below:

Tangibles : Physical facilities and the appearance of personnel
Reliability: Perform the promised service
Responsiveness: Willingness and promptness in helping customers
Assurance: Ability to inspire trust from the customers
Empathy: Individualized attention given to the customers

During the design of this instrument, the researchers had considered data from bank, credit card company, repair and maintenance company and telephone company. Retail store was not a part of the study. While the conceptual basis of SERVQUAL model is universal, there was a necessity for research efforts at identifying the important dimensions specific to measuring retail service quality.

Scales Specific to Retail Service

Dabholkar, Thorpe and Rentz ** have developed a Retail Service Quality Scale comprising of the following five dimensions.

(i) *Physical aspects*: Retail store appearance and layout. Therefore, the physical facilities of the store, the materials and the equipment should physically appeal to the customer. Also, the physical aspects should offer convenience to the customers — like the items being easy to find and the movement within the store being easy. The latter has to do with the layout of the store and the arrangement of the items within the store.

(ii) *Personal Interaction*: Employees having knowledge to answer questions, inspiring confidence and willing to respond to customers' queries and request; employees being courteous and helpful to the costumers and giving individual attention to the custormer.

(iii) *Reliability*: The retail store keeps the promises and does the right things.

(iv) *Problem-solving*: The store's personnel are able to handle customer's problems and complaints.

(v) *Store's Policies*: Policies regarding the store operation hours, credit card accpetance, parking facilities and the merchandise quality.

Store's policies, the ease of locating items and the easy movement for the customers are some of the new dimensions in this instrument developed specifically for the retail service.

Further research into the retail service quality scale development indicated that the same scale may not be very appropriate across different countries as the customer's service quality perceptions are influenced by social, cultural and economic environment surrounding them

* Parasuraman A., Zeithaml V.A. and L.L. Berry, "SERVQUAL: A Multiple-Item Scale for Measuring Consumer Perceptions of Service Quality", Journal of Retaling, Vol. 64, No. 1, (spring 1988), pp. 12-39.

** Dabholkar A.P., Thorpe, and J.O. Rentz, "A Measure of Service Quality of Retail Stores: Scale Development and Validation", Journal of the Academy of MARKETING sCIENCE, Vol. 24, No. 1, (1996), pp. 3-16.

and would differ. In the Scandinavian and North European retailing context, the main competitive service dimension emerged to be the width, quality, freshness and reputation of the brands of items carrid in the store, according to a study.*** This means, the dimension of 'store policies' has different sub-dimensions. In Vietnam, the dimension of 'Service personnel' — the overlap of personal interaction and problem-solving ability — emerged to be a key retail servcie quality dimension, according to another study. **** Thus, the scale in that country's context could very well have only four dimensions. A research study done in India, for retail service quality for supermarkets and hypermarkets, proposed the dimensions of process (or ease) of shopping, atmospherics, personal service, merchandise assortment, store policies and value-added services. *****

Worldwide, the retail market is huge. Globalization is the order of the day. Hence, a good understanding of the retail service quality aspects is an urgent necessity.

The past quarter of a century has seen an upsurge in work related to quality. As business started getting globalised and competition increased rapidly, companies started paying increased attention to product and service quality. Several quality-related programmes were initiated.

The statistical process and quality control methods were good and necessary but not sufficient to give a company any competitive advantage. Industries realised that just like service quality, product quality has several dimensions. It was also increasingly realised that quality does not merely come through meeting the product/service specifications. Quality of a product (and service) was seen to shine through the quality of the organisation. Hence, Total Quality Management (TQM) became a popular initiative in several organisations. Some firms tried to surpass the three sigma controls of the usual statistical process control methodology and substitute it with very stringent requirements of Six Sigma controls. TQM and Six Sigma have been the most popular initiatives of the present day. These two will be discussed next in this chapter.

WHAT IS TOTAL QUALITY MANAGEMENT (TQM)

It is very important to note the first word viz. 'Total'. Total Quality Management is about:

1. Total customer satisfaction as the objective.
2. Totality of functions (i.e. all functions) in an organisation.
3. Total range of products and services offered by an organisation.
4. Addressing all aspects and dimensions of quality.
5. Addressing the quality aspect in everything—products, services, processes, people, resources and interactions.
6. Satisfying all customers—internal as well as external.
7. Addressing the total organisational issue of retaining customers and improving profits, as well as generating new business for the future.
8. Involving everyone in the organisation in the attainment of the said objective.

*** Anselmsson J., "Customer Perceived Service Quality — Examination of a Measurement Scale in a Swedish context", Working Paper series, (2006/1), Lund Institute of Economic Research, Lund, Sweden.

**** Nhat, N.D.D. and L.N. Hau, "Determinants of Retail Service Quality: A Study of Supermarkets in Vietnam", *Science and Technology Development*, Vol. 10, No. 8, (2007), pp. 15-22.

***** Shahaida, Rajashekhar H., Nargundkar R. and B. Venkatesh, "Assessing Service Quality: Supermarkets and Hypermarkets in India", *Focus*, Vol. 3, No. 1, (April 20007), pp. 6-16.

9. Demanding total commitment from all in the organisation towards the achievement of the objective.

When one does such a total or comprehensive job with an eye on quality (total quality), the result is organisational excellence. Thus, TQM is not just about quality in the traditional sense. It is about organisational excellence. It is like Midas' touch, where everything that is touched turns to gold. TQM is about turning all products, all services, all processes and all people into 'gold'.

Total Customer Satisfaction

The traditional view of quality has been 'corrective' (quality control) or at best 'preventive' (quality planning). 'Corrective' actions ensure that the defective products do not slip through and get into the consignment that is to be shipped to the customer—at least not beyond a certain limit. 'Preventive' action ensured that the occasions to take 'corrective' action are far and few. Management scientists spoke of 'costs' of quality.

Until a quarter of a century ago, the costs concerned directly the immediate user of the product. The definition of a customer was narrow, as was the definition of quality. A customer was the person or organisation that bought the product that left the factory or its warehouse. It was Taguchi from Japan who educated the industries about the 'costs to the society'. It was the society that was the ultimate customer—as shown by the Taguchi Loss Function.

Ishikawa and several others of his time concentrated on 'loss prevention' through an analysis as to why do losses occur. In general, quality management was perceived to be an auditor and at best an advisor on how the losses may be prevented.

TQM, on the other hand, looks at quality as a value provided to the customer. It is a methodology to maximise value to the organisation's customers. Continuous value addition in order to satisfy the customer totally, is the aim. A customer desires that the life cycle costs be minimal. But, that is only speaking about the floor level requirement. He expects several additional things, which are known as 'values' pertaining to the product or service. It is not enough to have a result which says the customer is 'not unhappy'. In a competitive world, this is similar to an 'also ran' situation, or worse—one may not even qualify for the actual race. TQM is, therefore, focused intensely on the customer, his requirements, preferences and expectations. TQM involves studying where and how does the customer interact by design and/or by default with the product/service, and how satisfied he is in all these interactions. It is important to note that anybody who interacts with the product or service, even by default, could be a customer—albeit a potential customer.

Totality of Functions

When such a focused job is to be done, it goes without saying that the entire organisation's energies are to be put into it. Every function—be it marketing, logistics, production/operations, purchasing, engineering or product design—has to get actively and fully involved. All functions are inter-related and interdependent and, therefore, all will have to get involved much like conducting a symphony.

Total Range of Products and/or Services

TQM should not be stopped after applying to a select few of the company's products and services. While one may chalk out certain priorities for the TQM programme in the initial stages, the

programme should assume a comprehensive nature at the earliest. The reason is simple: a customer cannot be offered some products that are good and some not so good. One product/service has an effect on the other. In a customer's mind, the images of the products overlap with each other. The full benefit of TQM will not be realised unless it encompasses the full range of services offered by an organisation. The resultant benefit is realised by both the customer and the organisation.

All Dimensions of Quality

Chapter 12 discusses the various attributes of quality such as performance, features, aesthetics, reliability, durability, serviceability, safety, user-friendliness, customisability and environment-friendliness. The earlier section on service quality mentioned its determinants such as responsiveness, courtesy, communication, competence, reliability, credibility and security, among others. A product and/or service (by now it is understood that a product is not too different from a service in today's business world) has to spell excellence on all of these dimensions of quality. It has to meet the competition on all of these—at the least—and surpass the competitors on several other dimensions. This is the dictum for TQM.

Usually the customer does not specify many of these dimensions of quality. He may not even be aware of the dimensions. It, therefore, is really the job of the organisation to find out as to what might be the stated and unstated needs and expectations of the customer. The determinants of quality that are most important to the customer have to be identified. The organisation also needs to investigate the competitors' products/services and how well those are in meeting the customers' needs/expectations. TQM would involve intensive and extensive probe into the market behaviour and consumer behaviour in specific. This search has to be frequent or continuous, because the market or the customer's relative priorities amongst the determinants may change.

Quality Instilled into Everything

Products, services, processes, people, resources and interactions—all of these should be of quality i.e. suitable to the customer's needs and expectations. A product's or a service's design may be good, but, if the manufacturing process is not good, or if the people delivering it are not good enough, the ultimate quality reaching the consumer will not be good. The aspect of the 'moments of truth' discussed in the section on service quality has much relevance here. Every input, every procedure, every person who is into the making of the product/service and every interaction has tremendous significance. TQM has to address the all these factors.

Satisfying Both the 'Internal' and the 'External' Customers

Quality is about satisfying—at least—the external customer. However, the capability of an organisation to satisfy the external customer depends significantly upon the level of satisfaction within its own organisation. If process number 1 feeds into process number 2, then process 2 is the customer of process 1. Since process 2 may input into another process down the operations stream, unless process 2 is satisfied it may not be able to give right input into the next process—its customer. This chain of processes ultimately reaches the external customer. An organisation cannot afford to have a weak link in this chain. Customer satisfaction has to begin internally. In the context of supply chains, it is amply clear that a company would not be able to satisfy the ultimate customer unless it satisfies the immediate customer in the supply chain.

Retain Present Customers, Improve Profits and Generate New Business

TQM is for an organisation's survival in the competition and for its healthy existence so that it may keep contributing to the economy and the society. To achieve that, it needs at least to retain its current customers and generate adequate returns on investment. A TQM programme that does not address the returns on investment issue would more likely fizzle out soon enough.

TQM should also spur an organisation towards the development of additional customers or new business. TQM is not for *status quo*. In the context of fast-changing technology and with it people's tastes for products and services, it is essential to develop new products, new services and a new set of customers. Rapid obsolescence is the fate of several products and services. An organisation cannot risk becoming obsolete. TQM has to facilitate this organisational rejuvenation.

Total Involvement in the Organisation

Although one could devise improved processes and systems, ultimately these are operated upon or made to deliver through people working in the organisation and handling these processes and systems. Therefore the need is to:

(i) develop technical and/or interaction skills of the employees specific to their jobs

(ii) keep the employees informed about related aspects such as
- specific customer needs/expectations
- specific market developments and changes
- organisation's mission and specific goals
- organisation's policies and procedures
- critical requirements/factors for quality
- processes that an employee may operate or interact with
- an employee's specific role, responsibility and authority
- metrics that are used to measure performance
- rules and regulations of the regulating bodies
- values important to the organisation

(iii) widen the employees' knowledge about the market in general, its trends, competition, their organisation's role in the market and in the society and the organisational culture and philosophy.

Skills, information and knowledge are the three areas where the organisation needs to constantly improve the employees. This could be done through (a) training, (b) providing information and (c) education (formal or informal).

Organisational Culture

An employee could be imparted skills, be well-up on information and be educated to understand the organisation's philosophy, but skills, information and knowledge do not amount to the employee's involvement, which needs 'motivation'. It requires transformation in the way person thinks, behaves and acts. This transformation has to occur in all the employees. Since it consists of individual as well as group behaviour, it amounts to the organisational culture. The organisation's culture has to be transformed as a part of TQM programme. The desired attitudes, beliefs and behaviours on the part of the employees at all levels have to be developed.

It is this culture which will inspire an employee and guide him in decision-making in his job. True empowerment of the employee cannot come about unless there is the organisational culture supporting it. An employee in delivering his task may come across cross-roads of decision. It is the organisation's culture and values imbibed in him which will guide him in decision-making. Same is true about team behaviour. Team work may be desirable and necessary, but it has to be fostered. It has to come as an organisational value—part of the organisation's culture. Though team work and conflict management have a significant component of skills, these should be manifested as internalised behaviour. To take another example: 'Integrity above everything else' may be a desirable characteristic in the employees but it can be taught to a limited extent, and has to be brought in through a cultural transformation.

In short, organisational culture inspires, guides and supports an employee in carrying out his tasks.

Leadership and Commitment

Developing the desired culture is largely the function of the top management of an organisation. Instilling a culture requires a transformation in the individuals, in the teams and in the organisation. In this transformation, the part played by the leaders in the organisation cannot be overemphasised. The top management cannot ask for the desirable values to exist in the employees at other levels, unless it demonstrates those values. If it is not committed to satisfying the customer's requirements, one cannot ask the lower level employees to be involved in that endeavour. If it is not committed to punctuality, it cannot expect the lower-level employee in the shipping department to be committed to delivering a shipment on time to the customer. The important word here is commitment, which is being highly convinced to perform under all circumstances 'come what may'. The other aspect of effective leadership is its clarity of vision regarding the goal. Commitment and clarity of vision drive the leadership phenomenon.*

What TQM asks for is transformational leadership. There is no doubt that the higher level management has to show the way. The organisation's senior leaders have to set the directions, develop values and increase expectations. They have to be the role models. Their own value systems, attitudes and behaviour have a great bearing on the outlook of the lower level employees to get involved in the organisation's activities and programmes. It is the top management's commitment that drives the transformation within the organisation.

As Deepak S. Parekh, Chairman and Managing Director of Housing Development Finance Corporation (HDFC)—India's pioneering and leading home finance company—says, "Leadership is not a one-person phenomenon. There must be formal and informal leaders at all levels in the organisation."**

An effective leader should give rise to several other leaders. An employee at a lower level in the organisation may have a seemingly small function or minor task, but he should be able to exhibit leadership in that task.

TQM needs such creation of leadership at all levels. Quality is about all tasks done excellently by the respective persons. Empowerment is not just a transfer or conferment of authority. It is about people 'feeling' empowered. It is only then that they bring the initiative, energy and creativity into

* Chary, S.N., 'New Concepts in Leadership Effectiveness', *Leadership and Organisational Development Journal*, Vol. 11, No. 2, MCB University Press, UK, 1990.

** Chary, S.N., *Business Gurus Speak*, Macmillan, New Delhi, 2002

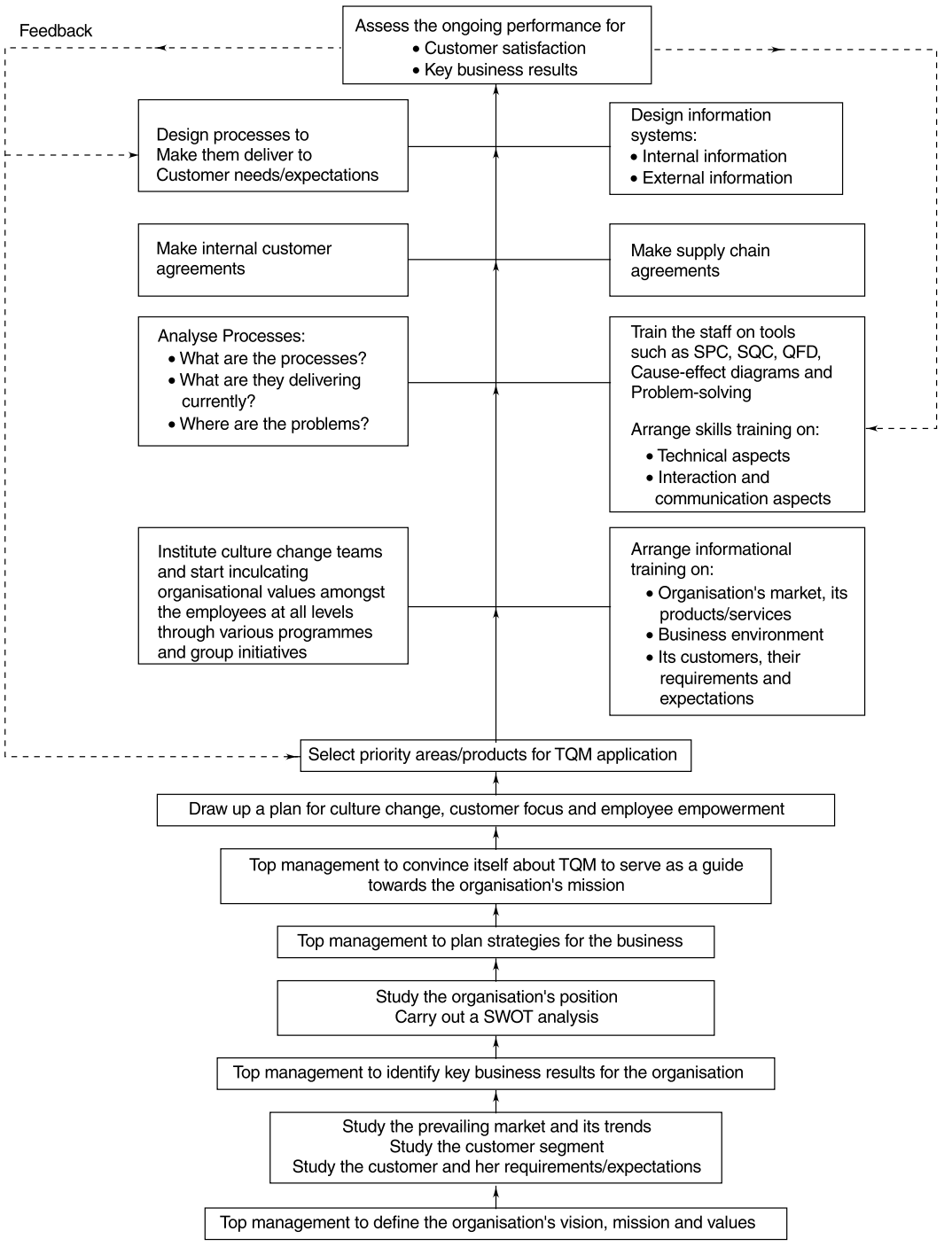


Figure 11.10 Roadmap for Total Quality Management

their respective tasks. Employees should feel fulfilled in doing their tasks. The top management should cause such seeking of fulfillment by these employees. Leadership is not about asking somebody to follow one's goal. Instead, it is about creating the sense of ownership amongst all regarding those desired goals. A salesman, for instance, should feel that serving the customer promptly and courteously is his own goal. When a janitor takes pride in cleaning the floor spotlessly in a plant producing pharmaceuticals, then he is taking ownership for the job; at the same time, the company's objective about contamination-less production is also being served.

ROADMAP FOR TQM

TQM, which involves a huge transformation in an organisation, is an initiative about the entire organisation's quality, which refers to organisational excellence in whatever the organisation chooses to have as its mission. Product or service quality may only be one of the results. A general roadmap for a TQM initiative may be as depicted in Fig. 11.10.

The seminal role played by the top management is obvious from this figure (Fig. 11.10). TQM flows from the organization's vision, mission and values. TQM is largely about 'leadership'. It is basically about the top leaders causing other 'leaders' to be produced at all levels. It is about this team of leaders to imbibe a uniform organizational culture and values conducive to the production of required business results. The business results have to be planned, which means there should be a strategic plan drawn up prior to the start of the TQM initiative. Other point to note is that TQM is an ongoing activity. As the market changes, as the customer preferences change, the organization has to steer itself in accordance. As the top square in the figure shows, customer satisfaction and the key business results for the organization have to be simultaneously produced. One is not at the cost of the other.

POINTS OF CAUTION IN TQM IMPLEMENTATION

1. TQM implementation should not be a half-hearted activity. Full commitment from all levels of employees is essential for its success. Commitment is continued pursuit of goals/tasks under all circumstances.
2. TQM requires the employees at all levels to undergo attitudinal, informational and skills training. Training the managers as well as the other non-managerial staff is essential to TQM's proper implementation.
3. TQM should be a clearly directed activity with a definite goal towards which the organisation would slowly but surely move. Therefore, there should be strategic plans and specific attainments chalked out. The goals should be clearly measurable for their quantum of realisation. There should be clear metrics for the same.
4. TQM should be focused on the customer. Complete satisfaction of the customer is the aim. Other factors should not confuse or dilute this aim.
5. TQM is an ongoing activity, because the requirements/preferences of the customer may change.
6. TQM should also not lose its sights on key business results. Focusing on the customer can only be done if the organisation is able to survive and produce sufficient returns on investment. As is amply clear, without an undiluted customer focus, the organisation's business results would suffer in the longer run, if not in the short run. Full attention to both—customers and key business results—is essential.

CRITICISM OF TQM

Despite TQM's objective being pursuit of organisational excellence, it has been criticised for a gradual change towards what the customer desires. Therefore, while it is radical in its aim of total customer satisfaction, its approach seems incremental. TQM is criticised on the count of not showing the same sense of urgency as Six Sigma which attempts at drastic changes.

Another criticism is that TQM is rather vague or imprecise in defining as to what needs to be achieved. Total customer satisfaction as an objective is fine. But, does a TQM programme translate that into exact requirements? TQM is accused of being platitudinous in this respect.

Another criticism is 'general' in nature. It is about the goal of any programme of quality improvement. It says that any such programme, including TQM, attempts to reach the quality level expected by the customer. According to the critics, the customers may not know to expect better. Sharply new improvements in product performance or its features (or the services that go along with it) have rarely occurred through these basically 'quality-related' initiatives. Noritaki Kano's model may be referred to in this regard. Kano distinguishes between 'basic quality', 'expected quality' and 'exciting quality'. Basic quality is that level of quality which the customer takes for granted ('unspoken' wants). If it is not met, customer will be dissatisfied; but, if it is provided, she does not become happy either. Expected quality represents those expectations which the customers consider explicitly. Not meeting these expectations also results in customer's dissatisfaction. As the fraction of satisfied expectations increases, the customer dissatisfaction decreases. Thus, upto the expected quality level the situation is similar to the hygiene factors in Maslow's Hierarchy. Exciting quality is that which is 'unexpected' by the customer. She is pleasantly surprised by the presence of those factors that belong to 'exciting quality'. Figure 11.11 depicts Kano's model.

All quality-related programmes, including TQM and Six Sigma are supposed to reach only upto the 'expected quality' curve.* They do not go beyond. Therefore, the major portion of satisfaction (of the customer) would come from surprise improvements in the product/service. These are more in the domain of creative product design and research and development.

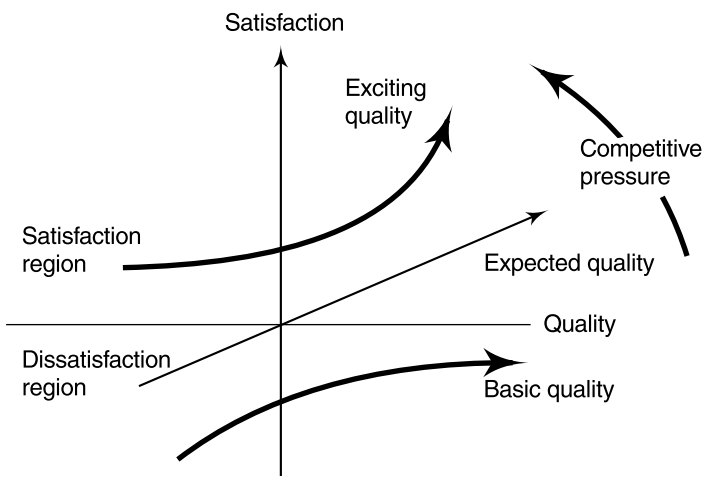


Figure 11.11 Kano's Model of Quality

Source: Kano Noritaki, 'A New Perspective on Quality Activities in American Firms', *California Management Review*, Vol. 35, No. 3, Spring 1993, pp. 12–31.

* This Particular view is that of the author and not Kano's.

However, despite some of these plausible limitations, TQM should be hugely credited for bringing the customer sharply in focus, for cleaning up the organisation and for instilling positive culture and values from which the organisation can draw sustenance for a long time to come.

SIX SIGMA

The term 'Six Sigma' indicates that

(a) this is a quantitative methodology, and

(b) it is much more stringent than the traditional 'three sigma' statistical process control (SPC) model.

One may indeed look at Six Sigma as the big brother of traditional SPC. But, that would amount to taking a very narrow view of Six Sigma. First of all, in statistical terms, the change from three sigma to six sigma is a drastic change. Table 11.3 depicts this.

Table 11.3 What do Various Sigma Levels Mean?

Sigma Level	*Yield %*	*Defects per Million Opportunities*
1	30.9	6,90,000
2	69.2	3,08,537
3	93.3	66,807
4	99.4	6,210
5	99.98	233
6	99.9997	3.4

In purely statistical terms, having six sigma control limits on either side of the mean of a process is so stringent a control that it ceases to be just a control methodology. Rather, the traditional corrective mechanisms used for the three sigma process controls will not work here. In order to get to the level of perfection needed for this new six sigma, an adjustment to the process here and a tinkering to the process there will not at all suffice. Six Sigma requires that an organisation takes a huge and sustained initiative to bring about a transformation in the way it functions in all areas of its endeavour.

Why Do Companies Need Six Sigma?

Technological Complexities and Multi-stage Processes Today, the technology of products like computers is such that it has to be totally defect-free. The need for 'zero defects' is acutely felt in these technologically advanced times. To add to the woes, manufacturing has become a more complex activity than in the earlier days—it has now multiple processes following each other. Defects can arise at any or all of these successive processes. If the processes have a three sigma quality level i.e. 99.73 per cent yield (as per Standard Normal Distribution tables) and if there are just three such processes, the overall yield would be:

$0.9973 \times 0.9973 \times 0.9973 = 0.9919$ (i.e. 8,100 defects/failures per million or 24 defects per thousand)

For a 9-step process the overall yield would be:

$0.9919 \times 0.9919 \times 0.9919 = 0.9759$ (i.e. 24,100 defects/failures per million or 24 defects per thousand)

Since most modern production processes involve much more than nine successive processes, one can imagine what might happen if just three sigma quality levels were to be used. The yields would be very low and unacceptable, indeed. Imagine a computer manufacture having 3-sigma controls. Or, imagine a mother-machine i.e. a machine tool—say a CNC variety—being manufactured with 3-sigma controls. Obviously, such quality levels would be a nightmare. The imperative of six sigma levels of quality is, therefore, quite obvious. It appears like an absolute 'must'.

The requirement of extremely high quality is not limited to multiple-stage manufacturing process. Table 11.4 shows what it would be if the traditional three sigma quality level is applied to some other processes.

Table 11.4 What if Traditional Three Sigma Quality Level Were to be Applied*

• Virtually no modern computer would function.
• 10,800,000 healthcare claims would be mishandled each year.
• 54,000 cheques would be lost each night by a single large bank.
• 540,000 erroneous call details would be recorded each day from a regional telecommunications company.
• 270,000,000 erroneous credit card transactions would be recorded each year in the United States.

* *Source*: Pyzdec, Thomas, *The Six Sigma Handbook*, McGraw-Hill, New York, 2001.
Note: The data is about USA.

Table 11.4 presents several situations that are pertaining to service operations such as bank cheques and credit card transactions. Service industry is a major industry these days. Six Sigma is required in the service industry as much as in the manufacturing industry.

Rapid Growth of the Service Industry and of the Service Components in a Manufactured Product The service industry is much more quality-sensitive than manufacturing. The reason is the proximity of the customer in service operations. She is within the operations system itself and is a part of the process. So, the effect and the feedback is immediate. Moreover, in manufacturing, the defective products can be discarded or reworked on and then sent to the customer. There can also be a physical inventory of goods. Such things are not possible in services. A service—good or bad—reaches the customer directly.

A service delivered badly cannot be recalled like manufactured products. Even potentially hazardous drugs can be recalled from pharmacies. A service cannot be. Even if there was only one in a million occurrence of finding a small dead roach in a dish in the restaurant of a 5-star hotel, that is bad enough to kill the reputation of the entire hotel. So, even the fact that the hotel is maintaining good quality 99.999 per cent of the time may not help the hotel.

During the last decade, some of the service industries have started building the recall facility into their services. For instance, the supermarket chains in the US and also in some of the European countries allow the customers to return any item if they do not like it—without giving any reason—with full refund of money. With such a facility, these supermarket chains have won the customers' trust—a very important gain for the sustainability of these companies.

Service, by definition, is more flexible—less bound by rigid controls. It has to be more customised. This amounts to considerable variations. The quotient of unpredictability is high. Therefore, a

service is lot more prone to producing defects i.e. providing a service that is not acceptable to the customer. A service is quite 'fragile'. If a good crystal glass were to break, it cannot be mended. Same is true about most services.

The need for the input of quality is thus acutely felt in the service industry. A stern quality initiative such as that of Six Sigma is justified in service operations. Six Sigma measures would mean reducing the variations to such an extent that six sigmas i.e. six standard deviations can be squeezed within the limits prescribed by the customer's specifications. It would mean that out of one million encounters with customers, only 3.4 will be defective i.e. unacceptable to the customers. For a service industry, even this defect rate appears to be on the higher side.

Three Sigma to Six Sigma is a Sea-change

Motorola was one of the first few companies to use the six sigma concept. In applying this concept, Motorola presumes that the process mean can 'drift' 1.5 sigma in either direction. Over a period of time, the output from a process would change. The mean could drift or the standard deviation would change. This is depicted in Fig. 11.12 which is for the traditional three sigma control limits.

As seen in Fig.11.12, more and more areas of the normal curve go outside the three sigma limits. Because of this 'drift', observed empirically over several years in the manufacturing industry, more and more companies are now discounting three sigma ideal to the actual 1.5 sigma. That is, any process which is initially delivering a three sigma performance would over time deliver

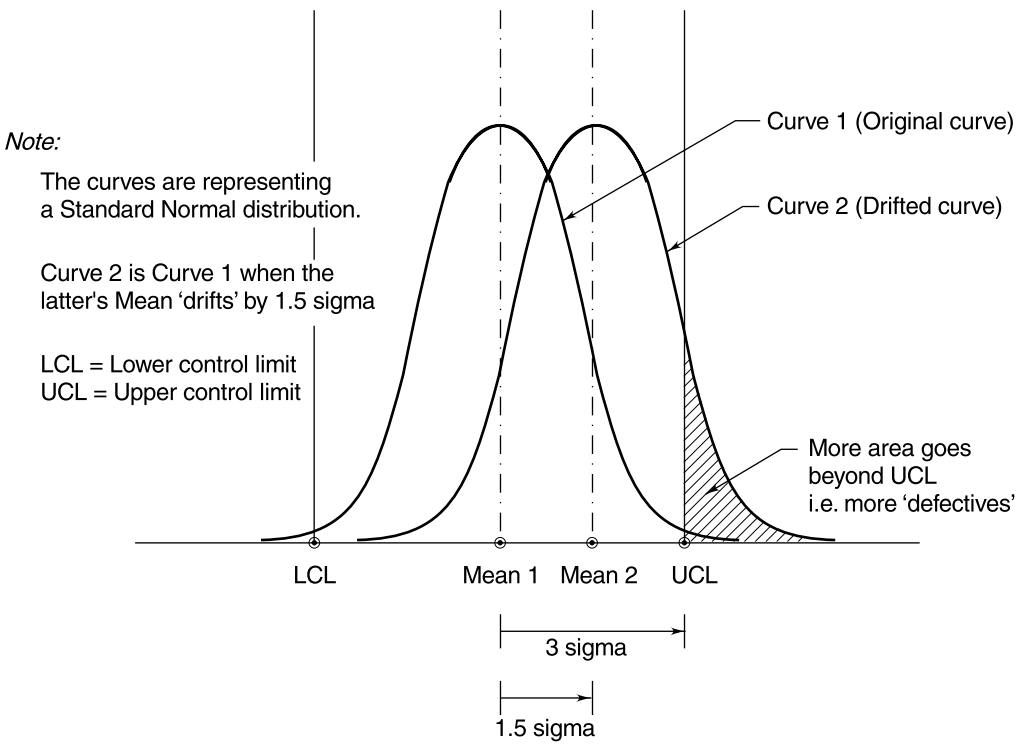


Figure 11.12 Effect of 'Drift' in the Mean

only a 1.5 sigma performance. The process produces about 7 per cent defectives or unsatisfactory performances, the per cent area of the drifted normal curve that is outside of the three sigma limits.* Thus, according to this empirical rule, a four sigma limit is actually a 2.5 sigma limit. A five sigma limit becomes actually a 3.5 sigma limit over time. And, by the same token, a six sigma limit is really a 4.5 sigma limit. That is, over time a Six Sigma process would come down in its performance to a 4.5 sigma level, which is about 3.4 defectives per million.

Table 11.4, presented earlier, gives these 'practical' figures. Otherwise, Six Sigma means an expected non-conformance of 0.002 ppm which is the same as 2 parts per billion (ppb). This is obtained by referring to special statistical tables, as the usual Standard Normal Distribution tables go only up to 3.1 sigma (standard deviations). Thus, in the short-run, Six Sigma would mean a stupendous quality performance of 2 ppb. The contrast between the Process Control charts with 'Per Cent' defectives and now the Six Sigma's 'Parts per Billion' is very very huge, indeed. Companies have reaped real benefits— large benefits—with its implementation within their organisations.

Considering the practical phenomenon of drift and therefore observing Table 11.4, one can see that if a company were to transform from a three sigma level to a six sigma level of capability, the defects per million opportunities come down from a large 66,807 to a tiny 3.4—an improvement of almost 20,000 times. It is ironical therefore that on the face of it, a change from three sigmas to six sigmas looks like a proportion of 1: 2.

Benefits of using Six Sigma

These are several benefits of applying Six Sigma.

1. *It introduces rapid and almost radical improvements*

   Several of the quality initiatives of the earlier days such as Quality Circles, Kaizen and Quality Function Deployment are very necessary for an organisation at all the times. However, by their very nature, these measures produce incremental improvements. The pace of improvement is, therefore, slow. In addition to these kinds of improvements, an organisation in today's fast-changing business world needs improvements to be brought in very rapidly in order to match the pace of changing technologies and changing customer requirements. Six Sigma is such an instrument of change, which can bring about radical changes in the way an organisation functions.

2. *It transforms the entire organisation*

   When Six Sigma is implemented, the entire organisation in all its constituent parts is geared for absorbing rapid and radical changes. One cannot possibly bring in large changes in one part of the organisation, without adequate measures in the other parts. Six Sigma initiative makes the management to take a closer look at the various functions and departments and the inter-relationships between them.

3. *It provides a consistent metric*

   By its very nature, Six Sigma provides measures and targets that are quantifiable. Specific defects—deviations from the customer requirements—are identified and measured. Improvement performance is also measured. A consistently uniform measurability is one of its important distinguishing characteristics.

* If the drift is to the right, most of the area falling outside is beyond the limit on the right hand side.

Organisational changes are brought about by the implementation of Six Sigma. These transformations are general in nature. But, the improvements they generate can be and should be measurable against a yardstick. Six Sigma uses 'customer requirements' as that yardstick.

4. *The customer is always in focus*

   The benefit of constant measurements is that the customer is always in focus with her requirements being the standard against which the measurements are done. Due to the presence Six Sigma, an organisation is always aware of the changes in the market.

5. *It is a continuous improvement process, as well*

   Since six sigma is a measurement-based initiative, the organisation that implements this initiative would have to constantly keep itself appraised of the customer's requirements. In short, a Six Sigma initiative never stops. It is forever. It is true that Six Sigma signifies radical improvement. But, a radical improvement system does not have to negate continuous improvement.

Methodology of Six Sigma

Six sigma methodologies are about

(a) Customers,
(b) Metrics,
(c) Processes,
(d) Employees and business associates, and
(e) Organisational transformation.

The Customer Total customer satisfaction is the goal of Six Sigma. Therefore, customer is the focus of Six Sigma action in any of processes. The customer's needs are to be thoroughly understood in all its various dimensions and an assessment needs to be made about the present status of satisfaction of these needs and the measures that need to be taken to satisfy the needs.

The Metric Understanding the customer and his requirements and a design of appropriate metrics are central to the Six Sigma efforts in an organisation. Six Sigma is quantitative in nature and quite exacting at that. Hence it is essential that an appropriate metric be established as to how customer satisfaction may be measured. A correct metric would lead to properly directed efforts. An incorrect metric would lead to wastage of efforts.

The Processes With the customer requirements and the metrics in view, the processes leading to customer satisfaction have to be improved—many of them radically. A study of the processes—a series of interlinked activities that lead to the organisation's goal—is required to be made. How are the processes performing vis-à-vis the desired quantified goal? What are the reasons that the processes are not achieving the targeted performance? What could be done to overcome the obstacles? An analysis which addresses these questions would give a plan of action for the Six Sigma programme.

Actions to Improve the Processes The following are some of the actions, to improve processes amongst many:

(i) Technology upgradation or having an appropriate technology,
(ii) Supply chain adjustments,

(iii) Integration of several functions and operations,
(iv) Improvements in communication, in information flows and information sharing,
(v) Alignment of objectives, goals and targets with the business associates,
(vi) Improvements in logistics,
(vii) Elimination of human errors,
(viii) Improvement of the staff members in their communication skills especially while communicating with the customer, and
(ix) Improving the work atmosphere within the organisation.

These actions should be linked to the quantified performance goals for the different processes. Actions may not necessarily be quantifiable with exactitude; but the results of these actions are quantified so that the Six Sigma implementing organisation could track itself along its journey to Six Sigma and the attainment of the desired end objective.

The Employees Planning an action is one thing and getting it done is another. The importance of the human element cannot ever be overstated. An organisation may plan for a radically new technology or a radical change in the delivery systems, but this has to be achieved through and/or facilitated by the human input. The employees have to be informed/educated about the processes and the final goal, aligned with the organisation's objectives and have to be motivated and involved for sustained efforts.

The Partners in the Supply Chain In today's business environment where several organisations form a supply chain, it is not enough if just one organisation attempts at Six Sigma. The latter can only be achieved with the participation of all the partner organisations that form this supply chain. Therefore, whichever organisation takes the initiative for Six Sigma attainment, it has to get the other partners involved and committed to the Six Sigma goal too. This is not to discourage the more enthusiastic organisation amongst them. It is better to try and come as close to the objective as is possible rather than having a plain status quo.

The Transformational Leadership But, *who* would start the cascading process of the improvements organisation-wide? The importance of top management leadership is absolute in Six Sigma. In order to have the employees and the business associates/partners to bring in momentous changes, there has to be a cultural shift in the Six Sigma implementing organisation. Many of the changes that are required to achieve the Six Sigma goal may mean a total paradigm shift. Do the concerned organisation and its people have the fibre to take the paradigm shift—rather, to get the paradigm to shift? This is the question that may be addressed before undertaking the radical programme of Six Sigma. The 'fibre' mentioned herein has to do with the culture and the value system of the organisation. If the prevailing culture and the prevailing value system is not appropriate for the transformational process of Six Sigma to set in, then the culture and the value systems have to be appropriately modified/redesigned and robustly installed.

Roadmap to Six Sigma

Figure 11.13 depicts the roadmap to Six Sigma. The following points may be noted:

(a) Customer is the foundation of Six Sigma.
(b) There has to be a 'fit' between the customer's requirements and the organisational culture and values. Six Sigma initiatives need a base of suitable organisational culture and value system.

(c) Six Sigma is a dynamic process. As the customer requirements change, the performance may not remain at Six Sigma. It may come down, necessitating another round of Six Sigma efforts. Even if the performance is at Six Sigma level, it may be wise to periodically check the customer requirements for changes, if any. Six Sigma is not a one-time project.

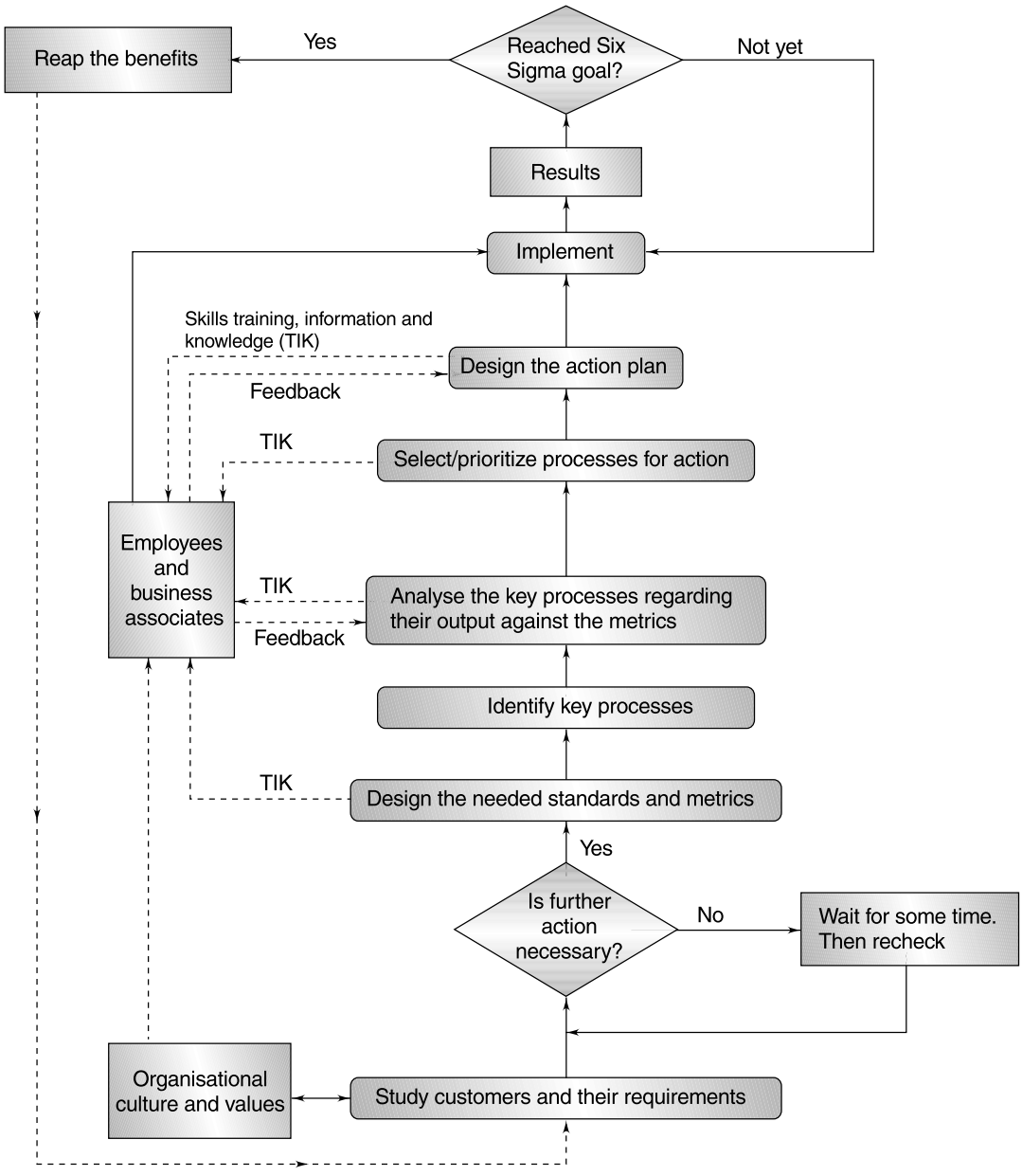


Figure 11.13 Roadmap to Six Sigma

(d) Skills training, information and knowledge (TIK) about the company's initiatives must be given to the employees and to the partners in business or to other businesses interacting with the company. This is vital for the success of a radical step like Six Sigma to succeed.

(e) While it is ultimately necessary to bring every process to Six Sigma level of capability, the Six Sigma effort may be carried out selectively on a few processes on a priority basis for maximum initial impact.

Are there Any Drawbacks with Six Sigma?

The very phrase 'Six Sigma' spells perfection. So, what could ever go wrong with it?

Six Sigma is 'Exacting' but not Necessarily 'Exciting' For one, in this intensely competitive business world, quality—even six sigma or even literally zero defects quality—forms just the basic minimum. When a firm implements Six Sigma it is only trying to reach the level of customer's expectations. This means, the firm is only trying to catch up with the competition. A customer is 'satisfied' after the Six Sigma efforts; but, she may not be 'delighted' or 'excited'. (Exciting Quality was referred to in this chapter during the discussion on TQM.) Six Sigma is good, but it does not 'surprise' the customer. While quality is about prevention of non-conformance, it is more so about delightfully surprising the customer. This is particularly true in today's business environment. However, Six Sigma does not address that delightful surprise part.

Detraction from 'Creativity'? Because Six Sigma believes in metrics-and-measures that detect/account for the minutest one in a million error, it is feared that, it may get caught in its own numbers' trap. It is possible that such mathematical maze might bind up the creativity in an organisation. An organisation's preoccupation with the exacting Six Sigma might detract the organisation's attention from the vital activities of innovation which flourish, generally, in a loose unfettered organisational environment.

There are organisations that innovate. There are organisations that do a perfect job as regards quality. Today's business environment calls for an organisation that is excellent in both these aspects. Though it seems like a tall order, that is the need for a society that is ever evolving and is on a path to progress.

Highlight

TQM at TVS Motor Company

TVS Motor Company Limited, the manufacturer of motorcycles and other two-wheelers, is a part of the almost one-century-old TVS Group of companies that was first established in the year 1911. TVS Motor Company has plants at two locations—Hosur (Tamil Nadu) and Mysore (Karnataka). The company's sales during the financial year 2002–03 were to the tune of Rs 2700 crore. The company began its TQM journey around the year 1987. During 2002 the company won the internationally coveted Deming Application Prize; it was the first two-wheeler company in the world to get that prize.

The company's philosophy towards quality is reflected in its following statements.

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Our understanding of TQM

TQM is the company-wide effort of *continuous quality improvement* of all processes, products and services through *total employee involvement*, that results in increasing *customer satisfaction and loyalty* and *improved business results*.

Quality Policy

TVS Motor Company Limited is committed to achieving total customer satisfaction through excellence in TQC. We will continuously strive to provide the customer the best value for money by supplying quality products at the right time and at the right price.We shall provide superior after-sales service to maintain and reinforce customer satisfaction. This objective will be achieved by continuous improvement through total employee involvement.

Date: January 3, 2002 (signed by) Managing Director

Total Employee Involvement

What is most striking about the company's TQM programme is the tremendous emphasis that is laid on Total Employee Involvement (TEI). The above two statements also clearly mention that it is through TEI that they would achieve the TQM objective. TEI is at the very foundation of the TQM movement at TVS Motors as depicted in the company's TQM Model presented in Fig. 1.
The company tries to obtain TEI basically through:

(a) Suggestions scheme,
(b) Quality Circle activities,
(c) Cross-Functional Teams (CFTs),
(d) Supervisory Improvement Teams (SITs), and
(e) Task forces.

The notional relative allocation of responsibilities among the different levels of employees in the organisation i.e. top and senior management, middle management and workers is clear at the company. Following are three kinds of responsibilities which are shared by three levels (however, the time spent by each of these levels is different):

(a) Retainment (i.e. Retaining the performance levels achieved),
(b) Improvement, and
(c) Breakthroughs.

Staff and workers would be more involved in 'retainment' part through good daily management practices and contribute to improvement through Employee Suggestions System and through participation in the Quality Control Circles (QCCs). The middle-level people such as the executives would be more into 'improvement', while the top management would be mainly responsible for 'breakthroughs'. The projects through TEI are well aligned to the company's targets. The company's long-range plans and annual policies are the main inputs for selecting and prioritising the TEI projects. Department-wise 'Project banks' are created which are then picked up by SIT, CFT or QCCs and commitments are made in the QCC convention and SIT/CFT convention. Hence, the QCC, SIT and CFT projects and their schedules are in alignment with the company's targets and objectives. There is a two-way deployment mechanism: Targets flow from the top and bottom up on identification of projects to achieve the targets. Any gap between the two is resolved through a

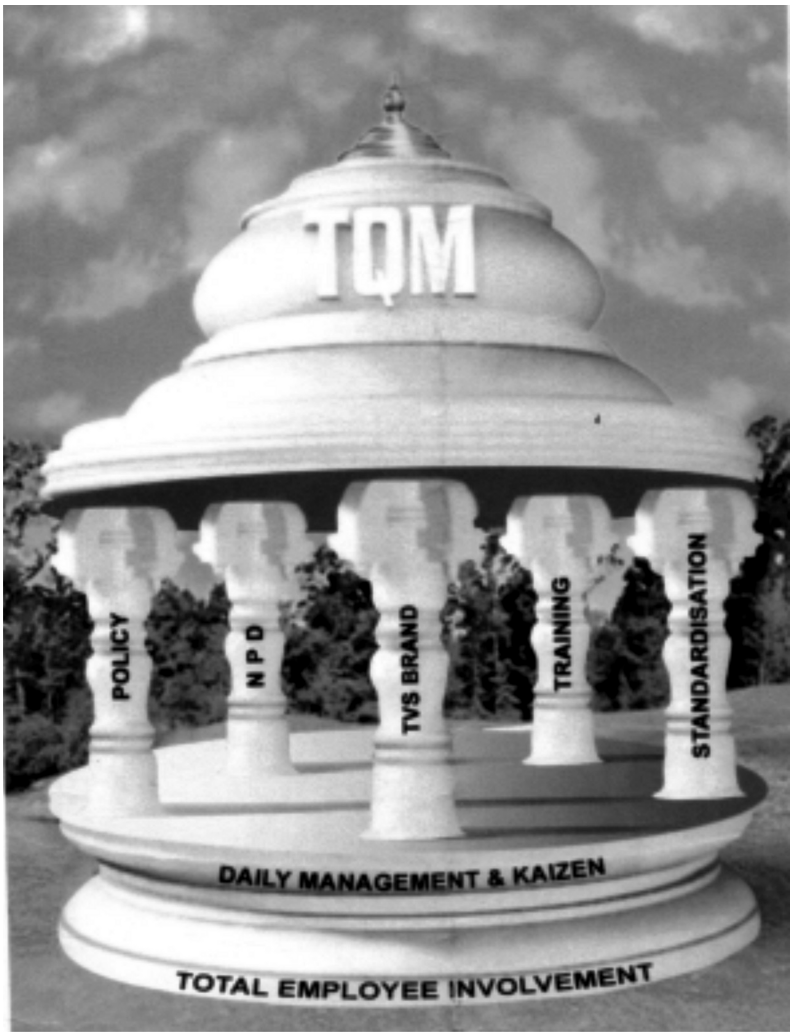


Figure 1 TQM Model

structured discussion. The implementation (i.e. fructifying the project ideas) is a major responsibility which is as much with the grass-roots level as with those at the executive level.

Employee involvement is recognised and appreciated through awards and recognition to the employees, who cross milestones, regularly. These awards are received through the hands of Managing Director of the company. This would accomplish the following:

(a) It would demonstrate the personal involvement of the topmost level of management in the company's TQM journey,

(b) It would improve the bond between employees at all the levels,

(c) It would improve a sense of belonging to the company, and

(d) The company's goals could be directly articulated/communicated to the employees at such functions.

(NPD means New Product Development which is one of the five pillars of TQM.)

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However, a TEI programme takes time to take root and grow. From 30 per cent participation in suggestion schemes during 1993–94, it has grown to 100 per cent in 2001–02. The impact of the TEI activity on the performance of the company in terms of its desired objectives (as reflected in the quality policy mentioned earlier) has been substantial. To take just one dimension, that of cost savings to the company, the TEI activities have produced savings of Rs 17 crore during 2002–03.

'*Home Kaizen*' TVS Motors Company believes that if an employee has truly transformed as an individual through the TQM training and participation, she/he should exhibit similar behaviours outside the work-place and at home. Company encourages employees to do Kaizen at the work-place as well as at home. The company gives recognition through the distribution of awards for 'Home Kaizen'. Improvements performed by an employee at her/his home are as important to the company as the improvements done at the company. The company believes in more permanent transformations in values and behaviour of the employee rather than just short-term results for the company.

Integration along the Supply Chain The company has spread its TQM movement to its dealers and suppliers. It realises the importance of the integration of its entire supply chain in the journey towards TQM. Therefore, the TEI activities—the very foundation of TQM in the company's philosophy—are extended to dealers and suppliers.

Courtesy: TVS Motor Company Limited, Hosur, Tamil Nadu

QUESTIONS FOR DISCUSSION

1. What is 'quality'? How is it an organisation-wide activity? Discuss.
2. What is the difference between the Six Sigma and TQM initiatives? Discuss.
3. Why is an ISO 9000 certification important to a firm? What are the advantages to the firm? Explain.
4. Is an ISO 9000 certification a guarantee for the firm's product quality? Explain your answer.
5. Why is a Taguchi Loss Function parabolic in nature? Explain.
6. What is 'loss to the society'? Take a product that you know as an example and explain.
7. Explain each of the words of the phrase 'Quality Function Deployment'.
8. Is product design important to quality? If so, how? Explain. Is 'design' important in services? Discuss.
9. How should supply chain considerations be incorporated into the design of a TQM programme? Discuss.
10. Would a six sigma implementation involve significant financial investment? Discuss.
11. Read about Dr Juran's contribution to quality. Discuss the similarities and the dissimilarities between Juran's and Deming's approach to quality.
12. What may be the key areas to address when improving the Cost of Quality? Explain.
13. What are the differences, if any, between the Zero Defects and the Six Sigma approaches to quality? Discuss.
14. Are quality and creative product design inimical to each other? Discuss.
15. What is organisational learning? Is it important for quality? Discuss.

16. Can total customer satisfaction be achieved while a company is also aiming for key business results? Is there a conflict in these two goals? Discuss.
17. Is TQM more aplicable in manufacturing industry as compared to service industry? Discuss
18. How is Deming's PDCA cycle useful in services? Discuss.

ASSIGNMENT QUESTION

1. Study a retail supermarket regarding the service quality attributes desired by the customers. Present your detailed observations and your analysis for improvement in the operations.

12 Product Design

Product design is the mother of all operations processes in an organisation. The processes for manufacture, the planning of production, the processes and checks for quality depend upon the nature of the product. One may say that it all starts with the design of the product. Even the logistics or plain shipment of the product depends upon how or what the product has been designed for. Design gives the blueprint. When the design engineer keys in the computer aided design or when a product design artist draws lines on a sheet of paper, it starts a train of activities.

PURPOSE OF A PRODUCT DESIGN

Is product design a creative designer's fancy? In popular perception, the term designer conjures up images of a maverick yet highly creative artist who in his fits of imagination comes up with a hitherto not seen product. What is design without creativity in it? Indeed, designs are 'creative' in nature and they should be so. However, in an organisational context, the design should serve the organisational objectives while being creative. Since an organisation has a purpose, the product design should help to serve that larger purpose.

Design starts with conceptualisation which has to have a basis. Providing value to the customer, the return on investment to the company and the competitiveness of the company should form the basis of the product design effort. What separates a product designer from a freelance artist is the former's orientation towards these organisational objectives.

A product's design has tremendous impact on what materials and components would be used, which suppliers will be included, what machines or what type of processes will be used to manufacture it, where it will be stored, how it will be transported. Since a customer does not necessarily imply an already tied-up customer, but also a potential one, what and how will the general yet target customer community be informed depends upon what the design of the product is. For instance, a simple product like toothpaste which is also designed to act as a mouth freshener needs to be placed, advertised, promoted and priced differently. Thus, marketing is also impacted by product design. A product design reflects a company's overall strategy.

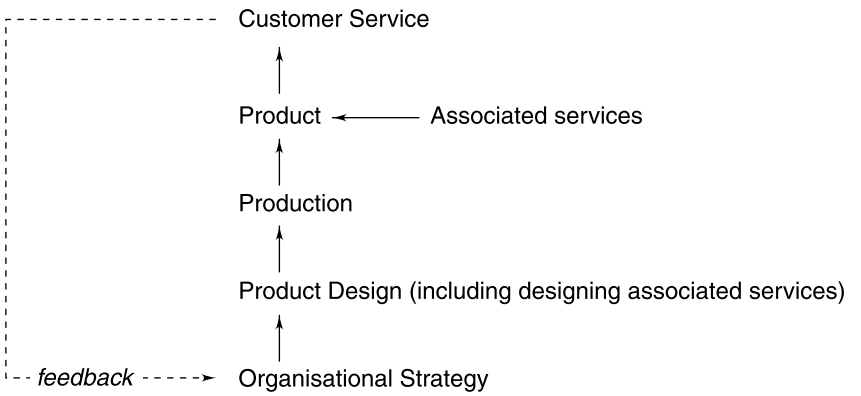


Figure 12.1 Product Design as a Strategic Activity

Design as a Strategic Activity

A company's design of its products indicates who its customers may be. It indicates the company's approach to people and business in general. A design includes the physical product and the plan of all the associated services that should go with it. On the face of it, it may appear like a drawing or a prototype of just a physical product with the specified dimensions or characteristics. But, it is much more than that. In its physical dimensions or other properties are embedded the various unsaid messages about who would use it, how would it be used, where would it be used and when. It is the 'seed'—the conceptualisation and culmination of all thinking as to what the customer would be offered. It has all the genetic material for the growth performance and viability of the organisation in the face of competition in the present and the future. A design of a physical product or that of a service product represents the total approach to doing business. Figure 12.1 depicts this strategic role of designs.

As mentioned earlier, while the customer's needs and preferences may be of help to define an organisation's strategy and the latter would help in designing a product, the product design in its turn would influence production/operations strategies and marketing strategies. A particular design would necessitate a particular type or a mix of these functional strategies, if the organisation has to remain competitive.

Take the case of a watch manufacturing company that starts making watches designed as jewellery. This may be the result of its effort to cater to a unique customer need—its own particular organisational strategy to position itself differently amongst the multitude of other watch-makers. This is the case of a company driving a product design to fulfill its objectives. However, even if the company entered into this specialised design without a preconceived plan, it would have to take special measures in its production process, distribution network, marketing channels and associated service operations consistent with the jewellery product. The very fact that the company has entered a jewellery business would demand different production, procurement, quality and logistics strategies. It would then be the case of a design driving the company.

Therefore, either the design could be used consciously as an active representation of an organisation's strategic framework or it would—in the absence of a conscious effort—itself drive the organisation's strategies. Either way—by design or by default—product design has strategic implication and impact.

PRODUCT DESIGN FOR ORGANISATIONAL COMPETITIVENESS

Product designs provide much needed variety in terms of the features and the appearance. An appropriate product design also helps an organisation to compete in the market place on the basis of cost, quality and time.

Cost Competitiveness

A high proportion of a product's production cost is determined at the design stage. Take the following cases:

(i) General Motors: 70 per cent of the cost of manufacturing truck transmissions is determined at the design stage.

(ii) Rolls-Royce: Design determines 80 per cent of the final production costs of the 2,000 components.

At this point, a revision of the cost concepts may be in order. Considering the fixed and the variable costs of a product, the following relationships hold good:

$$\text{Total Cost} = (\text{variable cost} \times \text{quantity}) + \text{fixed cost}$$

$$\text{Unit Cost} = \text{variable cost} + (\text{fixed cost/quantity})$$

Therefore, if a product is not profitable because the fixed cost is high, it would be possible to make it up in volume. Since the fixed cost is divided over the number of units, higher volumes of production should result in lower *per unit* cost. However, a product that is not profitable because of a high variable cost cannot be helped by increasing the volumes of production and sales. In fact, the more one sells, the more he loses.

That being the case, it is essential to get a handle on the variable cost components such as:

(a) Materials cost,
(b) Labour cost,
(c) Cost of plant and machinery,
(d) Machinery and plant maintenance cost, and
(e) Cost of packaging the product.

The point to realise is that all these components of the variable cost of production are dependent upon the design of the product. The kind of materials to be used, the number of material items that go into the product, the required level of skills of the production workers (higher skills cost more money), the number and the sophistication of the machinery and automation that is required, the amount of maintenance activity that is required (which in turn depends upon the kind of machinery used and the wear-and-tear of the machinery per unit of production) and the type of packaging (kind and variety of materials used, amount of materials used) depend significantly upon the particular design of the product. A design dictates a certain level of variable cost.

Once the variable costs are under control, it is important to minimise the fixed costs in order to realise further cost economies. The fixed cost originates from:

(a) Plant or machinery and automation,
(b) Labour, and
(c) Tooling.

A good design effort should take cognizance of these production cost aspects.

Life Cycle Costs

The production cost is only a part of the total costs. A particular product design may lower the production costs, but it may significantly increase the costs of quality. It may have reasonable costs on both these counts, but may require much enhanced operating costs for the customer when he uses the product.The product, during its use, may necessitate frequent and more expensive maintenance. The costs of built-in obsolescence due to a bad design could be substantial to the customer. Now, everyone realises the importance of environment and ecology. Certain product designs, due to the kind of materials they use or due to the frequent disposal of the product, disturb the environment more than some other designs. Alternatively, the product design may be such that it involves environmentally more damaging production processes. Life cycle costs are borne by the possessor of the product and also by the society as a whole. They are borne during and even after the life of the product when it is disposed.

A good design effort should facilitate the reduction of all types of cost. It should minimise

— Materials cost,
— Manufacturing cost,
— Quality costs,
— Operating cost for the customer,
— Maintenance cost for the customer,
— Depreciation cost for the customer, and
— Environmental costs (for the customer and for the society).

What is ideal is that the total cost of the product over its life has to be minimised. There are two points that are being made here:

1. The total 'life cycle' cost is important, and
2. A high proportion of a product's life cycle cost is 'locked in' at the design stage itself.

The Westinghouse Curve shown in Fig. 12.2 illustrates how the life cycle cost of a typical product is strongly affected by the decisions made during the early stages of product design.

According to the curve, by the time the concept is formulated and validated, 75 per cent of the ultimate costs have been fixed or committed.* This means, cost reduction efforts after that stage will have a limited potential. Relatively small portion of the product costs are determined, and thereby controllable, during the production stage. Therefore, it is important to consider the life cycle costs right at the stage when the product design is getting conceptualised. In order for a product to have low life cycle costs, it has to be designed with such an objective in the first place.

This is in consonance with the general experience that the conceptualisation and formulation of an activity in any sphere is of vital importance. This is observed even in the formulation of projects. The projects that are well thought out, well investigated and formulated seem to have an excellent success rate during and after implementation. On the contrary, those that are only cursorily investigated and formulated seem to face immense problems during their execution and operation. Product design is thus the seed that contains all the genetic material for the future performance of the product.

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* *Improving Engineering Design—Designing for Competitive Advantage*, National Research Council, National Academy Press, Washington, DC, 1991. This curve was shown at some internal meetings of the Westinghouse Corporation but has since been widely reprinted.

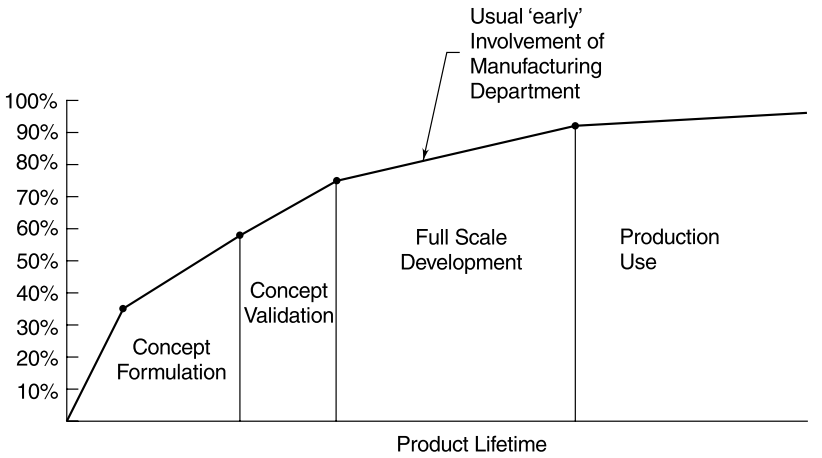


Figure 12.2 Westinghouse Curve*

Competitiveness through Quality

While quality has become an essential prerequisite these days, it still has a great potential to be used further as a strategic measure. This is apart from the considerations of the cost of quality. A good product design contributes, in a large measure, to the product's quality. The various attributes of product quality, as derived from a good product design, are mentioned in Table 12.1.

In purely cost terms, the cost of quality generally constitutes a significant portion of the life cycle costs of a product. Therefore, designing good quality into the product would substantially reduce the costs over the product's life cycle. Taguchi has been one of the pioneers of this philosophy of quality. The concept of a 'robust design' of a product—where the product is designed to be robust enough to perform under several external variations—flows from this thinking.

In the context of 'designing quality in', it may be worth the while to look into some of the quality characteristics such as reliability and user-friendliness. The initial manufacturing costs may increase as the reliability is improved, but the overall life cycle costs can decrease. The cardinal principle guiding improved reliability and also user-friendliness is to keep the design simple. Simple designs tend to minimise human errors in using/handling the product. The designer has to anticipate the possible human errors. Data on field-failures of existing similar products of the company may offer some tips in this respect. Another method to improve reliability is to have redundancy (i.e. if one part/system fails, an alternate part/system would take over the function). This may increase the initial cost to the company but the overall costs in the long run may reduce. Similar thinking operates in cases where the designers design the product for use conditions that are harsher than those generally encountered. Another important tip is to improve the weakest component or part of the product and give priority to it. Thus, the weakest links are strengthened first. Indeed, these

* These are the 'committed' costs, and not the 'actual' expenditure incurred at that stage. For instance, the actual expenditure at the end of concept formulation-and-validation may be just 10 or 15 per cent of the life cycle costs. This curve is typical of almost every product (from any firm) and that the figure of 75 per cent indicates that a very large fraction of the life cycle costs of a product are committed right at the early stages of its design.

Table 12.1 Attributes of Product Quality Derived from a Good Product Design

1.	**Performance:** How well the product functions.
2.	**Conformance:** How well the product conforms to the specifications or standards set for it.
3.	**Features:** How many secondary characteristics does the product have to enhance its basic function.
4.	**Aesthetics:** How attractive the product is.
5.	**Reliability:** How well does the product maintain its performance during a certain given time period.
6.	**Durability:** How long the product lasts in use.
7.	**Serviceability:** How easy is the product to maintain.
8.	**Safety:** How little, if any, is the risk to the users and those in the vicinity of the users (a) when the product is in use, and (b) when the product is thrown away after its useful life.
9.	**User-friendliness:** (a) How easy is it to use. How easy is it to operate with. (b) Is it ergonomically all right.
10.	**Customisability:** How easily can the product be modified (a) in case the requirements of the customer were to change, or (b) in order to accommodate improved/additional features in the future to suit the customer's needs then.
11.	**Environment-friendliness:** How safe is the product for the environment (a) while it is being used and (b) when it is discarded after its use.

Table 12.2 Principles of User-friendly Product Design*

1.	Consciously simplify tasks of the user in using the product.
2.	Be in the user's shoes and understand the user's skills and knowledge. The product should allow a user to easily operate it. (e.g. if a personal computer is to make inroads into the articles used everyday by a housewife, then the hardware and the software should become simple enough for her to handle quickly and easily.)
3.	The product design should be such that the operations to be done by the user while using it are very obvious.
4.	Standardisation might help in increasing the familiarity of the user to the product. Therefore, use standardisation in the product designs.
5.	Use principles of *Poka Yoke* i.e. preventing incorrect use. There should no chance for the user to make a mistake.
6.	Display the instructions (regarding how to use the product) clearly.
7.	Expect mistakes and human errors in using. Have a design that will not offer any chance for such mistakes occurring and/or a design that will ensure that the product's functioning will not be affected despite such mistakes.

are very simple and seemingly obvious tips. But, they would go a long way in improving reliability of the product. The principles of user-friendly design are mentioned in Table 12.2.

* Adapted from: Bralla, J.G., *Design for Excellence*, McGraw-Hill, New York, 1996

Again, these are seemingly simple and commonsense tips. However one may encounter situations, particularly in the usage of information technology products where the practice is to give trouble-shooting instructions over the telephone. Sometimes, these functions are even handed over to a call centre. The user is usually not as technically savvy as assumed to be. The exponential growth of the PC is a testimony to the pioneers who thought up of a product that does not require technical savviness on the part of the user.

In addition to Robust Design and Design of Experiments (DoE), the other tools to include quality into a product's design are Quality Function Deployment (QFD) and Value Engineering (VE). These have been described in other chapters in this book. QFD and VE very emphatically bring the customer's point of view into the design of a product.

Competitiveness Based on Time

One of the ways a product design helps a company to gain advantage over its competitors is through reducing its reaction time to the market. When competing firms have products giving similar service/functions to the customer, it is important to reduce the time to manufacture the product and thus reach the product to the customer quickly. Whereas, when it is a case of an improved or new product design, it is impsortant to minimise the overall time for the product to enter the market. This would, most crucially, include the time to develop (the improved design of) the product. The economic penalty for time delays is quite severe for new products in a dynamic market. Figure 12.3 illustrates this.

Thus the following lead times are important:

1. Product development lead time
2. Manufacturing lead time

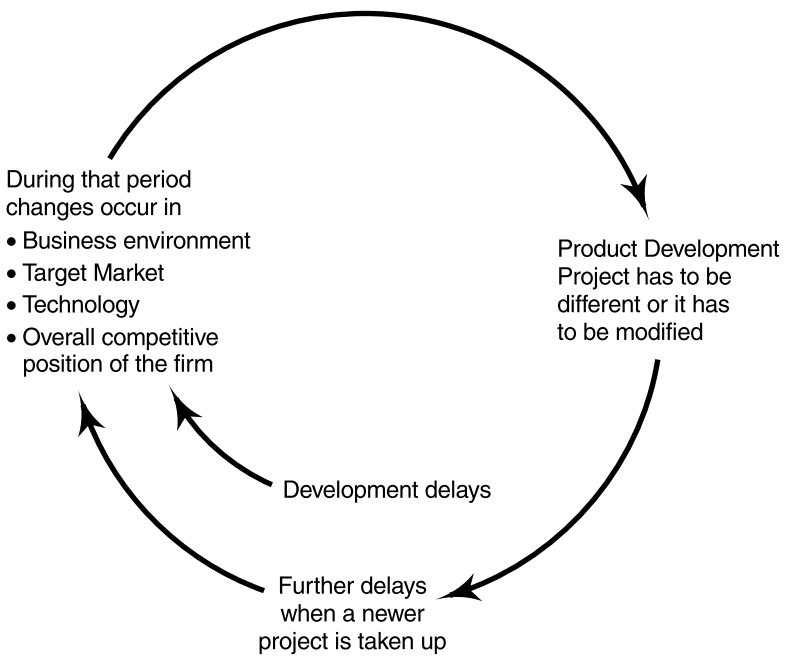


Figure 12.3 The Vicious Cycle of Product Development Delays

The Nature of the Product Development Process Product development consists of the following type of activities:

(i) Concept development
(ii) Marketing/sales provide market brief
(iii) Prototype drawing
(iv) Prototype/cost approval
(v) Product design
(vi) Get production inputs
(vii) Interact with suppliers
(viii) Detailed design of the product
(ix) Build full-scale prototype and test
(x) Manufacturing approval
(xi) Pilot production
(xii) Design certification
(xiii) Launch in the market
(xiv) Design review

While the above are the activities of the product design function, these have much interaction during several stages with the production, marketing and finance functions.

The manufacturing activities typically include:

(i) Defining the required processes
(ii) Developing cost estimates
(iii) Interacting with suppliers
(iv) Detailed design of the process
(v) Developing tools and equipment
(vi) Approving prototype
(vii) Trying out tools, installing equipment
(viii) Pilot production and verification
(ix) Ironing out supplier and other problems
(x) Full-scale production
(xi) Reviewing the process

The marketing function has its own activities, such as:

(i) Making the marketing/sales brief to the product design personnel
(ii) Verifying the target market
(iii) Estimating sales
(iv) Evaluating the prototype
(v) New product forecast
(vi) Preparing the customers
(vii) Planning the distribution of the product
(viii) Training sales personnel
(ix) Conducting sales promotional activities
(x) Selling
(xi) Providing market feedback

Concurrent Engineering to Speed up Product Development During the entire process—from conceptualising to the launch of the new product—the activities of the production and marketing

functions are as important as those of the product development/design function. In fact, many of these activities are interdependent and the new product design must fit in with the production and marketing functions of the company. The new design must also fit with a company's marketing and operations strategies and the existing systems and policies. If a new design warrants a change in these strategies or policies or systems, it needs the wholehearted concurrence of the production and marketing functions.

The product development can be speeded up by:

- having concurrence of the various functions,
- doing several of the activities in parallel, and
- having integration and information-sharing across the functions.

It is obvious that a serialised approach to product design/development would mean a considerable lead time to introduce the product in the market. If manufacturing has to wait until a product design is released, it will only make the company miss a market opportunity. Many companies have come to appreciate the disadvantages of a sequential approach to product development. Concurrence is the key to a more compact and integrated approach to a design project. The other advantage is that it can help in doing the design right the first time. Otherwise, a lot of time may be wasted in the 'football match' between the design, manufacturing, quality and marketing functions. A concurrent approach to product designing is termed as concurrent engineering. It is also called simultaneous engineering as it invariably involves doing several activities pertaining to different functions simultaneously.

Cross-functional Teams for Product Development Concurrent engineering may involve cross-functional teams to solve/resolve any issue that may impede the new product design / development project in the company. Cross-functional teams serve to integrate the various activities of the product development effort and help in information-sharing on a regular basis. The frequent interaction between persons from two different departments may help them educate each other and thus enhance each other's capabilities. While in the traditional product design approach one department audits the other department, in a team approach there is collaboration right from the start. An essential benefit of involving various constituencies in product development is that the various departments become familiar with the product early enough.

However, a team approach to product design is not without its problems. It works well only when:

- the team members have good interpersonal skills,
- the roles and responsibilities of the team members are clearly understood by the individual members,
- the authorities and responsibilities between the functional departments and the product development project team are clearly defined,
- the team is adequately empowered to do what it needs to do,
- the team leader is effective,
- the team members are dedicated to their responsibilities, and
- the team does not exist only on paper.

Thus, a cross-functional team approach places greater demands on the members in terms of learning new skills, both technical and interpersonal. However, most organisations today have the ability to absorb changes rapidly (they have very little choice) and hence they would be able to handle team approaches quite effectively.

While the concurrent engineering has several merits, it can run the risk of scrapping the process planning as it is done before the final design is released. This can happen in an extremely dynamic business environment. This means the concurrent engineering effort itself has to speed up.

DESIGN FOR MANUFACTURE (DFM)

Competing on time has much to do with the manufacturing/operations flow times. It is obvious that a proper planning of the production processes, their workload distribution, the scheduling decisions, planning of the required materials and men, and removing bottlenecks would result in improved throughputs. However, what is not obvious is the fact that a good product design can help substantially towards the reduction in the manufacturing flow time.

A good product design would be such that it makes many or all of the manufacturing related functions to be done in less time, less effort, and with less cost. Such a product design would facilitate the manufacturing function. The manufacturing related operations include:

- Material procurement,
- Material handling,
- Product conversion (e.g. machining processes),
- Changeovers and set-ups, and
- Quality control procedures.

All of these, if not handled properly, could lead to increased lead times. A good product design takes the facts or realities of these operations into consideration, incorporates them into the design and thereby facilitates these operations.

What is DFM?

The idea behind a DFM effort is to modify the existing product's (and/or its components') design or have a new product designed in such a way that the processes to manufacture the same are easier, quicker and/or less expensive. Reducing the manufacturing time is a major consideration. This, of course, has to be achieved without compromising on quality.

DFM, as a concept, is not new although its huge importance has dawned on the manufacturers only lately because of the intensity of competition in the present times. It was Eli Whitney (and Le Blanc) in the Western part of the world, who developed a system 200 years ago for manufacturing muskets that incorporated the concept of interchangeable parts. Earlier, all muskets were hand-made. This was cumbersome in addition to being expensive. It was also terribly time consuming and made the immediate availability in large numbers a difficult task. Whitney redesigned each part to a specific dimension with a limited tolerance. This paved the way for mass manufacture of muskets. Thus, he designed the musket (and its components) for large scale manufacturability.

Henry Ford seemed to have grasped the concept of DFM about 90 years ago. The following statement by him, about Model T succinctly expresses the idea behind DFM.

'… It was up to me, the designer, to make the car so completely simple …. The less complex the article, the easier it is to make, the cheaper it may be sold…. We start with the consumer, work back through the design, and finally arrive at manufacturing.'*

* Henry Ford, *My Life and Work*, Ayer, Salem, N.H., USA, 1922.

Product design influences the efficiency of manufacturing. Thereby it influences the flexibility of marketing strategies and the organisation's success in a competing business world.

Cultural Barrier It is indeed surprising that despite the emphasis during the last several decades on increasing efficiency in manufacturing, the importance of product design for manufacturing efficiency has not been appreciated. A majority of the organisations have had the design department and the manufacturing department hardly ever interacting. Product designers in some manufacturing industries have been sitting in ivory towers. They are highly respected, as their job is perceived to be creative like that of an accomplished artist, whereas, the manufacturing executive is seen as a rough-and-tough person who has risen from the ranks, and therefore lacking in such finer abilities. A cultural barrier seems to separate the designer of the product and the person manufacturing the product.

'Over the Wall' Syndrome Product designers believe that their job is over once they release their drawings. They, so to say, throw their designs 'over the wall', for the manufacturing person to do the next job of producing it. Manufacturing engineers then struggle to produce the product that is 'dumped into their laps'. At their best, design and development people have been more concerned with how a particular feature requested by marketing may be translated into a physical parameter. How it may be produced, what it may cost and in what time, have not been much of their concern.

As a result there are several engineering changes *after* the design has been released, because the design gives multitudinous problems when taken up for manufacture. The solution of these problems wastes precious time, and by the time the company has made the product it is too late as the market has shifted. It would have been so much better if the two departments—design and manufacturing—had sat together during the early stages of product design and exchanged notes.

With the heat of the global competition intensifying, companies have now started to seriously think as to how their products could remain competitive in a dynamic market. The Japanese companies such as Toyota, Honda, Mitsubishi and several others have been the forerunners in manufacturing products that were of high quality, yet inexpensive and available at short notice. They have done this consistently over the years, have been quite profitable all through and growing in the international markets, notably in the Western markets. They achieved this despite the fact that it was the West that had been the harbinger of computer technology and automation. While it was Whitney and Henry Ford who had initiated the concept, their message was lost because of the preoccupation with technological superiority. The Japanese have much automation in their factories too; however, they seem to have grasped the value of simplicity in the plants—fewer parts, same or similar parts, and parts that are simpler to manufacture. Table 12.3 on the next page presents some DFM principles for assemblies, while Table 12.4 on page 12.13 presents the advantages of minimising the variety of parts used in a product or product-line.

Much of the direct cost of manufacture is incurred in making components. The cost of assembling these parts is comparatively small. Then, why is Design for Assembly made an important issue? As can be seen from Table12.3, the Design for Assembly effort results in reducing the number of components and in standardising them. In fact, most of the suggestions made for Design for Assembly are about the components. Reducing the number and variety of components has considerable cost–time–resource–effort economies combined with the economies associated with simplicity. Processes, systems, or parts made simple have a considerably high probability of improved quality and productivity. Table 12.4 presents some interesting aspects of this.

Table 12.3 DFM Principles for Assemblies*

I. Minimise the number of parts

(i) Reduce the absolute requirement of the variety of parts
- Design the product in such a way that it consists of very few parts.
- Use a different technology, if necessary.

(ii) Combine parts where feasible

Parts can be combined with other parts when:
- They are of the same material.
- They do not move relative to other parts in the assembly.
- Their combination would not affect the assembly of other parts.
- After sales service does not require these to be separated.

II. Standardise designs

Standardise wherever possible:
- Parts, modules, sub-assemblies, manufacturing processes and systems may be standardised.
- Where the parts cannot be the same, see if they can be similar.
- Apply 'group technology' concept of 'families' of parts.
- Where possible use standard catalog components.

III. Minimise number of operations in the assembly

IV. Modify the part/s with simplification of assembling in mind

Even minor modifications yield greater Assembly simplification:
- Slight changes in a part's geometry can reduce the difficulty in grasping, positioning and inserting a part. The effort and time taken can reduce significantly. Human errors of putting a wrong part or of orienting it wrongly can be reduced.

  Figure.12.4 depicts the use of funnel-shaped openings and tapered ends to facilitate insertion of parts.

V. Use modules

This allows for more standardisation and speeds up the assembly process.

VI. Minimise 'new'-ness

Minimise:
- new parts
- new processes
- new suppliers
- new machines

New things—particularly too many new things—introduce many imponderables and increase uncertainty and, consequently, errors resulting in unacceptable quality and time delays in assembling.

VII. Use 'Poka Yoke' or fool-proofing

Design in such a way that the parts cannot be assembled incorrectly.

Figure 12.5 shows two parts that should not be interchanged. The design shown on the left is more prone to human errors while assembling. Whereas the design on the right, which is a simple modification, ensures that the wrong part can never go in.

* Bralla, J.G., *Design for Excellence*, McGraw-Hill, New York, 1996.

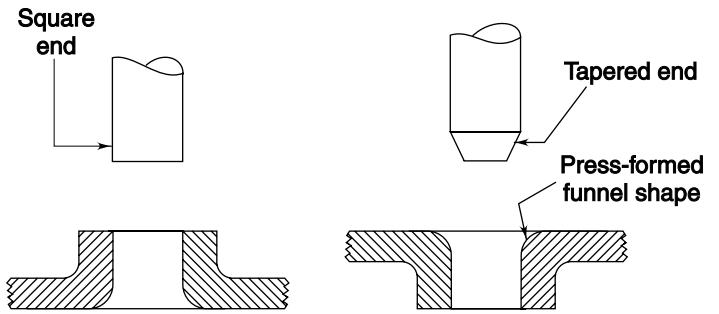


Figure 12.4 Facilitation of Insertion of Parts by the use of Funnel-shaped Openings and Tapered ends

Source: Bralla, J.G., Design for Excellence, McGraw-Hill, New York, 1996.

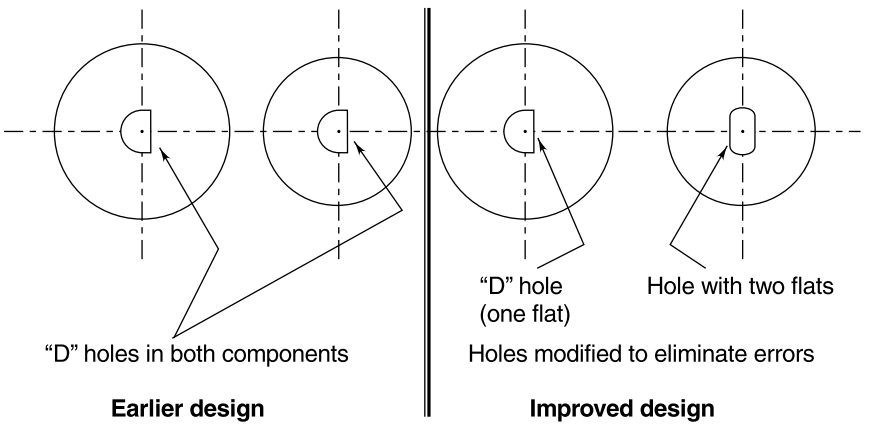


Figure 12.5 Fool-proofing the Assembly by Modifying the Design of the Components

Source: Bralla, J.G., *Design for Excellence*, McGraw-Hill, New York, 1996.

Table 12.4 Advantages of Minimising the Number of Parts

• By reducing the variety, the time to make the assembly (or the sub-assembly) is reduced, because, there are less number of operations/movements of the workers.
• By reducing the number of components to be produced, there can be longer production runs and economies of scale.
• Each eliminated part means that much less costs of producing, moving, handling, buying, storing, monitoring, inspecting, repairing, maintaining, reworking and paper-work.
• Lesser the number, lesser is the complexity, cost, effort and confusion. Confusion is the biggest impediment to productivity. Confusion and waste are synonymous.

The DFM concepts emphasise simplicity and standardisation everywhere. Some may feel that this is contradictory to the very objective of a new product design. After all, a new product is supposed to open up hitherto untapped markets. Therefore, a new technology, a new process, a new resource and a new system may have to be used. While no one may have any issue against simplifying things, standardisation may mean as much of the old as possible.

The reply to this dilemma is that DFM attempts to strike an optimal balance between change and standardisation. It is about how to introduce change harmoniously into the production system. The required change, if obtained with several hiccups while producing, would only lead to undesirable delays, increased flow times and enhanced cost. Whether a company has same old products or new, the objective behind DFM is to have such a product design which would impart manufacturing/operations competitiveness to the organisation. To the extent competitiveness demands new products, these will be made and presented in the market. To the extent competitiveness demands efficiencies, these will be achieved and the advantage of the same passed on to the customers. The effort of DFM is to be able to produce new designs of the products while also achieving production efficiencies.

Tables 12.5 and 12.6 present the advantages of a modular design and design tips on components/parts.

Table 12.5 Benefits of Modular Design

1. Making changes in the production process or the product is simplified as the changes can be localised.
2. Tracking of errors and problem-solving is simplified.
3. Production and/or maintenance times are lower.
4. Documentation is simplified.

Geoffrey Boothroyd and Peter Dewhurst of the University of Rhode Island, USA, have done pioneering research on the design of components and the techniques for assembly. Their research pointed to standardising and reducing the number of components by redesigning / modifying them, with the effect that the assembly time is reduced and the quality is improved. Ease of assem-

Table 12.6 Design Tips on Components

1. Design so as to use standard tools as much as possible.
2. Standardise the parts features (slots, keyways, hole sizes, threading) as much as possible.
3. Use 'product families' concept.
4. Avoid complex contours.
5. Make use of tolerances to the extent possible while keeping in mind the quality requirements.
6. Reduce the usage of delicate/fragile materials.
7. For ease of assembly, a part should: • be self-aligning (i.e. does not require to be oriented) and with sufficient play for further convenience. • be such as to insert it from the top. • have as much symmetry as possible. • be easy to handle. • get into the assembly with preferably just one motion.

bly and freedom from quality related problems tend to go together. The principles these researchers espouse for product design are, in fact, seemingly quite common sense principles. Yet, they are extremely powerful in producing overall economies in the assembling and other production systems.

It is interesting to see that minor modifications in the component design pave the way for major simplification in assembling. Figure 12.6 shows how a minor modification like having a dual orientation in a carton can simplify and help speed up packaging work in a cosmetics factory.

In component production in engineering industries, there are various manufacturing processes that could be used like milling, turning, grinding, rolling and forging. Some metallurgical engineering processes may also be used such as casting, moulding and extruding. There would be special product design guidelines for each of these processes. In designing a final product comprising several component parts, the design team has to consider the different manufacturing processes that go into the manufacture of the components. The design of the components cannot be independent of the manufacturing process. The product design team should take into consideration the constraints and capabilities of the manufacturing process/es that will be used.

Moreover, a particular production process may be cheaper as compared to alternative production processes beyond a particular level of production volumes. Therefore, it is not just the ease or facility of manufacture alone that should guide the product design. Other issues such as the economies of scale are equally relevant in the selection between alternative processes. Thus, theoretically speaking, the design of a component should come after the selection of the process.

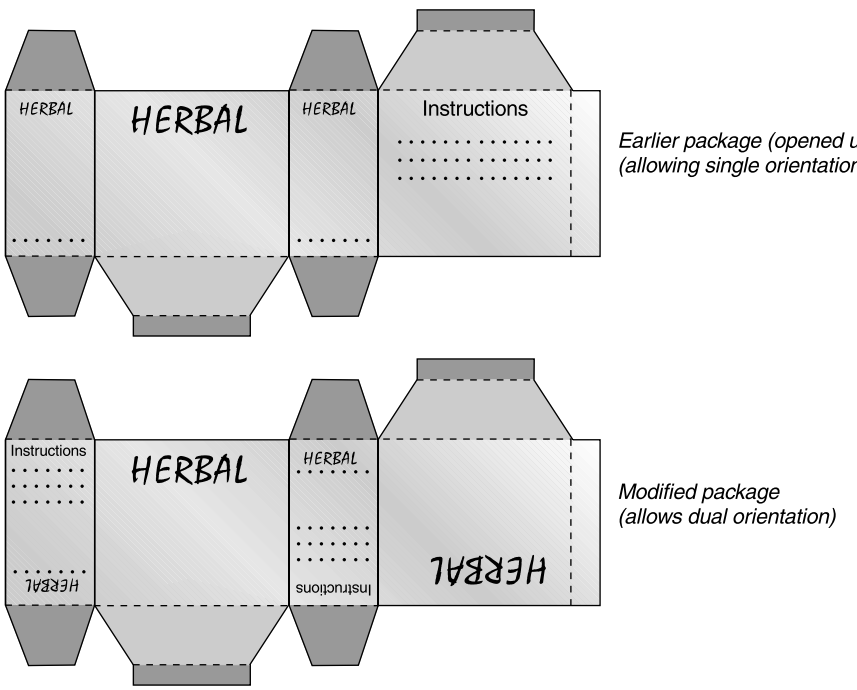


Figure 12.6 Modified Design of the Printing on the Carton makes Dual Orientation Possible and Saves Time during Manual Packaging

However, sometimes a new product design could provide an opportunity to develop an improved manufacturing process, in which case, the component and the process design may take place simultaneously.

It is interesting that a modification of the design of products can lead not only to improvements in manufacturing efficiencies but also to improving the system's ability to deliver better quality, improved reliability, better after-sales serviceability, and improved safety to people and to the environment in general. Not all the objectives necessarily get achieved by the same set of design actions. Some design actions may be prone to a conflict between different objectives. For example, a design for reliability may require redundancy i.e. the inclusion of a spare sub-assembly module or component. This means increase in the number of parts, which may go against material and manufacturing efficiency objectives. Taking another example, manufacturing time (component making and assembly time) can be reduced considerably by using injection moulding of plastics to produce a complex integrated part in the place of several individual metallic components. However, plastics are undesirable from the viewpoint of protecting the environment. Plastics have several other drawbacks regarding strength, resistance to high variations in temperatures and prolonged loads. Thus the reliability may be lower with the use of plastics in a product's design. To take another example, better serviceability (in the field, after sales) may require easy disassembly of the parts. Having a number of simple components may facilitate this objective rather than having an integrated and more complex part in their place. Hence a good product design should primarily focus on the priority objective/s. Next, it should find a balance between various other objectives.

Design for Excellence

While designing for manufacturability, the product design team should keep in its consideration the entire product family. Unitary approach may only result in sub-optimisation. Moreover, by the same logic, the designer/team should look beyond its own organisation to other associated organisations in the value chain. Design being a strategic activity, the design effort should not only improve the present efficiencies but should also keep the future in view while making the design and other changes. Finally, customer service should be the motto that should drive the product design effort in any organisation. Hence product design should be an all-round exercise, contributing to the overall excellence of the organisation. DFM is only about one aspect amongst many. Truly, the efforts should be towards design for excellence or DFX (X ≡ Excellence).

PRODUCT DESIGN IN THE SERVICE INDUSTRY

While product design is extremely important for a manufacturing industry, for the service organisation it defines its very 'genes'. A service 'product' defines the type of customer segment the organsiation has chosen for itself. A service product design is not merely a choice of the design of component parts that can be put together. It is verily the choice of the kind of customers the organisation has decided to cater to and the choice of the type of customers it has decided *not to* cater to.

Service Design Defines the Very Business of the Service Firm, not Just the Lifetime Costs

A manufacturing company's product design has cost implications that last a lifetime of that product. So, it is very important for the manufacturing industry. But, a servcie company's choice of

product design—i.e. the servcie porduct that it offers—can have either excellent or devastating effects on the compnay's business itself for a long time to come. For a servcie industry the choice and design of its service offering will be of a long time strategic importance.

The service company's offering (i.e. product) defines the company's strategic posture. It defiens the kind of industry segment it plans to play/compete in. For the service company, product design speaks of its very long term commitment. For the service compnay, product design is serious business but less serious than that for the service compnay. A service product or service offering defines the service company. It is not so with the manufacturing compnay; it is not a statement of the company. 'Budget hotel' is a term that defines the product and also the very business of the hotel company. A manufacturing company can upgrade its product to include more quality features and change its market segment. However, a Budget hotel will find it an extremely uphill task to get out of its image of a low cost or budget hotel. A higher priced hotel is an entirely different business.

Service Design Decides on the Attributes it will Cater to and also Those it Will Not

Wal-Mart is into the customer segment or business of low cost and wide selection. The Wal-Mart chain of stores has chosen its customer segment to be those who value low cost and wide selection most over any other attribute. So, it only focuses on these two attributes and does not mind if it does not do well on other attributes of some other stores chains like Saks Fifth Avenue. Those who do nto prefer Wal-Mart's service attributes buy elsewhere. Wal-Mart may not at all worry about that; because, these are two very different customer segments. In fact, Wal-Mart may refuse to over-invest in attributes other than low cost and wide selection. It would not waste its time its time and resources into something that is not its value preposition. For a service company, 'product design' is the choice of the customer segment and the value being proposed. It may be noted that here 'customer segment' is not chosen by the traditional market segmentation methodology but by finding a population of customers who share a nation of what constitutes excellent service. Wal-Mart would concentrate on the chosen segment and provide those 'excellent service'. Attributes preferred by the customers and not bother much about any other attributes.

To take another example: Mavalli Tiffin Room (or MTR), a restaurant, is an institution in Bangalore. Its customers expect mainly one attribute: taste food that is traditional presented. So, MTR does not bother about providing veriety of items at all times or about customers waiting for long to get into the restaurant. The menu is fixed at different broad time zones of a day and the variety is quite limited. Customer may sometimes wait for as much as an hour to have an *idly* or *dosa*—he does not have the choice, the restaurant would have decided the menu for that part of the day.

In today's world of net-banking, Commerce Bank in the USA focuses on the segment of customers who like visiting a physical bank. So this bank has evening operations and weekend hours. Understandably, this bank emphasises on the cheerfulness of its employes' interactions with the customers. Thus, a real person as a teller (not an ATM machine or a website or a phone-banking system) who smiles at you is the bank's 'product design' or 'servcie offering'. Regarding the rest of the attributes like the price and product range, Commerce Bank's management is willing to cede the battle to other banks. Because, Commerce Bank has chosen its value proposition and its kind of customers, i.e. the customer group that places priority on this value. Personal banking with utmost friendlines is its service product. The bank will not be able to change its product design

in ages to come, unlike a manufacturing compnay that can change its product design very much more frequently.

A service organisation tries to excel in its chosen design attribute and, *by design* it does not care about other attributes. It most probably will not be able to excel on all the attributes. In fact, such an effort may end up in doing nothing well. Therefore, a service firm may have to decide also on what *not* to do well in. It may have to decide what to target for excellence and also what to target for *inferior* performance. This sounds strange, but it is true. A service product design defines what to excel in and what not to. In a manufacturing context, user friendliness would always be a desirabel additional attribute of product design. But in the case of a specific service, the latter may want to eliminate any operation by the customer and user friendliness may be an undesirable attribute. So, one cannot describe a general set of quality attributes of a good service product design, unlike in the manufactured product.

Service Design is Primarily Defined by the Customer Needs; Service Provider's View Point is Secondary

Moreover, generally things are not seen from the viewpoint of the service provider; the service is defined from a data of what the customer wants. Hence, there may be few parallels here with DFM — what the service firm's employees can do. The focus is almost entirely on what the customers of the chosen segment want. Difficult or otherwise, the needed service attribute has necessarily to be provided. If in doing that some relief or ease of serving can be provided to the employee, it may be so done. Services are almost totally customer-driven. Service attributes as desired by the customer must be provided undiluted.

Reliability is Crucial in the Service Industry

Reliability is not just another attribute in the service organisation; it is of crucial importance. Consistency of performance, dependability and delivering on the promises made are vital elements of service quality. The service offer should be such that it has these characteristics. Services are fragile; mistakes made are difficult to correct. Credibility once lost is hard to retrieve. There is no 'rework' possible as in the manufacturing industry. The service offer should be designed keeping in view these special aspects of the service industry.

Customer is Right There in the Service Operations

Customers are not simply the consumers of the service provided; they can be integral to the production of the service. In the manufacturing industry, the firm buys the material imputs, tranforms some of them and the value-added product is delivered to the customer who pays for it. The situation in the service firm could be quite different; employees and the customers both can be part of the value generation process.

In banks, the teller's or personal banker's service could be slow if the customer is not fully ready with all necessary paper work. Queues at the railway booking counters or at airline check-in counters could be shorter if the customer is ready with change or tickets, identification papers and screened bags. Self-service counters in buffets in hotels are more or less efficient depending upon the customers' level of involvement. Because of the involvement of the customer, there is an element of uncertainty about the quality of the service product or its delivery. The customer involve-

ment is a part of the service product design. In some cases, the customer is trained to perform his role in the service delivery. This also is a part of the service product design. The level and type of customer involvement in the service production depends upon the service product design. This is peculiar to the service industries. Manufacturing product design does not have to worry too much about customer involvement in production. Along the lines of Design for Manufacturability, one can think of a concept of Design for Customer Participation (DCP) in production of the service. After his involvement in the production of the service, he has to be finally a happy customer. The challenge in service product design (service process design could be a part of service product design) is to keep customers happy while taking care of their involvement in the production of the service.

QUESTIONS FOR DISCUSSION

1. How does a good product design increase organisational efficiencies?
2. Should the product design concern itself with organisational efficiencies? Discuss.
3. Why did, in your opinion, Henry Ford's message on product design get lost for so many decades? Discuss.
4. 'DFM is Value Engineering for manufacturing'. Do you agree with this statement? Explain.
5. Discuss the merits and demerits of using plastic parts in a product.
6. Wouldn't DFM suppress creativity in a firm? Discuss.
7. Several functions in the companies are getting to be strategic, product design being one of them. If that is the case, how should the organisation cope with this situation of multiple strategic functions?
8. 'A good product design contributes to TQM in the organisation.' Explain how this may happen.
9. Wouldn't reliability concerns clash with DFM concerns? Discuss.
10. What is DFX? What all is included in DFX?
11. Time is money. How can a product design project be hastened?
12. What are the problems, if any, with Concurrent Engineering?
13. How will you incorporate environmental concerns into product design? Discuss.
14. Can there be a design for disassembling? Where could this concept be useful? Give your tips for such a design.
15. Can a concept similar to DFM be useful in the service industry? Explain.
16. Is 'service design' a stategic activity for the organisation? Discuss.

ASSIGNMENT QUESTION

1. Choose any product or service you frequently use. Describe its merits, demerits and make suggestions for changes in its design.

13 Maintenance Management — I

Maintenance Management, as a support function to the production operations and to the service operations, is very important. It has a tremendous impact on the condition of the plant and machinery in the factories and the equipment that may be used in the service industry. For example, in a continuous process plant such as a petroleum refinery if there is a breakdown in one section, it may immediately affect the entire operation downstream and the other operations a little while later. If it is batch operation, breakdowns may damage the condition of the batch of materials in production or it may disturb the schedules of various batches to be produced, thereby leading to considerable confusion. Breakdowns and slowdowns are quite unwelcome, anywhere. In a software services industry or in a call centre, the functioning of the telecommunication and transmission equipment is vital to their business. The lack of good maintenance could be disastrous.

As medical doctors might say that the importance of maintaining good health is generally not fully realized by many people until they happen to fall sick, similarly the importance of Maintenance Management is not adequately realized by the industry. This is particularly true of the Indian industry. In several factories, scant attention is paid to the proper stocking of the spare parts, to maintaining proper policies and procedures, to have appropriate preventive maintenance schedules, to have updated maintenance manuals, to the acquisition and development of required number and quality of technicians and junior and senior managers who may have appropriate skills to operate and maintain the modern equipment properly, and to the application of the principles of work study, incentives and performance evaluation to the extent possible. Maintenance management is perceived to be of secondary importance to the production of goods. In the service industry, it has a similar or even less importance.

There is a general lack of management input in maintenance. The reasons given by many for the same are:

1. Machine failures occur at random and are, therefore, unpredictable.
2. One maintenance job is not like another maintenance job so as to put it in a standard category.
3. Different types of equipment are imported at different times, resulting in a heterogeneous stock of equipment; this makes it difficult to provide proper skilled manpower and facilities for maintenance and repair.

4. Obtaining spare parts from foreign countries is difficult; making them within the country is not economical since the quantity required of each item is small. It is difficult to apply management principles and generate economies in such circumstances.

True, the above given explanations are some of the real problems in applying management principles/techniques to maintenance; the last two reasons are particularly true for developing countries such as India. But then, looking at the quantum of positive impact of having good maintenance management in a factory or in an operations facility, the need for proper management of maintenance is vital as also the need to make best us of the management concepts available even if the circumstances do not permit their application in toto. Good maintenance management is an important input for achieving the desired quality of the products and services. In the following paragraphs, we will discuss the concepts, principles and techniques of management useful in maintenance.

PRIMARY OBJECTIVE OF MAINTENANCE MANAGEMENT:AVAILABILITY OF THE OPERATIONS SYSTEM

The objective of maintenance is to facilitate the optimal use of capital equipment through actions such as replacement, repair, service and modification of the components or machinery so that these will continue to operate at a specified availability for as long as it is beneficial to do so. Maintenance encompasses keeping the 'availability' of the entire production/operations system of the organisation. One of the basic definitions of 'availability' is as follows:

$$\text{Availability (over a specified time)} = \frac{t_{\text{running}}}{t_{\text{running}} + t_{\text{down}}}$$

where t_{running} = Total time of operating in the normal operating state.

and t_{down} = Total time for which the plant (or equipment) is out of operation either because it is being given maintenance service or waiting for it.

The availability of a plant can be improved by various means, such as:

1. Diagnosing the faults or failures as early as possible and taking quick decisions regarding the same.
2. Reducing major break-downs or crisis situations with the help of appropriately organised preventive maintenance programmes;
3. Designing and Installing the equipment in such a way that the failures of the equipment will be low over its lifetime or in other words, increasing what is known as the 'reliability' of the plant, machinery and equipment in the design stages itself. Also, the equipment could be so designed that the times for maintenance action are small i.e. the 'maintainability' should be high.
4. Having proper replacement policies of equipment and their component parts in such a way that the total reliability and availability of the system is enhanced at optimal costs.
5. Having standard times and standard procedures in maintenance as much as possible, so as to gain good control over maintenance operations and also to provide adequate incentives and motivation for maintenance personnel.

IMPORTANCE OF STATISTICS OF FAILURE

Most situations in the area of maintenance involve probabilities. An understanding of the statistics of failures may provide useful information for making maintenance decisions on or prior to the failure of an equipment and for planning general organisationwide maintenance policies. Generally, the following statistics of failure are collected:

(a) How long was the machine component working before it failed? This is the time-to-failure, *t*.

(b) What percentage of instances did it fail at time t. This is the relative frequency of failure corresponding to time *t*.

Obviously, one cannot collect a continuum of such data, but only in ranges (see Table 13.1).

Data shown in Table 13.1 can be used to construct a histogram. If collected in more detailed (smaller) ranges, it can be approximated to construct a continuous probability distribution.

Table 13.1 Representative Data of Failure of an Equipment

Range of Days Functioned before Failure	*No. of Times such a Range of Life was Observed*	*Relative Frequency*	*Relative Frequency Density*
		% of total	Fraction per day
0 – 99	5	5	0.0005
100 – 199	15	15	0.0015
200 – 299	20	20	0.0020
300 – 399	30	30	0.0030
400 – 499	20	20	0.0020
500 – 599	10	10	0.0010
Total	100	100	

TYPES OF PROBABILITY DISTRIBUTIONS

In maintenance we come across three types of probability distributions for the times-to-failure, in general:

1. Hyper-exponential distribution
2. Negative exponential distribution
3. Normal distribution

Each one of these corresponds to a particular category of cause of failure, as described below:

Hyper-exponential distribution shows a steep fall in the probability density function as the time-to-failure increases (Fig. 13.1).

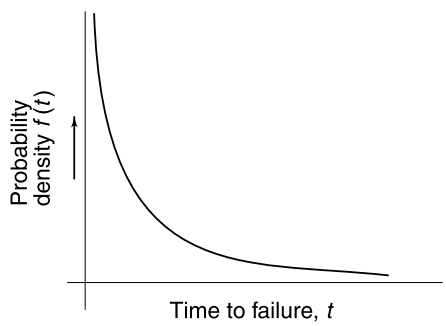


Figure 13.1 Hyper-exponential Distribution

In other words, the chances of failure are high in the initial periods and very much less in the later periods. Such behaviour of machines is a common observation in practice. When the machines are installed fresh, the initial failure rates are quite high, for most of the machines. This might be expected; because if there are any built-in design defects or defects in installation, these

will show up in the initial stages itself. Machines that survive the initial periods without failure are those, without such design/installation defects. Therefore, this is the second exponential fall which is quite flat.

We may compare this behaviour of machines with the infant mortality phenomenon in the case of human beings.

Normal Distribution

Normal distribution has the following peculiar properties:

- its *mode* is same as its mean;
- it is symmetrical around its mean.

In other words, a majority of failures occur around the *mean time-to-failure*; and the failures show symmetrical relative frequencies around the mean (Fig. 13.2).

Such a behaviour is usually observed in the wear-out of components or machines. Some will wear-out faster and some will do so slower. The peculiar properties of the normal distribution mentioned earlier, rule out the possibility of other causes of failure.

This phenomenon of the failures, has a parallel in the ageing (*old age*) phenomenon in the case of human beings.

Negative Exponential Distribution

The phenomenon of failure, where the probability of failure is constant and independent of running time, is given by the expression:

$$f(t) = \lambda \cdot e^{-(\lambda t)}$$

This is a negative exponential distribution. In such a case, therefore, the cause of failure is external to the system. It is neither due to wear-out, nor due to design-defect. An electrical fuse blows up because of a sudden extra load elsewhere or a short-circuit elsewhere. The negative exponential phenomenon is similar to the youth or middle age of human beings where the cause of death is generally due to accidental happenings.

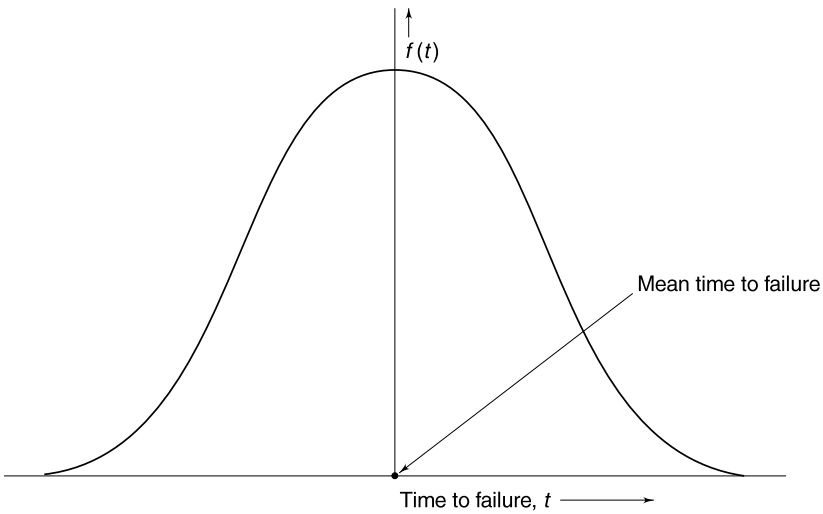


Figure 13.2 Normal Distribution

The McGraw·Hill Companies

Before we discuss the failure phenomenon further, it may be appropriate to recapitulate some basic definitions of probability distribution functions.

The probability of the time-to-failure falling within the values a and b is given by

$$p\ (a \le t \le b) = \int_a^b f(t).\mathrm{d}t$$

The cumulative distribution function, $F(t)$ is given by

$$F(t) = \int_0^t f(t)\,dt$$

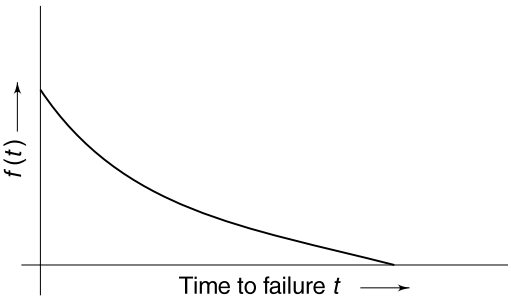


Figure 13.3 Negative Exponential Distribution

The probability of an equipment surviving at time t, designated as $P(t)$ is given by

$$P(t) = 1 - F(t)$$

Out of the items which have survived till time t, the fraction of them that will fail immediately after t is known as the age *specific failure* rate, $Z(t)$. It is a useful function in maintenance.

$$Z(t) = \frac{f(t)}{P(t)}$$

Figure 13.4 shows the above function for the three different failure behaviours.

Bath-tub Curve

Combine the three figures of age speczific failure rate (for Hyper-exponential, Negative exponential and Normal distribution failure behaviours, in that order) to give a whole-life figure and the result is a figure (Fig. 13.4) which resembles a household bath-tub in its contour. This is the famous 'bath-tub curve' in maintenance.

The extent of the three modes of behaviour differs from case to case. In some cases, the infant mortality pattern may be more, in some others the wear-out behaviour may be prominent. It is also possible that all three modes may not exist. For example, in a nuclear power plant the question of infant mortality must not arise.

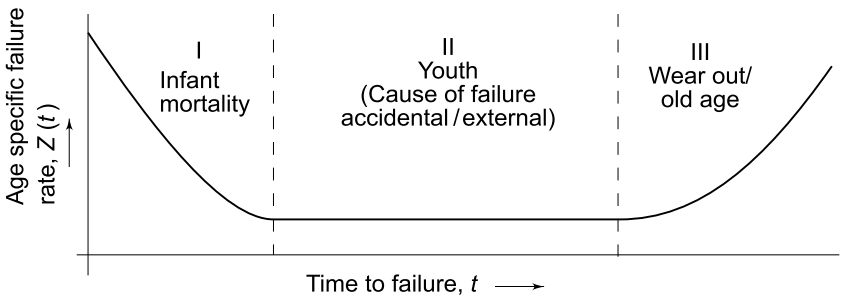


Figure 13.4 Bath-tub Curve

Benefits and Lacunae of Failure Statistics

Benefits

1. Diagnosis of a failure when it occurs can be easily done. Depending on the time-to-failure, one can immediately say whether the cause is due to design or installation defect, or due to a simple wearing-out, or due to a flaw not belonging to the equipment but to other machinery/system connected to the equipment. Maintenance decisions to repair/replace/etc. can therefore be taken with more confidence, more ease, and more speed.
2. Failure data provide valuable information to the designers and experts regarding the life of the equipment and the reliability of the equipment. Therefore, if necessary, appropriate modifications in either the equipment or the plant system, may be made to get the desired reliabilities and plant availabilities.
3. Failure statistics can be used to formulate appropriate preventive replacement and other preventive maintenance policies. What kind and quantum of preventive action is to be taken will depend upon the failure characteristics. The load on and the nature of the preventive maintenance will depend upon the analysis of the available failure data.
4. The policies for stocking spare parts make use of such failure data.

Lacunae Failure statistics have to deal with large numbers (population) and therefore may not be suitable for equipment which is unique in the plant. When only a single piece of equipment exists, the value of failure-statistics is limited. By the time the failure data (of every breakdown and repair) is collected, the value of the analyzed results may be less significant, since a large portion of the life of the equipment would have been over. Of course, such a difficulty can be overcome if the data on similar equipment elsewhere is available. For example, the data from similar thermal power stations elsewhere can be quite useful in maintenance decisions in a thermal power plant. The utility of the failure analysis is particularly high in those organizations where many identical equipments, in a comparable environment, can be observed simultaneously. For instance, in a road transport corporation, in a large machine shop, in a caustic soda plant with a number of identical electrolytic cells, in an aluminium industry, etc.

Some executives feel that the collection of data for such analysis is difficult. Actually, the cause for this attitude may be more due to the lack of appreciation of maintenance-management concepts than due to real problems in data collection. With the presence of a proper information/reporting system, the data on failures such as time-to-failure, salient points of repair/replacement/result, time taken to carry out the maintenance job, manpower and other resources used, etc. can be gathered without much difficulty.

Weibull's Probability Distribution

The three probability distributions have been properly combined into a single expression by Weibull. This is given below:

$$f(t) = \frac{\beta(t - t_0)^{(\beta-1)}}{\eta^{\beta}} e^{-(t-t_0/\eta)^{\beta}}$$

This leads to:

$$F(t) = 1 - e^{-(t - t_0/\eta)^{\beta}}$$

$$P(t) = e^{-(t - t_0/\eta)^{\beta}}$$

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and $$Z(t) = \frac{\beta}{\eta^{\beta}} e^{-(t - t_0/\eta)\beta}$$

where t_0 = guaranteed life,
η = characteristic life,
β = shape factor

} The significance of Each of these can be seen from the following discussion

$Z(t)$, the age specific failure rate, is positive only after a time t_0 has elapsed. Till $t = t_0$, the survival probability $P(t) = 1$, Therefore, the time t_0 is the *guaranteed life* of the equipment.

When $\eta = t - t_0$, $P(t) = e^{-1} = 0.37$. Therefore, η is the time elapsed after the guaranteed life at which 37% may be expected to survive and 63% expected to have failed. This is characteristic of a particular failure process and is called the *characteristic life*.

The *shape factor* β is the parameter whose value determines which of the three modes of failure is prevalent:

β quite less than 1 : indicates the hyper-exponential distribution and infant mortality phenomenon.
β almost equal to 1 : indicates a negative exponential distribution and external cause of failure
β larger than 3 : indicates a normal distribution and cause of failure as wear-out.
β between 1 and 3 : both the latter causes may be present in varying degrees.

Diagnostic Utility of Weibull's Probability Distribution

The failure data can be analyzed by plotting them on Weibull probability paper. The latter resembles a nomograph as is illustrated by Fig. 13.5. By assuming different values of t_0 (guaranteed life), a straight-line plot is first obtained. The t_0 value for the straight-line plot is then the guaranteed life.

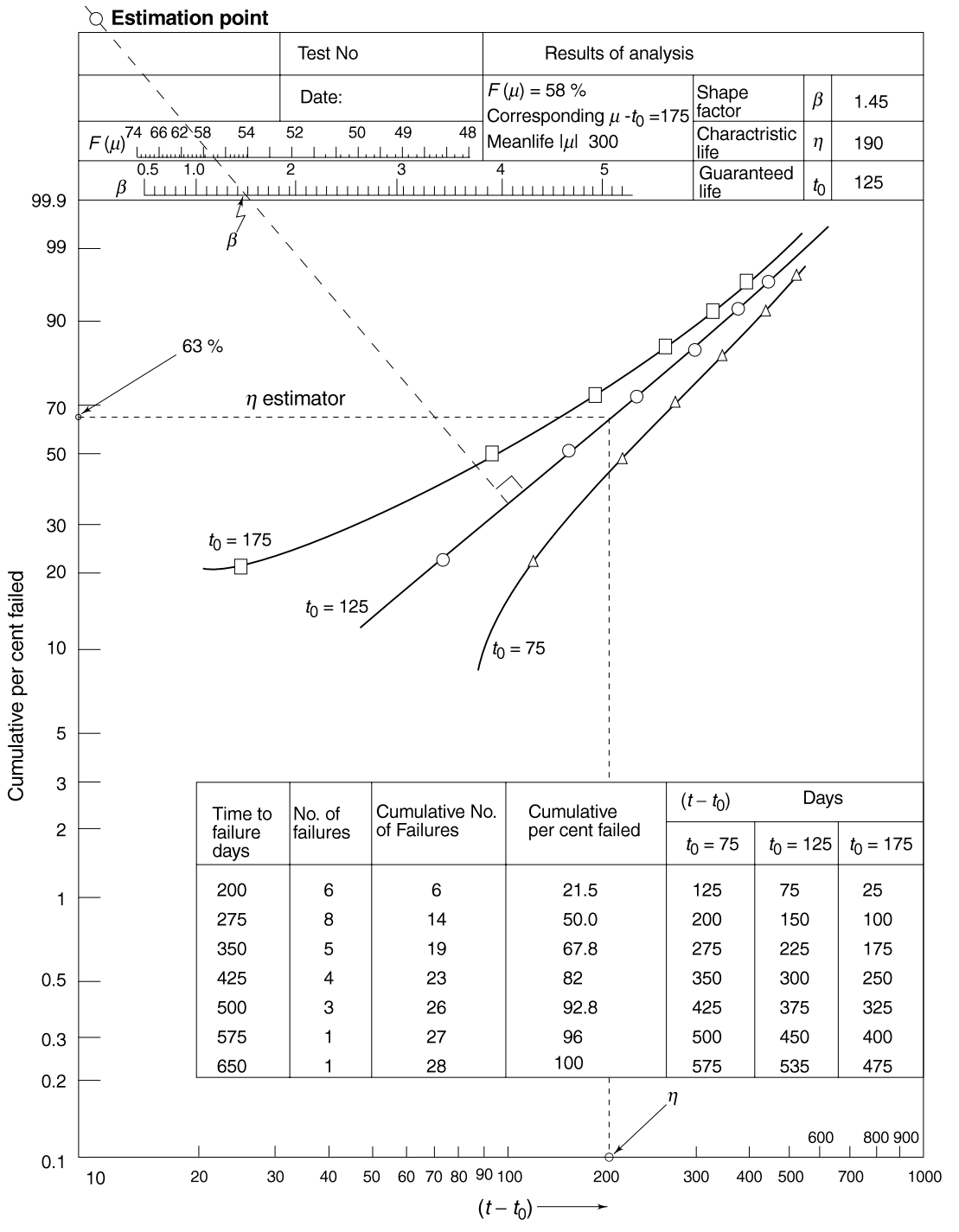
A perpendicular is dropped on this straight line from the 'estimation point'. The value at which this perpendicular intersects the β-line, gives the value of the shape factor β. In Fig. 13.5, β value is closer to one (1); hence predominantly random failure behaviour with a component of wear-out phenomenon is diagnosed.

Reliability Engineering

Closely connected to failure statistics is the topic of reliability, *Reliability is defined as the probability of a plant to give satisfactory performance in a particular period of time under specified operating conditions.*

The subject of reliability which is fairly new, is becoming more and more important because the complexity of equipment and plants is growing day by day. With increasing sophistication, failures have become more critical and sometimes catastrophic as in the case of nuclear reactors, superthermal power stations, automated chemical plants, etc.

It is becoming necessary to forecast or predict the life of plant and equipments, the availability of plant and equipment, and thereby the expected maintenance work required. The amount of maintenance work, either preventive or breakdown will depend upon the reliability of the system and the system components. If the reliabilities of the system and the system components are known



Time to failure days	No. of failures	Cumulative No. of Failures	Cumulative per cent failed	$(t - t_0)$ Days		
				$t_0 = 75$	$t_0 = 125$	$t_0 = 175$
200	6	6	21.5	125	75	25
275	8	14	50.0	200	150	100
350	5	19	67.8	275	225	175
425	4	23	82	350	300	250
500	3	26	92.8	425	375	325
575	1	27	96	500	450	400
650	1	28	100	575	535	475

Figure 13.5 Weibull Diagram

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and calculated ahead of time, then the workload for maintenance can be fairly well estimated and allocated with respect to time and with respect to different machinery and equipment. Reliability estimates will provide guidance in stocking the spare parts and stand-by machines. Reliability figures will help in deciding when to replace machines and components. Reliability calculations will tell what improvements in the design of equipment and total plant system would make the probability of failure low enough for acceptance.

Reliability of equipment depends much upon the *design* of the equipment. Of course, it also partially depends on how the preventive maintenance for the equipment is carried out. Additionally, reliability of a plant depends upon the design of the plant system, that is, the way various equipment are linked functionally) with each other.

Function Series and Parallel Connected Components

There are two basic types of functional linkages of equipment in a plant (or that of the components in an equipment):

(i) Series
(ii) Parallel

The principle is the same as in electrical connections. With series-connected components it is essential that all the components should work in order for the system (equipment) to work. Whereas, a parallelly connected system will fail only if all the components so connected fail; even if one of the parallel components is working the system will work (Fig. 13.6).

When we talk of 'series' and 'parallel' we are *not* talking of mechanical linkages; rather, we are describing functional relationships. To illustrate, in Fig. 13.7 the motor, the shaft of stirrer, the impeller, the support are all connected in series.

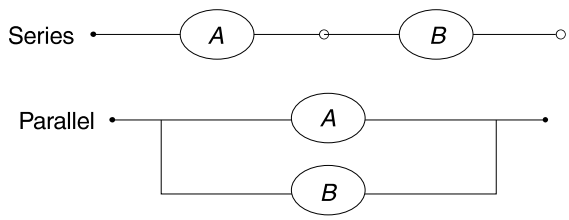


Figure 13.6 Series and Parallel Connections

If we had two series-connected components, the reliability for this linkage would be given by

$$P(t) = P_1(t) \cdot P_2(t)$$

If these components are showing a second stage (useful-life) and hence a negative exponential behaviour

Then, $$P(t) = e^{-\lambda 1 \cdot t} \cdot e^{-\lambda 2 \cdot t}$$
$$= e^{-(\lambda 1 + \lambda 2)t}$$

Thus the probability distribution for the system is also negative exponential. *More importantly, the probability of survival of the series system is lower than the lowest of the component survival probabilities*. For example, if probability P_1 was 0.9 and P_2 was 0.7.

Then, $$P_{system} = P_1 \cdot P_2 = 0.9 \times 0.7$$
$$= 0.63$$

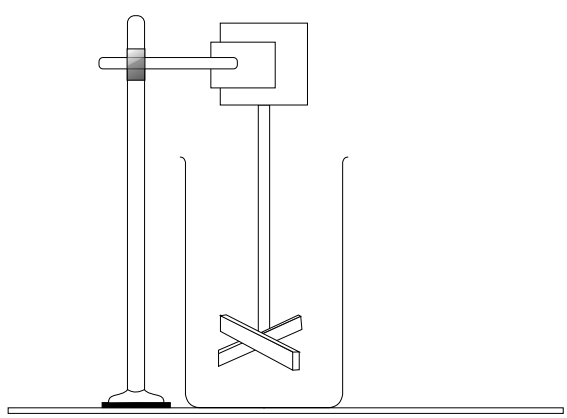


Figure 13.7 Motorized Stirrer—An Example of a Series Connection

If the same components were connected in parallel, then by the definition of a parallel connection:

$F(t) = F_1(t) . F_2(t)$, where $F(t)$ stands for the cumulative failure probability as earlier.

Therefore, $P(t) = 1 - F_1(t) \cdot F_2(t)$

$=1 - [1 - P_1(t)] [1 - P_2(t)]$

$=P_1(t) + P_2(t) - P_1(t) \cdot P_2(t)$

Substituting the reliability figures for the components:

$P(t) = (0.9) + (0.7) - (0.9) \times (0.7)$

$= 0.97$

This shows that in parallel connection, the system reliability is greater than the reliabilities of individual components. The benefits of parallel connection are more obvious when the components' reliabilities are low. If $P_1 = 0.3$ and $P_2 = 0.4$, the system reliability is $P = 0.3 + 0.4 - 0.3 \times 0.4 = 0.58$ which is quite high as compared to individual reliabilities. Another benefit with parallel linkage is that the components can be given good preventive maintenance individually without the loss of availability.

For the previous example of the two component system, we have

$$P(t) = e^{-\lambda_1 t} + e^{\lambda_2 t} - e^{-(\lambda_1 + \lambda_2)t}$$

Therefore,

$$f(t) = \frac{d}{dt} (P(t))$$

$$= \lambda_1 e^{-\lambda_1 t} + \lambda_2 e^{-\lambda_2 t} - (\lambda_1 + \lambda_2) \exp(-(\lambda_1 + \lambda_2)t)$$

This is not a simple negative exponential distribution.

The Mean Time to Failure,

$$\text{MTTF} = \int_0^\infty f(t) \cdot t \cdot dt$$

$$= \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$$

The above given examples were quite simple. The intention was to illustrate the concept of 'reliability' which is gaining more and more importance and acceptability in the management of maintenance particularly as the sophistication and complexity of technology is increasing at a rapid pace.

The concept of reliability engineering are very useful in service operations, where there is much premium on unbroken services.

PREVENTIVE MAINTENANCE

Planning for maintenance is one of the important jobs of the Maintenance Manager. Planned maintenance is alternatively known as Preventive Maintenance. It includes the following:

(i) Usual care of the equipment, such as lubricating, cleaning, adjusting/resetting the equipment or parts while the equipment is either idle or running.

(ii) Periodic inspection or overhaul of the equipment and scheduled replacement of parts.

(iii) Contingent work done at regular intervals when the equipment is down. For instance, in chemical plants the rotary kilns, the multiple effect evaporators, large vessels, the thickners

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and the reaction tanks are all inspected for their various parts, linings, etc. when these equipments are down. Contingency work is particularly encountered in chemical plants which operate on a continuous basis.

(iv) *Condition Monitoring* is a new technique where high cost critical equipment are monitored continuously or at frequent periodic intervals to observe the values of various parameters reflecting the condition of the equipment and the components within.

The parameters being monitored may be (a) temperature, (b) vibration, (c) noise, (d) lubricant, (e) corrosion, (f) leaks, and others. The Monitoring of temperature might indicate, for instance, malfunctions such as coolant failure, damaged bearing, damaged insulation, improper heat generation, build-up of sediment or dust or corrosion by-products in the equipment, etc. Vibration monitoring and analysis may point out faults such as misalignment, imbalance in rotation, bend and assymmetry in the shaft, damage in the gears, vanes, tubes, hysteresis whirl, etc. Lubricant monitoring might indicate wear or rate of wear of components and the type of wear (whether abrasion or cutting or surface fatigue).

Thus, much indicative information is given by condition monitoring. The information comes in advance of the probable major failure which is the most important benefit of condition monitoring. For high cost and/or critical machinery, where one can ill afford a breakdown, this monitoring system is of immense value. The cost of such monitoring is high, because of the requirement of sophisticated monitoring/measuring instruments. But, the high cost is justified or more than compensated in several cases.

Benefits from Preventive Maintenance

The benefits from preventive maintenance are:

- Reduction of the total down-time and consequent reduction in production losses.
- Reduction in the number of major repairs, and consequently reduced maintenance expenses.
- Reduction in the number of rejects and an improvement in product quality.
- Reduction in the inventory of spare parts.
- Reduction in the number of accidents in the plant.
- Reduction in the unplanned or crisis management in maintenance.

Besides the benefits mentioned above, there are certain costs associated with the preventive maintenance programme. The costs are those of:

- Scheduled down-time of production.
- Replacement parts and supplies.
- Instruments e.g. in the case of condition monitoring.
- Wages of preventive maintenance technicians and staff.
- Minor costs such as those of record-keeping.

It follows, therefore, that too much or too little of preventive maintenance is not good. There has to be a balance in the allocation of resources to preventive maintenance and breakdown maintenance. Not all items can be scheduled for preventive maintenance; neither can all the time be spent on preventive maintenance only.

Each plant should have its own preventive maintenance policies suited to that plant's needs. The needs are based on comparative cost criteria. The working environment, the type of operations, the type of equipment, the age of equipment and plant, and other factors determine the incidence

of breakdowns, their severity, and the costs associated with these in the absence or presence of the preventive maintenance programme of a smaller or larger size. There is no hard and fast rule as to what should be the total time spent on preventive maintenance as opposed to breakdown maintenance. In general, plants which are maintained efficiently spend almost three quarters of their time on preventive maintenance, while only one quarter is spent on breakdown maintenance.

In designing a preventive maintenance programme, the failure statistics will be of much use. The nature of the failure, the MTTF, the reliabilities, combined with the costs of avoiding or delaying failures by preventive action as against the costs of emergency breakdown will determine the frequency, nature and extent of preventive action. One may treat the failures as the arrivals or arriving customers in the Queueing Theory model. The behaviour of servicing times may also be gathered as past data. With an assumed number of servers (servicing capacity such as the number of mechanics/technicians), the delays or waiting times of breakdowns may be computed. The costs of different strategies, with different total number of technicians in both categories of maintenance, may be compared in order to arrive at an optimum total number and mix of the resources in the two categories of maintenance.

It is important to include in the cost data, the estimates of costs of safety to the workers and the costs of rejects or low quality output.

Replacement Policies

Mathematical models have been built for preventive replacements of parts and equipments. It has been observed that many a time cost-savings are generated by a Group Replacement of the parts, rather than replacing parts only when they fail or are about to fail. The example given below will illustrate the concept and present the mathematical analysis.

Example Following is the data available on the failures of 10 identical special-purpose bulbs being used in a plant:

Time in Months	*Failure Probability*
1	Nil
2	Nil
3	Nil
4	0.05
5	0.15
6	0.30
7	0.25
8	0.15
9	0.10

The cost of replacing the bulbs individually, when they fail, is Rs. 100 (per bulb). The cost of replacing all the 10 bulbs together is Rs. 500. Four different replacement policies are possible:

(i) *Independent Breakdown Replacement,*
i.e. replace bulb/bulbs as and when they fail to function.

(ii) *Group Breakdown Replacement,*
i.e. as soon as one bulb fails, all the ten bulbs are replaced.

(iii) Individual Preventive Replacement,
i.e. each bulb is replaced when it is n (some number) months of age, even though it does not fail.

(iv) Group Preventive Replacement
i.e. at fixed intervals, all bulbs are replaced; but within the interval, independent breakdown replacement is undertaken if a bulb/bulbs fail.

The cost of independent preventive replacement of a bulb is Rs. 70. Which will be the best policy?

Solution

Case (i) Independent Breakdown Replacement Policy

Mean life of a bulb = $(4 \times 0.05) + (5 \times 0.15) + (6 \times 0.30)$
(from the given data) $+ (7 \times 0.25) + (8 \times 0.15) + (9 \times 0.10)$
$= 6.6$ months

$\therefore$ Cost per month, for the policy $= \dfrac{Rs.100}{6.6} \times 10$ (bulbs)
$=$ Rs. 151.5 per month

Case (ii) Group Breakdown Replacement Policy

Cost of replacing all 10 parts together = Rs. 500

$$\text{Per month cost} = \frac{500}{\text{Average life (for 1st failure)}}$$

$$\text{Average life} = 4\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 4}\end{array}\right] + 5\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 5}\end{array}\right]$$
$$+6\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 6}\end{array}\right] + 7\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 7}\end{array}\right]$$
$$+8\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 8}\end{array}\right] + 9\left[\begin{array}{l}\text{Probability that}\\ \text{the first failure}\\ \text{occurs at month 9}\end{array}\right]$$

Now, the probability of surviving up to the 4th month
$= 1 - 0.05 = 0.95$

$\therefore$ Probability of all 10 bulbs surviving up to the 4th month $= (0.95)^{10}$
$= 0.599$

$\therefore$ Probability that any one of the bulbs fails for the first time at month 4 $= 1 - (0.95)^{10}$
$= 0.401$

We can find the other probabilities as follows:

Probability of all 10 bulbs surviving up to the 5th month $= (0.80)^{10}$
$= 0.107$

$\therefore$ Probability of any one bulb failing either in the 4th or the 5th month $= 1 - (0.80)^{10}$
$= 0.893$

$\therefore$ Probability that the first failure occurs in the 5th month
$= [1 - (0.80)^{10}] - [1 - (0.95)^{10}]$
$= 0.893 - 0.401$
$= 0.492$

Similarly, we have
Probability that the first failure occurs in the
6th month $= [1 - (0.5)^{10}] - [1 - (0.8)^{10}]$
$= [0.999] - [0.893] = 0.106$
7th month $= [1 - (0.25)^{10}] - [1 - (0.5)^{10}]$
$= [1.000 - 0.999] = 0.001$
8th month $= [1 - (0.10)^{10}] - [1 - (0.25)^{10}]$ = negligible
9th month $= [1] - [1 - (0.10)^{10}]$ = negligible

Therefore, the average life
$= 4(0.401) + 5(0.492) + 6(0.106)$
$+ 7(0.001) + 8(0.000) + 9(0.000)$
$= 1.604 + 2.460 + 0.636 + 0.007 = 4.707$

Hence, per month cost
$$= \frac{500}{4.707} = \text{Rs. } 106.22$$

Case (iii) Individual Preventive Replacement:

Let us consider a *preventive replacement period of 5 months*.

The total cost per unit replacement comprises two components: (a) the possibility that the bulb may fail before the replacement age needing breakdown replacement; and (b) the possibility that the bulb may not fail till its replacement age.

Component (a) $= \text{Rs. } 100 \times (0.05 + 0.15)$ $= \text{Rs. } 20.00$
Component (b) $= \text{Rs. } 70 \times (0.80)$ $= \text{Rs. } 56.00$

$\therefore$ Total Cost of Unit Replacement = Rs. 76.00

$$\text{Now, cost per month} = \frac{\text{Total cost of replacement}}{\text{Expected life of a bulb}}$$

$$= \frac{76 \times 10}{\text{Expected life of a bulb}}$$

Expected life of a bulb $= (4 \times 0.05) + 5(0.15 + 0.30 + 0.25 + 0.15 + 0.10)$
$= 0.20 + 4.75$ $= 4.95$ months

Therefore, cost per month = $\frac{760}{4.95}$ = Rs. 153.53

(This was for a preventive replacement period of 5 months.)

If the preventive replacement period was 6 months:

Then,

Component (a) = Rs. 100 × (0.05 + 0.15 + 0.30) = Rs. 50.00

Component (b) = Rs. 70 × 0.50 = Rs. 35.00

Total Cost of Unit Replacement = Rs. 85.00

Expected life of a bulb = (4 × 0.05) + (5 × 0.15) + 6(1 – 0.05 – 0.15)

= 0.20 + 0.75 + 4.80 = 5.75 months

Therefore, cost per month= $\frac{85\times10}{5.75}$ = Rs. 147.83

Similar calculations are made for other values of the replacement period.

Replacement period of 7 months:

Component (a) = Rs. 100 × 0.75 = Rs. 75.0

Component (b) = Rs. 70 × 0.25 = Rs. 17.5

Total Cost of Unit Replacement = Rs. 92.5

Expected life of a bulb = (4 × 0.05) + (5 × 0.15) + (6 × 0.30) + 7 (0.50)

= 6.25 months

Therefore, cost per month= $\frac{92.5\times10}{6.25}$ = Rs. 148.00

Replacement period of 8 months:

Component (a) = Rs. 100 × 0.90 = Rs. 90.0

Component (b) = Rs. 70 × 0.10 = Rs. 7.0

Total Cost of Unit Replacement = Rs. 97.0

Expected life of a bulb = 0.2 + 0.75 + 1.80 + 7(0.25) + 8 (0.25)

= 6.50 months

Therefore, cost per month = $\frac{97.0\times10}{6.50}$ = Rs. 149.23

Replacement period of 4 months:

Component (a) = Rs. 100 × 0.05 = Rs. 5.0

Component (b) = Rs. 70 × 0.95 = Rs. 66.5

Total Cost of Unit Replacement = Rs. 71.5

Expected life of a bulb = 4 months

Therefore, cost per month = $\frac{71.5\times10}{4}$ = Rs. 178.75

With this policy, the replacement period of 6 months is found to be optimal.

Case (iv) Group Preventive Replacement

Let us consider a replacement period of 8 months to start with.

The total costs under this policy comprise two components:

(A) Cost of Group Replacement = Rs. 500

and (B) Cost of the Individual Breakdown Replacement

= Rs. 100 × number of failures within 8 months

Now, the number of failures within 8 months

$$= \underbrace{(10 \times 0.05)}_{\text{(for the 4th month)}} + \underbrace{(10 \times 0.15)}_{\text{(for the 5th month)}} + \underbrace{(10 \times 0.3)}_{\text{(for the 6th month)}} + \underbrace{[(10 \times 0.15)(0.05) + (10 \times 0.05)(0.15) + (10 \times 0.15)]}_{\text{(for the 7th month)}} + \underbrace{[(10 \times 0.05)(0.05) + (10 \times 0.25)]}_{\text{(for the 8th month)}}$$

$$= 9.175$$

$$\therefore \quad \text{Cost per month} = \frac{500 + 100(9.175)}{8}$$

$$= \frac{1417.5}{8} = \text{Rs. } 177.20$$

We can in fact construct a table for all assumed values of replacement periods (Table 13.2). The lowest figure in Table 13.2 is Rs. 137.50 per month.

Summarising the costs for different policies:

(i) Independent Breakdown Replacement Rs. 151.50 per month

Table 13.2 Group Preventive Replacement Policy, Costs

	Breakdown Replacement Costs in Different Periods						*Total Costs,**	*Average Cost,*
	4	*5*	*6*	*7*	*8*	*9*	*Rs.*	*Rs.*
Replacement Period								
3							500	166.66
4	100(0.5)						550	137.50
5	100(0.5)	100(1.5)					700	140.00
6	100(0.5)	100(1.5)	100(3.0)				1000	166.66
7	100(0.5)	100(1.5)	100(3.0)	100 × (2.525)			1252.5	178.92
8	100(0.5)	100(1.5)	100(3.0)	100 × (2.525)	100 × (1.65)		1417.5	177.20
9	100(0.5)	100(1.5)	100(3.0)	100 × (2.525)	100(1.65)	100(1.525)	1570	174.44

* Total costs = Breakdown Replacement Cost + Group Replacement Cost. Group Replacement Cost is Rs. 500.

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(ii) Group Breakdown Replacement Rs. 106.22 per month
(iii) Individual Preventive Replacement Rs. 147.83 (replacement period of 6 months)
(iv) Group Preventive Replacement Rs. 137.50 per month
(this is the optimal cost for this policy; replacement period is 4 months)

It goes without saying that we should choose the Group Breakdown Replacement Policy.

MAINTENANCE POLICY

It is clear from the earlier discussion that there is nothing like a purely preventive maintenance; rather there is always an appropriate mix of the preventive and breakdown maintenance.

Moreover, not all items are amenable to all types of preventive maintenance. If, for instance, an item is showing a time-independent, i.e. a Negative Exponential failure behaviour, then the cause of the failure is external to the item; therefore, any amount of preventive replacement is not going to serve the intended purpose. Preventive or fixed-time replacement of parts (individually or in a group) is a policy that is appropriate for items that wear out with time due to use, i.e. for items that show a Normal failure mode. Moreover, such a policy may be useful only if the costs of preventive action are significantly lower than those of the breakdown maintenance replacement, which means, that the item should preferably be a 'simple replaceable' item and not a complex one for replacement action. Of course, preventive replacement is not ruled out for a complex part; the 'cost-cum-safety' factors have to be taken into account while deciding on a policy.

Condition monitoring would be advised for a complex-replaceable part, if the economics of monitoring by instrumentation and that of cost (tangible) plus safety (intangible cost) work out in favour of such monitoring. Such a policy can be used in the cases of normal as well as negative exponential failure mode, since the purpose of condition monitoring is to detect the extent of wear-out and/or a minor defect that may have developed which could be a precursor to a major disaster eventually in a short period of time.

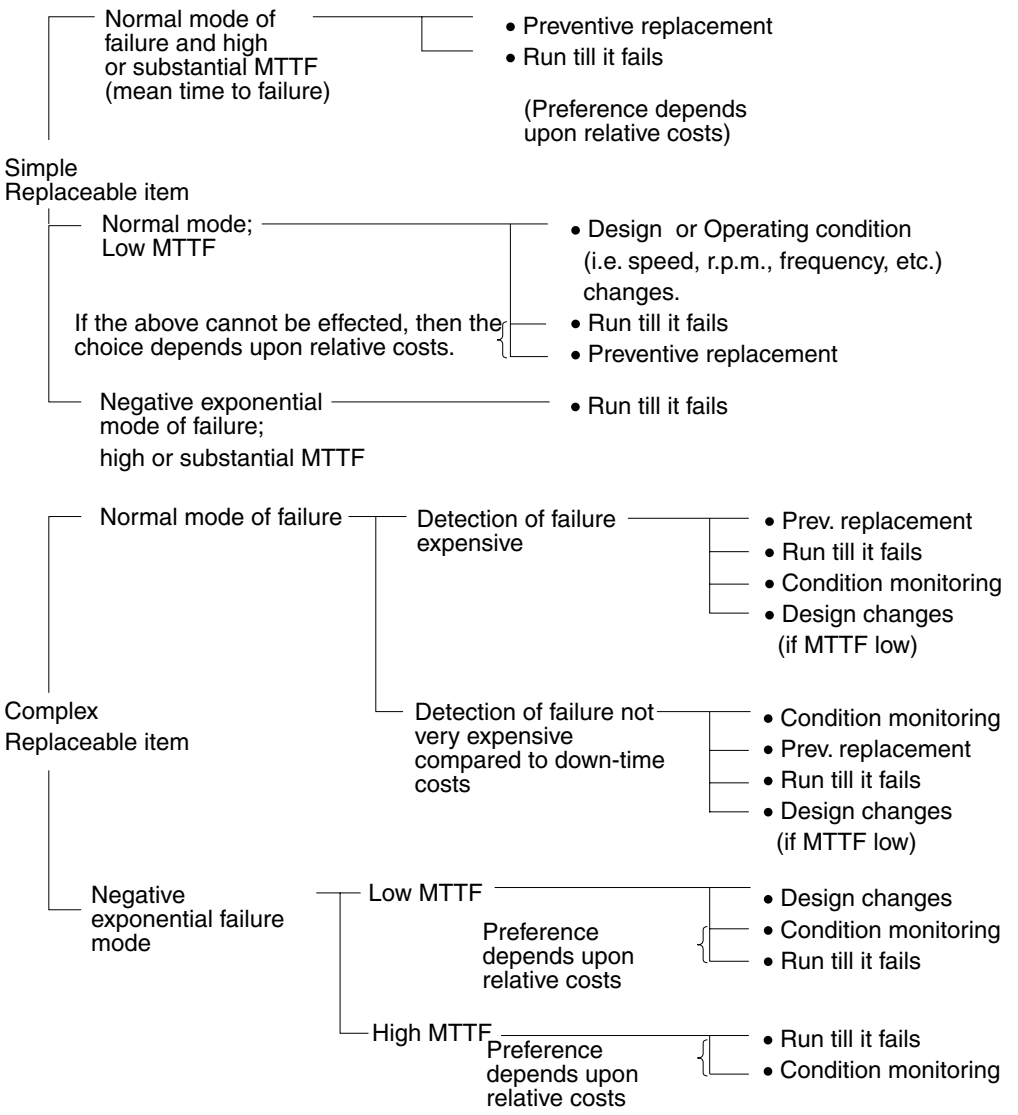
However, if the negative exponential failure mode shows a low mean time to failure (MTTF), perhaps there is more cause to worry about the design of the item which may not be suited to the operating conditions or vice versa. In either case, the action is external to the usual maintenance action. And, of course, if a breakdown is not costly (cost = monetary-plus-human life or anguish), then it may be worthwhile to let the item be used till it breaks down.

The diagram (Fig. 13.8) should provide a broad guideline to the reader for formulating an appropriate maintenance policy.

SUPPORTIVE ORGANISATIONAL CONDITIONS FOR BETTER MAINTENANCE MANAGEMENT

In order that the preventive maintenance, and maintenance in general, should succeed, the following supporting conditions are necessary. Many of these are the organisational aspects.

1. Good cooperation and coordination between the production and maintenance functions, in general, is essential.
   — Annual planning for maintenance should be done along with the annual production plan.
   — Monthly, weekly and daily maintenance schedules should be drawn, preferably in consultation with the production people. These must be properly communicated to the production people.
   — If there are any changes in the capacity-utilization, process-changes and method-chang-



[*Note: `Costs' here include tangible as well as intangible (e.g. human life) costs.]

Figure 13.8 Formulation of an Appropriate Maintenance Policy

es, etc., the maintenance department should be aware or made aware of the same.

— In short, there should be much interaction between maintenance and production people at the policy-planning, schedule-making, and all the other levels.

2. Maintenance function should not be under production management (e.g. a Plant Engineer should not report to the Production Manager. Both should report to a manager one step higher). Otherwise important and genuine maintenance considerations may be shelved in preference to the short-term production considerations.

— If a maintenance manager feels that a critical equipment needs quick maintenance

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attention, in order to avoid a probable breakdown, he should have the full authority to order the shut-down of the equipment. By 'full authority' is meant not only the organizational 'formal' authority, but also the confidence of the production people.

3. Proper equipment records should be kept giving details such as breakdown-statistics, maintenance carried out, the causes of breakdown, time taken for maintenance, the components and parts of the machinery, the suppliers, dates on which preventive maintenance was carried out, the type of preventive action carried out, etc. Such information helps in policy-planning, scheduling, and allocation of maintenance resources. For instance, it can help in deciding about the nature, time, technique and manpower of preventive maintenance action.
4. Spare-parts inventory should be controlled properly, so that adequate numbers are available for maintenance purposes.
5. To ensure good control, the maintenance work (preventive and breakdown) should be standardized as much as possible.
   - — Preventive work is more easily standardised; standard procedural manuals for the same may be prepared.
   - — Breakdown maintenance jobs also may be fit into work-standards; the Universal Maintenance Standards (UMS) technique of work measurement may be of help here.
6. Good research in materials is a helpful accompaniment to maintenance. For example, good lubricating oil could save a lot of equipment from premature breakdowns.
7. Many plants have reported excellent results with good operator training in inspecting his own machine/equipment and carrying out minor preventive maintenance jobs on it. Of course, in many cases there may be resistance from the labour unions, since this procedure might constitute, in their opinion, an addition to the operator's duties. But, it can also be looked at from the job-enrichment angle. Many Japanese companies have been rotating the production operators in the maintenance department so as to train them in preventive maintenance. This has yielded excellent results. Although Japanese industrial culture is very different from that in India, such an effort—to the extent it is possible—could be beneficial.

WORK STUDY FOR MAINTENANCE

In order to control and improve maintenance performance, one should have adequate work standards. The variety, variability and uniqueness of the jobs of maintenance may not lend easily to the measurement of work by analytical techniques alone. Some degree of estimation in the work measurement techniques is unavoidable. But, even the rough or broad-level work standards have produced significant increases in productivity in many organisations.

Universal Maintenance Standards (UMS)

One of the noteworthy techniques of work measurement in maintenance management is that of Comparative Estimating based on UMS. Here, Standard Work Groupings are first established based on a range of time. If most of the maintenance jobs fall within a total time range of say 0 to 8 hours (which is what usually happens), then this total range is split into 8 or 10 ranges of time. For instance,

0–0.25 hours		0.25–0.50 hours
0.5–1.0 hours		1.0–1.5 hours
1.5–2.5 hours		2.5–3.5 hours
3.5–4.5 hours		4.5–5.5 hours
5.5–6.5 hours	and	6.5–8.0 hours

A given job is then fitted into one of these Work Groupings with the help of benchmark jobs. These are the reference points for comparison and time-estimation. The timings of bench marks may be derived by any alternative technique (such as UMS or PMTS).* If derived from UMS, they will have a range of time and an average of the range. The benchmark jobs are different for different trades/crafts (repair of pumps, repair of large electric equipment, repair of process instruments, etc.).

A given job at hand is compared with the benchmarks to find which Work Grouping it will fit into. To the average time for this Work Grouping is then added the (i) Job Preparation Time, (ii) Travel Time, and (iii) Personal Needs Allowances. The Job Preparation Time is the time for receipt of tools, equipments, preparation on the job-site, cleaning the tools, cleaning the job-site, etc. The Travel Time is time spent in transit to carry out a job.

The job-times are thus estimated in terms of a range with an average time mentioned. Even so, the total for all the jobs to be done in a fairly long time period (such as one week) will have an error of at the most ± 5%. So that, group incentives can also be introduced in the maintenance function.

Other estimating techniques such as Category Estimating which is similar to Comparative Estimating, and Data Block Synthesis on lines similar to PMTS are available for work measurement in maintenance.

As mentioned earlier, a good organization, a proper information system, and good rapport between workers and the management are important pre-requisites for any technique such as work measurement to yield better productivity. Work measurement alone cannot be depended upon to produce results, however much, it may be linked with an incentive scheme.

MANPOWER PLANNING FOR SKILLED TECHNICIANS

In addition to all the problems and their possible solutions mentioned above on the subject of maintenance management, one important fact—particularly true of India—needs mention. It is the inadequate availability of skilled technicians/tradesmen. A country, which produces degree engineers in a large number every year—only to join the ranks of the unemployed—, does not produce enough skilled technicians. In addition to this problem, there is the exodus of these skilled workers to foreign countries especially the Middle East.

There are not enough training institutions. The Industrial Training Institutes which exist, seem to be lacking in the quality of their training and are therefore facing a high drop-out rate. The author feels that somewhere the priorities have got mixed up and unless a sound national manpower planning and its implementation is done, matters may deteriorate further.

TOTAL PRODUCTIVE MAINTENANCE (TPM)

The concepts of maintenance management presented so far have had one basic thread of assumption running throughout: that failure of breakdowns are inevitable. Hence the trade-off or compromise between the preventive maintenance and the breakdown maintenance; or, hence the computations for optimal stock of spare parts. Once there is a compromising attitude, it leads to

*PMTS stands for Predetermined Motion Time Systems. These will be described in Chapter 15.

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compromises in other areas. For instance, if the machines do break down, then the quality also may break down and the deliveries may get upset.

On this score, the Japanese have shown a new path to the world of management by ceaselessly working towards the ideal goals of zero breakdown and zero defects or zero defectives. During 1971 to 1982 the accidental breakdowns in Japan decreased drastically to 1 per cent of the original level. It will not be incorrect to say that the quality guru, Philip Crosby's goal of zero defects is helped considerably by the Japanese concept of the pursuit of zero breakdowns. Less the breakdown of machinery, the less would be the proportion of defective quality. Breakdown of equipment can occur in the following different ways.

1. *Equipment stops performing* its function. So, there are downtime losses of repair time, set-up and adjustment time.
2. *Equipment deteriorates* and its performing ability is diminished leading to a r*eduction in function* such as a reduction in the speed of the equipment leading to speeds and/or yields lower than designed. Or, the equipment keeps having minor stoppages and/or produces more defectives.
3. *Equipment has hidden defects* which do not become apparent until the breakdown situation is reached.

All these types of breakdowns have to be eliminated. There is no room for trade-offs. This is the rationale behind the Total Productive Maintenance (TPM). The objective of TPM is much wider than just minimising equipment downtime; the objective is to minimise the life cycle costs i.e. the costs for the entire lifespan of the equipment (here, by lifespan one means the time until the equipment gets obsolete).

In the earlier sections of this chapter, we only looked at the profitability or advantages gained through Preventive Maintenance (PM). Still, this is only a reactive approach to management. The proactive approach is Maintenance Prevention (MP) i.e. having a maintenance-free design. Stoppages of either kind—Breakdown Maintenance (BM) or Preventive Maintenance (PM)—are time-wasters and are not desirable. The problem should neither be removed at the 'flower' stage, nor at the 'bud' stage; the problem, in the first place, should not occur. It would be interesting to note that 'maintenance prevention' has much application in the service industry—a service being unbroken or unstopped. In fact, it appears that the concept of maintenance prevention in manufacturing industry may have been borrowed from the service industry where infallibility and proactivity are very important.

This proactivity can be helped significantly if all the concerned people participate actively. Hence, TPM includes:

(i) Optimising equipment effectiveness by elimination of all types of breakdown or failures, speed losses, defects and other wastes in operation.

(ii) Autonomous Maintenance by operators, which means the people who operate the machines will look after their machines by themselves. This would mean training and involvement of the operators. The idea is that the operating people would get to know their equipment even better so that they will be able to contribute not only in maintenance of the preventive and breakdown kind but also in the prevention of maintenance itself through their suggestions for improved designs of machines, processes, systems, materials and products.

(iii) Company-wide involvement of all employees through small group activities which would support the above. Such participative management would enhance creative thinking and cross-flow of information. Continuous improvement comes through such participative processes.

The following Table 13.3 depicts the progression in the field of Maintenance Management.

Table 13.3 Journey of Maintenance Management

I	Total Operations Orientation	Attend to machines predominently only when the machines breakdown (Breakdown Maintenance or BM). *Breakdown Maintenance = BM*
II	Cost Optimisation	Have Preventive Maintenance (PM) in addition to Breakdown Maintenance (BM). Optimal combination of the two is required for total cost minimisation. *Profitable Preventive Maintenance, PPM = BM + PM*
III	Systems Orientation	PM alone cannot eliminate or drastically reduce breakdowns. Supporting it, there should be various steps taken in design, development and engineering such that maintenance itself is found rarely necessary (Maintenance Prevention, MP). If ever maintenance is required, the maintainability should be high (i.e. reduction in losses of time, effort, resources), this can be called Maintainability Improvement (MI). *Productive Maintenance = BM + PM + MI + MP*
IV	Companywide Involvement	Autonomous maintenance by operators. Small group activities by R&D, Engineering, Manufacturing, Logistics, Marketing and such various departments at all levels company wide (Companywide Involvement: CI) *Total productive Maintenance, TPM = BM + PM + MI + MP + CI*

As automation is rapidly on the rise, TPM has gained centrestage in today's industrial scenario. The technology is getting to be more and more advanced. Human input, particularly the mechanical type of work, is getting replaced by machines. In short, the dependence on machines has been increasing at a fast pace. Therefore, we need to have machines and operating systems that do not fail. The problem of maintenance itself needs to be eradicated. This is particularly evident in industries such as nuclear power, petroleum refining, petrochemicals, etc. where the equipment handling the fluid, semi-fluid, or solid materials have to be maintenance-free.

In the industrially advanced countries such as Japan, USA, Europe there are factories that are totally automated. Belgian carpets, for instance, competitor of Indian carpets in the international markets, are made in highly automated or completely automated factories. As it is said, all one needs in these factories is a watchman.

At Nishio Pump factory in Japan, one must take off shoes at its entrance. As the Japanese say: 'No-man manufacturing begins with a no-dust workplace'. That may be reverence for the machines giving production or it may be a maintenance prevention action. It could be a combination of both. The reverence for machines should be taken in the right spirit. In India, we have 'Ayudh Pooja' i.e. worship of the equipments. Let us grasp the total meaning of our tradition and implement it.

SOLVED PROBLEMS

1. Dayanand Lamp Works in Chandigarh has a record of an average of 6 industrial accidents per quarter. The regional industry association gives a Good Safety award, if the number of accidents in a quarter is 5 or less. What is the probability that Dayanand Lamps qualifies for this award?

Answer

Refer to the Poisson distribution table (Appendix of Chapter 10) at $\lambda = 6$ and $x = 5$. We need the probability that $x = 5$ or less.

The probability of qualifying for the award is, therefore, 0.446

2. Hyderabad Electronics tests its prime product, the colour TV tube, for 1,000 hours. A sample of 50 TV tubes was put through this quality testing, during which 2 tubes failed.

(a) If the customers use the tube for 8 hours per day, and if 20,000 TV tubes were sold, then in one year from their selling, how many tubes will be expected to fail?

(b) What is the mean time between failures for these TV tubes?

Answer

Total time of testing = (50 tubes) × (1,000 hours) = 50,000 hours.

However, 2 tubes have failed and hence the total time of testing is actually smaller. Assuming that the failed tubes have lasted an average of half of test period, the actual total time of testing = 50,000 – (2 tubes) × (500 hours) = 49,000 hours.

Thus, the test shows that there are 2 failures during 49,000 hours.

Therefore, with 8 hours per day in 365 days of the year, the expected failures are:

(2 / 49,000) × (20,000 tubes) × (365 × 8 hours) = 2,383 failures.

The mean time between failures = (49,000 hours of testing / 2 failures) / (365 × 8)

= (24,500) / (365 × 8) = 8.39 hours.

3. Bandra Batteries makes mobile phone batteries that have a life-time showing a Normal distribution with a mean of 3,000 hours of operation and a standard deviation of 500 hours.

(a) What is the percentage of mobile batteries that fail before 2,000 hours of operation?

(b) What percent of these can be expected to have a life above 4,000 hours?

(c) What percentage will fail between 2,500 and 3,500 hours of operation?

Answer

The product is showing a wear-out pattern with a Normal distribution being applicable for its life.

(a) Mean = 3,000, Std. dev. = 500, z = (3,000 – 2,000) / 500 = 2.0

Refer to the Standard Normal distribution (Appendix II of Chapter 21).

Corresponding to $z = 2.0$, we have the area to the left of 2,000 of (0.5000 – 0.4772) = 0.0228.

Thus, the percentage of batteries failing before 2,000 hours of operation is 2.28 per cent.

(b) Again, we have z = (4,000–3,000) / 500 = 2.0

Hence, the percentage of batteries failing after 4,000 hours of operation is 2.28.

(c) 2,500 and 3,500 hours correspond to –1 and +1 standard deviation. Referring to the Standard Normal distribution table, an area of 0.3413 each falls on either side of the mean, which means, (0.3413 + 0.3413) = 0.6826 or 68.26 per cent of the batteries are expected to have a life between 2,500 and 3,500 hours.

4. An item shows a constant hazard rate of two per week of seven days. If two such items are connected in parallel:

(a) What are the chances that the system will fail within four days?
(b) What is the probability that the so connected system will fail on the 4th day?

Answer

The hazard rate being constant indicates negative exponential failure behaviour with $\lambda = 2/7 = 0.2857$ failure per day.
The reliability of the item $P(t)$ is $= e^{-\lambda t}$
If such items are connected in parallel, we have reliability of the system:

$$P(t) = 1 - (1 - e^{-\lambda t})\text{X}\ (1 - e^{-\lambda t}) = 2\ e^{-\lambda t} - e^{-2\lambda t}$$

The probability that an item survives four days is:

$$e^{-\lambda t} = e^{-(0.2857)(4)} = e^{-1.1428} = 0.318$$

Hence, the chances that the system will fail any time within four days

$$=(1 - 0.318) \times (1 - 0.318)] = 0.4651$$

(b) The probability that an item survives three days is:

$$e^{-\lambda t} = e^{-(0.2857)(3)} = e^{-0.8571} = 0.4245$$

Hence, the probability that this system will fail any time within 3 days

$$= (1 - 0.4245) \times (1 - 0.4245) = 0.3312$$

Now, the probability of the system failing on the 4th day
= (probability of failing any time within 4 days) – (probability of failing any time within 3 days)

$$= 0.4651 - 0.3312 = 0.1339.$$

5. The times elapsing between two successive failures of a press follow a negative exponential process with a mean of six hours. What are the probabilities that (a) a failure occurs between the 3rd and 4th hour? (b) What is the probability that an interval of at least one hour exists between two successive calls for maintenance action?

Answer

We have been told that $\lambda = 1 / 6$ failures per hour.
As the press is showing negative exponential failure mode, the failure probability density function is given by:

$$f(t) = \lambda \cdot \exp\ (-\lambda t)$$

The cumulative probability function $F(t)$ is given by the integral:

$$\int_0^t \lambda \cdot \exp\ (-\lambda t)\ dt$$

The probability that the failure occurs between 3 and 4 hours is:

$$\int_3^4 (1/6) \cdot \exp\ (-1/6 \cdot t)\ dt = \exp\ (-3/6) - \exp\ (-4/6) = 0.6066 - 0.5134 = 0.0932.$$

(b) Every time a failure occurs, a maintenance action occurs and the machine starts anew. So, basically we are looking at a survival up to 1 hour.
We have $\lambda = 1/6$ and $t = 1$
The survival probability $P_t = \exp\ (-\lambda t) = \exp\ (-1/6) = \exp\ (-0.1667) = 0.849$.

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That is, the probability that an interval of at least one hour exists between two successive calls for maintenance action = 0.849.

6. Assam Petroleum Corporation has 100 identical vacuum pumps in its refinery. Following is the data available on the breakdown of the vacuum pumps.

Months in Use	*Probability of Breakdown*
1	0.20
2	0.30
3	0.50

When a vacuum pump breaks down, it holds up the production process wasting precious time and also costing in terms of the materials and the effort of the repair staff. Dhrubajit Gogoi, the Maintenance Manager, estimates that every breakdown of the pump costs Assam Petroleum a whopping Rs. 20,000 on an average.

Gogoi knows the importance of preventive maintenance and estimates the costs of preventive action at Rs. 5,000 per such action. What should be the appropriate maintenance policy in terms of the mix of preventive and breakdown maintenance?

Answer

Case A: Cost of a totally breakdown maintenance policy

The expected number of months between failures

$$= 0.2(1) + 0.3(2) + 0.5(3) = 2.3$$

Cost per month of totally breakdown maintenance policy

$$= (\text{No. of Pumps})(\text{Cost per breakdown}) / (\text{Expected months between failures})$$

$$= (100)(\text{Rs. } 20{,}000) / (2.3) = \text{Rs. } 8{,}69{,}565$$

Case B: Costs per month for a policy of preventive maintenance every 1 month.

No. of breakdowns within the period of one month $=(100) \times (0.20) = 20$

Hence, the cost of breakdown $= 20 \times (\text{Rs. } 20{,}000) =$ Rs. 4,00,000

Cost of preventive maintenance $= (100 \text{ pumps}) \times (\text{Rs. } 5{,}000) =$ Rs. 5,00,000

Total cost during this preventive maintenance period = Rs. 9,00,000

Thus, cost per month for this maintenance policy = Rs. 9,00,000

Case C: Preventive maintenance period of 2 months.

No. of breakdowns within the period of two months $= [(100) \times (0.20 + 0.30) + (100) \times (0.20 \times 0.20)] = 50 + 4 = 54$

Hence, the cost of breakdown = (54) (Rs. 20,000) = Rs. 10,80,000

Cost of preventive maintenance = (100)(Rs. 5,000) = Rs. 5,00,000

Total cost during this preventive maintenance period = Rs. 15,80,000

Hence, the cost per month = (Rs. 15,80,000) / (2 months) = Rs. 7,90,000

Case D: Preventive maintenance period of 3 months.

No. of breakdowns within the period of three months $= [(100) \times (1.0)] + [(100 \times 0.20) \times (0.20 + 0.30)] + (100 \times 0.20 \times 0.20)(0.20)] + [(100 \times 0.30) \times (0.20)] = 100 + 10 + 10 + 0.8 + 6 = 126.8$

Hence, the cost of breakdown = (126.8) (Rs. 20,000) = Rs. 25,36,000

Cost of preventive maintenance = (100)(Rs. 5,000) = Rs. 5,00,000
Total cost during this preventive maintenance period = Rs. 30,36,000
Hence, the cost per month = (Rs. 30,36,000) / (3 months) = Rs. 10,12,000
It is noted that the 'per month' costs are lowest for Case C, i.e. when there is preventive maintenance every two months. Gogoi should carry out preventive maintenance every two months for these vacuum pumps.

7. A replaceable item shows the following failure behaviour. There are 4 such similar items in the office.

Month	*Probability of Failure*
1	0.1
2	0.2
3	0.3
4	0.4

Currently as each item fails, the failed item is replaced by a new one. Anjaneyulu, the Office Manager, is instead thinking of changing over to a group breakdown replacement policy, i.e. when one of these items fails, all four items are replaced.
If the cost of replacing all four items together is Rs. 200 while the cost of replacing an item individually is Rs. 100, is Anjaneyulu's decision economically justified?

Answer

Under the group breakdown replacement decision, since all items are replaced as soon as one item fails, the average life of an item corresponds to average life for first failure.
Average life for first failure =

1(Probability that the first failure occurs in month 1)
\+ 2(Probability that the first failure occurs in month 2)
\+ 3(Probability that the first failure occurs in month 3)
\+ 4(Probability that the first failure occurs in month 4)

Probability of an item surviving up to 1st month = 1 – 0.1 = 0.9
Hence, probability of all 4 items surviving up to 1st month = $(0.9)^4 = 0.6561$
Hence, probability that the first failure occurs at month 1 = (1 – 0.6561) = 0.3439
In a similar manner, all other first failure probabilities can be computed.
Probability of an item surviving up to 2 months = [1 – (0.1 + 0.2)]
Hence, probability of all four items surviving up to 2 months = $[1 - (0.1 + 0.2)]^4$
$= (0.7)^4 = 0.2401$
Hence, the probability of any one item failing either in the 1st or in the 2nd month is = 1 – 0.2401 = 0.7599
Hence, probability that the first failure occurs in the 2nd month

= 0.7599 – probability of 1st failure in month 1

= 0.7599 – 0.3439 = 0.4160

Similarly, we have the probability that the first failure occurs in the 3rd month

$= [1 - \{1 - (0.1 + 0.2 + 0.3)\}^4] - [1 - \{1 - (0.1 + 0.2)\}^4]$

$= [1 - \{0.4\}^4] - [1 - \{0.7\}^4] = 0.9744 - 0.7599 = 0.2145$

Similarly, we have the probability that the first failure occurs in the 4th month

$= 1 - 0.9744 = 0.0256$

Therefore, the average life for first failure is:

$= 1(0.3439) + 2(0.4160) + 3(0.2145) + 4(0.0256)$

$= 1.9218$ months

Hence, the per month cost of group breakdown replacement policy

$=$ (Rs. 200) / (1.9218) = Rs. 104.07

If Anjaneyulu followed an individual breakdown replacement policy, the per month cost would have been = (Rs. 100 × 4 items) / (Average life of an item)
Now, the average life of an item under such a policy would be:
1(0.1) + 2(0.2) + 3(0.3) + 4(0.4) = 3 months
Therefore, for the individual breakdown replacement policy, the per month cost would be = (Rs. 100 × 4 items) / 3 = Rs. 133.34
Comparing the per month cost of the two policies, group breakdown replacement is economically better of the two. Anjaneyulu's decision is economically justified.

8. A system consists of components A, B, C and D, with reliabilities of 0.9, 0.7, 0.9 and 0.7, respectively, connected in series. In order to improve the reliability of this system, redundancy is provided by connecting another system to it in parallel. The second system is composed of components E, F, G and H, with reliabilities of 0.9, 0.7, 0.9 and 0.7, respectively, connected in series.

(a) Is the reliability improved if A-B-C-D (connected in series) is connected in parallel to E-F-G-H (connected in series)? What, if any, is the improvement?

(b) Suppose we provide the module E-F in parallel to module A-B and provide module G-H in parallel to module C-D. Is there an improvement in system reliability as compared to case (a) above?

(c) Suppose we provide component level redundancy, i.e. E is connected in parallel to A, F to B, G to C and H to D. Is there an improvement in system reliability over that of case (b) – module level redundancy?

Answer

Case (a)

Reliability of A-B-C-D is = 0.9 × 0.7 × 0.9 × 0.7 = 0.3969
Reliability of E-F-G-H is = 0.9 × 0.7 × 0.9 × 0.7 = 0.3969
Hence, reliability of the system when there is system level redundancy is

$= [1 - (1 - 0.3969)(1 - 0.3969)] = 0.6363$

There is substantial improvement in system reliability from 0.3969 to 0.6363.

Case (b)

Reliability of module A-B is = 0.9 × 0.7 = 0.63
Reliability of module E-F is = 0.9 × 0.7 = 0.63
Hence, the reliability of the combined module where A-B and E-F are in parallel:

$= [1 - (1 - 0.63)(1 - 0.63)] = 0.8631$

Similarly, the reliability of the combined module of C-D and G-H in parallel is:

$$= [1 - (1 - 0.63)\,(1 - 0.63)\,] = 0.8631$$

Therefore, the reliability of the system is now:

$$= 0.8631 \times 0.8631 = 0.7449$$

System reliability, when modular redundancies are provided, is better than that in case (a).

Case (c)

In this case, the redundancies are at the level of the component.

Reliability of A and E in parallel $= 1 - (1 - 0.9)(1 - 0.9) = 0.99$

Reliability of B and F in parallel $= 1 - (1 - 0.7)(1 - 0.7) = 0.91$

Reliability of C and G in parallel $= 1 - (1 - 0.9)(1 - 0.9) = 0.99$

Reliability of D and H in parallel $= 1 - (1 - 0.7)(1 - 0.7) = 0.91$

Therefore, the reliability of the system is:

$$= 0.99 \times 0.91 \times 0.99 \times 0.91 = 0.8116$$

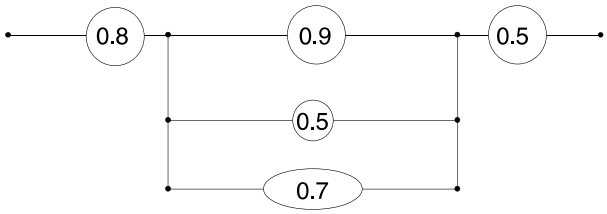
This case is the best when providing redundancies in order to improve reliability.

Modular level redundancy is better than equipment level redundancy and the component level redundancy is better than the modular level redundancy. It is seen that the lower the level at which the redundancies are provided, the better is the system reliability. However, from the viewpoint of 'maintainability', component level redundancy may be less desirable than at the modular level.

QUESTIONS FOR DISCUSSION

1. As a management discipline, does maintenance management differ from production management? If yes, in what way?
2. 'Engineering design (of machines, plants) is a purely technical matter and management science has very little to contribute in this field'. Do you agree with this statement? Explain why.
3. What are the limitations in the utility of statistics to maintenance management?
4. Cutting machines have an average life of 24 months. A cutting machine broke down in 2 months. Would you say that the breakdown was certainly due to bad design of the particular machine?
5. In what kind of situations will 'group replacement' find an application? Does it implicitly assume any particular stage of life?
6. Good organization is a key factor in the management of maintenance. Discuss.
7. The quantity of breakdown maintenance spares required was computed in Chapter 14. Did we make any implicit assumption there?
8. Explain how one could use Work Sampling in maintenance?
9. Can MTM be used in maintenance? Explain.
10. Suggest ways of Job Enrichment in maintenance?
11. Do maintenance management–principles have any relevance in the service Industry? Discuss.
12. Can TPM logic be extended to services? Discuss.
13. What applications do management techniques such as
    (a) Queueing theory and (b) Simulation have in maintenance.

14. What is the reliability of the following system? The reliabilities of components are indicated within the circles.



15. The machine breakdown distribution in a plant is observed to be Poisson (approximately). The servicing crew consists of four technicians. The servicing (repair) times are observed to be negative exponential. If the average arrival rate of the breakdowns was 2 per hour, the average time for servicing was 20 minutes, the labour cost was Rs. 20 per day (= Rs. 2.50 per hour) and the down-time cost of the machine was Rs. 100 per hour, find:
(i)Mean waiting times with one crew repairing the machines, and with two and three crews repairing the machines.
(ii) What would be the most economical of the three alternative maintenance policies?

16. The breakdown probability of an equipment is given below:

Month	Probability
1	0.05
2	0.15
3	0.30
4	0.30
5	0.20

There are 50 such equipments in the plant. The cost of individual preventive replacement is Rs. 15 per equipment and the cost of individual breakdown replacement is Rs. 30 per equipment. Which should be the preferred policy?

14 Maintenance Management – II (Spare Parts Management)

CHARACTERISTICS OF SPARE PARTS

Spare Parts Management needs special treatment, somewhat different from the inventory management of regular items. This is because the purpose of keeping a stock of these is different—to serve as a replacement to the worn-out parts in the machinery. The statistics of failure is of much importance in the management of spare parts. Moreover, spare parts are not always available during the entire life-time of the equipment. Spare parts are special independent demand items deriving their demand from the failure characteristics of the component, and with a specialised supply situation.

It is estimated that the inventory of obsolete and surplus spare parts in India runs to more than Rs. 10,000 crore. In fact, many inventory management problems have been noticed in the management of spares. This may be because of various reasons peculiar to the economy and industry of India. Capital investments have been made on heterogeneous equipments, many of which have been imported from different countries at different periods of time. Indigenous spares are not easily available. These have been some of the contributing factors to the significantly high level of the inventory of spares in India. Another probable factor which is of not less importance is that Indian industries are slow to appreciate even the simpler management theories and concepts either regarding inventory or regarding maintenance. The situation regarding the spare parts inventories has, therefore, been less than satisfactory. This has led the Reserve Bank of India to stipulate that spare parts inventory exceeding 5% of the total inventory value should be examined critically by the bankers while considering the request from industries for loans towards working capital. An attempt has, therefore, been made here to present some of the less complex and more practically applicable theories and concepts.

CONVENTIONAL CLASSIFICATION

One of the important concepts which has found much practical utility in terms of rupees saved in our country is the concept of VED/ABC analysis, which has been described in Chapter 22. VED analysis is of much significance, because it deals with the criticality (production-losses due to its absence, etc.) of the items in inventory; and one of the main purposes of spares is to avoid

production stoppages. 'Vital' items need to be stocked at a much higher level than the 'essential' items; the latter need to be stocked much more than the 'desirable' items. This is so, because the criticality decreases from 'vital' to 'desirable'. This simple principle combined with another principle, that A class items need to be stocked lower than B and C class items, will provide important guidelines to spare parts inventory control. The matrix depicted in Chapter 22 for classification of inventory, based on both ABC and VED considerations, is given here too.

The type of matrix classification in Fig. 14.1 has helped many an industry to keep appropriate service levels and therefore appropriate stocks of inventory of spares.

	V	E	D
A	90%	80%	70%
B	95%	85%	75%
C	99%	90%	80%

Figure 14.1 An Illustration of the Classification of Spares and Corresponding Service Levels. (The service levels are only for illustrative purposes)

CODIFICATION CONCEPT

Another concept which has yielded disproportionately large dividends by its application is the concept of appropriate codification of materials. Codification is primarily for unique identification of the items in an inventory. This unique identification has its own stream of benefits. It is of particular importance in the case of spares, because as opposed to the regular items in inventory the spares come in different varieties (the items or categories in spares are much more than in the regular inventory). This variety makes codification all the more important for spares management. By codification we do not mean necessarily a particular kind of system such as the Kodak System or Brisch System. By proper codification we mean, a system of identification suited particularly to the needs and purposes of an organization. The idea is to identify uniquely, and organize the total spares inventory, so that spares are easily located and available when required and are capable of being monitored with ease for the maintenance at appropriate quantities in the inventory. One may have a 10 digit code; it may be more or less. One may have a pnemonic code; it all depends upon the type of industry/organization in question. It is situational, varying from one organization to another. Lack of a proper system leads to unnecessary storage of large inventories of spares under two or more names or codes resulting to confusion at the time of locating them. The more the confusion, the more the procurement at varying times, the more the inventory, leading to more confusion, and so on. In most organisations codification and classification is the only solution. More on codification follows in Chapter 24.

One can also apply simple inventory models and safety-stock principles to spare parts control. Just as the behaviour of the consumption of spares is different from the consumption of the regular items in inventory, so also the supply of spares is different from the regular items. This being so, some modifications are necessary to the conventional inventory and safety-stock models. Before we proceed with this analysis, a little further categorisation of spare parts for analysis of optimum stocking policies needs to be studied.

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CLASSIFICATION OF SPARES FOR STOCKING POLICY ANALYSIS

1. Maintenance or Breakdown Spares These are the spares which are required in large quantities at more or less frequent periodic intervals as and when the breakdowns occur. These resemble, somewhat, the regular inventory items in their consumption patterns (rates). To some extent, the analysis for stocking policies of the spares could be similar to that of the regular items in inventory. The analysis will be presented later.

2. Insurance Spares As the name indicates, the purpose of these spares is to provide an insurance against the relatively remotely possible breakdown or failure of an equipment/component. The probability that such a component/equipment will survive the life-time of the machinery or plant is quite high. The reliability of such spares has been observed to be as high as 95 to 99% over the life-span of the machinery. These spares are sparingly needed. But they are needed all the same because they may hold up production resulting in considerable losses for want of them. Many of these spares are, also, high value items. These spares are, by and large, procured along with the capital equipments. This is so, because if these spares are required after 15 years (which may be say three-fourth of the life of the equipment) they may not be available, and if available they may be available at a very high cost. The difficulty in the availability may result in extra-large production down-time costs by way of loss of profits. Hence, at the time of the purchase of the capital equipment itself a decision regarding the purchase of the insurance spare is also made. Generally, the decision with regard to insurance spares may be to buy either no spare (0) or to buy a (1) spare.

3. Capital Spares These are also high-reliability spares, but not as high as the insurance spares. The reliability is not as low as that of the maintenance spares as well. Moreover, these spares have relatively higher purchase cost than the breakdown spares. The decision regarding these spares is usually made at the time of purchase of the capital equipment itself. But the decision may be to buy anywhere from 0 to say 6 or 7 spares. The analysis for the capital spares inventory policy is, therefore, somewhat different from that of the insurance spares.

4. Rotable Spares These are the reusable spare parts, which after their breakdown can be reconditioned and reused. Typical examples are the stepany in the car, jet-engine in aircraft, tyre tubes in cycles, electrical motors, etc. Since these have more than one life, the cycle of their various lives needs to be taken into consideration in the analysis of their inventory policy.

Let us now deal with these different categories of spares and present the theoretical or analytical models by means of examples.

MAINTENANCE OR BREAKDOWN SPARES

The rate of consumption or usage of spares can be derived from historical data regarding failure of the different components in the machinery. Failure statistics is an important basic information for this analysis. If the failure times show a negative exponential distribution (showing a behaviour of failure which is known as the useful life stage), the failure rates are distributed by means of Poisson distribution. If the failure times show a normal distribution due to aging or wear, then the failure rates will also show a normal distribution. From the failure statistics one can know the mean consumption rate of these spares and also find the level of consumption expected with a corresponding probability of its occurrence. Based on service level or risk level, the inventory level can be easily arrived at. As later mentioned in Chapter 21, the service level is given by the following formula:

$$\text{Service level} = \frac{K_u}{K_u + K_o}$$

where K_u = opportunity cost of understock of one unit, and

K_o = opportunity cost of overstock of one unit.

The following will illustrate the calculations of the level of Maintenance spares.

Example Compute the average level of inventory given the following information:

(a) Fixed order quantity system
(b) Average consumption rate: 16 units per quarter,
(Poisson distribution appears to hold good for the consumption)
(c) Service level: 95%
(d) Lead time for procurement: 1 quarter
(e) Cost of ordering: Rs. 500 per order
(f) Cost of carrying: Rs. 18 per unit per year

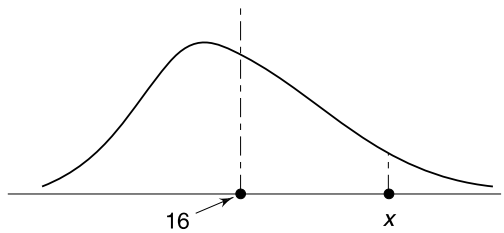
Solution

Mean consumption rate, $\lambda = 16$ units per quarter

Standard deviation = $\sqrt{\lambda} = 4$

Referring to Poisson distribution tables furnished in the appendix to Chapter 10, we have

$x = 23$ approximately



Since the lead time is 1 quarter,

Buffer stock = 23 – 16 = 7 units

Now the EOQ = $\sqrt{\frac{2 \times 500 \times 64}{18}}$ = 60 approximately

Since the EOQ is very close to the annual requirement, the item may be ordered only once in a year.

Therefore, the average inventory = $\frac{64}{2} + 7 = 39$ units

CAPITAL SPARES

As mentioned earlier, the decision here is to buy spares ranging anywhere from 0 to say 7 spares. These spares are bought along with the capital equipment. The reliabilities of such spares are much higher than those of the maintenance spares. Let us have the following notation:

C = Cost of spare parts,

C_s = Cost of shortage per unit,

S = Salvage value of the spare parts when they are salvaged,

P_i = Probability that the demand for the capital spare parts is 'i' in number.

N = Optimal number of spares required, and

TC = Total cost for stocking N items.

The demand may be either more than the optimal number N, or less than or equal to optimal number N. These are the two situations that are considered which have their own associated costs. The policy of buying N spare parts should be such that the total costs (i.e. summation for both the aforesaid situations) are minimum.

Situation No. 1 Demand is less than or equal to N. In this case, there is no shortage cost. There is some revenue to be expected from salvaging the excess spares, which is

$$S \cdot \sum_{i=0}^{N} P_i \cdot (N - i)$$

Situation No. 2 Demand is more than N. Naturally, we shall have the shortage cost which will be

$$C_s \cdot \sum_{i=N+1}^{\infty} P_i \cdot (i - N)$$

Therefore, Total cost for the policy of buying N spares would be

$$= N \cdot C + C_s \sum_{i=N+1}^{\infty} P_i \cdot (i - N)$$

$$- S \cdot \sum_{i=0}^{N} P_i \ (N - 1)$$

Because N^* is the optimal policy, we have

$$TC\,(N^* - 1) - TC\,(N^*) \geq 0$$

and $$TC\,(N^* + 1) - TC\,(N^*) \geq 0$$

The above two equations are obvious. From the former of these two, it follows that:
Since

$$TC\,(N^* - 1) - TC\,(N^*) \geq 0$$

Therefore,

$$(N^* - 1) \cdot C - N^* \cdot C + C_s \sum_{i=N^*}^{\infty} P_i \cdot (i - N^* + 1)$$

$$- C_s \sum_{i=N^*+1}^{\infty} P_i \ (i - N^*) - S \sum_{i=0}^{N^*-1} P_i \ (N^* - 1 - i)$$

$$- S \sum_{i=0}^{N^*} P_i \ (N^* - i) \geq 0$$

That is,

$$- C + C_s \left[1 - \sum_{i=0}^{N^*-1} P_i\right] + \left[S \sum_{i=0}^{N^*-1} P_i\right] \geq 0$$

That is,

$$- C + C_s + \sum_{i=0}^{N^*-1} P_i \ [S - C_s] \geq 0$$

That is,

$$\sum_{i=0}^{N^*-1} P_i \cdot [S - C_s] \geq C - C_s$$

Therefore, $$\sum_{i=0}^{N^*-1} P_i \leq \frac{C_s - C}{C_s - S}$$

Similarly, we have from $TC(N^* + 1) - TC(N^*) \geq 0$:

$$\sum_{i=0}^{N^*} P_i \geq \frac{C_s - C}{C_s - S}$$

Therefore, the optimal number of capital spares to be stocked shall be such that

$$\sum_{i=0}^{N^*-1} P_i \leq \frac{C_s - C}{C_s - S} \leq \sum_{i=0}^{N^*} P_i$$

Example The probability of the demand of spares in a textile unit is observed to be

No. of Spares Required	*Probability*
0	0.05
1	0.15
2	0.30
3	0.25
4	0.15
5	0.05
6	0.05

The cost of stock-out for lack of a spare, is computed to be Rs. 5,000. The price of spares is Rs. 1,000 each. The salvage value of the spare part is estimated to be almost nil.

What is the optimal number of spares to be stocked?

Solution The optimal N^* should be such that it should satisfy:

$$\sum_{i=0}^{N^*-1} P_i \leq \frac{5000 - 1000}{5000 - 0} \leq \sum_{i=0}^{N^*} P_i$$

At $$N^* = 4, \sum_{i=0}^{N^*} P_i = 0.90$$

and $$\sum_{i=0}^{N^*-1} P_i = 0.75$$

This satisfies the required condition.

Therefore, $N^* = 4$ or 4 spares should be stocked.

Let us see if we could have arrived at the same solution by another method. Table 14.1 lists the costs of different stocking policies.

Expected total cost is the lowest for the stocking policy of four spares. This is the same as the result we got earlier, which is to be expected since the previous formula was a condensed version of the procedure given in Table 14.1.

INSURANCE SPARES

Since the question here is whether to procure no spare at all or one spare along with the equipment, the analysis is fairly simple.

A spare is to be procured only if the expected value of the down-time costs exceeds (or equals) the purchase value of the spare.
That is,

If cost of down-time (in the event of failure)	×	Probability of failure during the life-time of the equipment
	≥	Cost of the spare then, purchase a spare along with the equipment.

The probability of failure = (1 – Reliability).

The reliability figures for such spares are generally provided by the manufacturer.

Typical examples of insurance spares are a stand-by generator, or special purpose gear, or a turbine rotor.

ROTABLE SPARES

Items such as a jet-engine or an electric motor can be reconditioned after failure and put back in operation. These are called the rotable spares. (see Fig. 14.2)

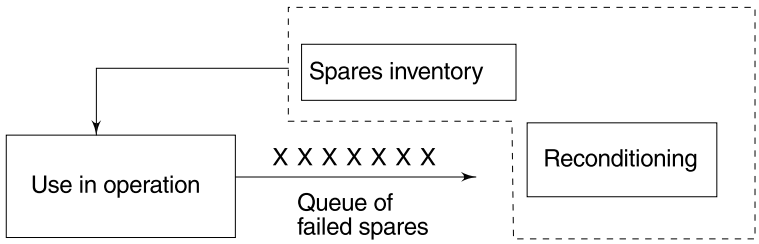


Figure 14.2 Rotable Spares' Flow

The situation can be viewed in the Queueing Theory format.
where,

Arrivals (customers)	≡ failed equipment/components
Servers	≡ the spares inventory
Queue discipline	≡ first come first served
Service times	≡ given by the distribution of times to recondition a spare
Arrival times	≡ given by the distribution of the times (intervals) at which the failed equipments come for replacement

Please note that replacement takes very little time (theoretically almost nil). But while counting the service times one must consider the time required to recondition the failed spares as well. Reconditioning and replacement are one system.

The down-time significantly appears when no reconditioned spare is available and the equipment is waiting for a replacement. This means all the 'servers' (spares) are busy in this case. Assuming different values of the number of spares to be kept, we can compute the probability of all servers being busy in the Multiserver Queueing model. This can be used to calculate the expected value of the down-time cost. The cost of carrying spares should balance the expected down-time cost, for the optimal numbers of spares.

Table 14.1 Costs of Different Stocking Policies

Stocking Policy	*Probable Requirement*	*Expected Cost of Stock-out (Rs.)*			*Cost of Spares (Rs.)*	*Expected Total Costs (Rs.)*
0	0	—				
	1	5,000 × 0.15		750		
	2	+ 10,000 × 0.30		+ 3,000		
	3	+ 15,000 × 0.25	=	+ 3,750	= 13,250	Nil	13,250
	4	+ 20,000 × 0.15		+ 3,000		
	5	+ 25,000 × 0.05		+ 1,250		
	6	+ 30,000 × 0.05		+ 1,500		
1	0	—				
	1	—				
	2	5,000 × 0.30		1,500		
	3	+ 10,000 × 0.25		+ 2,500		
	4	+ 15,000 × 0.15	=	+ 2,250	= 8,500	1,000	9,500
	5	+ 20,000 × 0.05		+ 1,000		
	6	+ 25,000 × 0.05		+ 1,250		
2	0	—				
	1	—				
	2	—				
	3	5,000 × 0.25		1,250		
	4	+ 10,000 × 0.15	=	+ 1500	= 4,750	2,000	6,750
	5	+ 15,000 × 0.05		+ 750		
	6	+ 25,000 × 0.05		+ 1250		
3	0	—				
	1	—				
	2	—				
	3	—				
	4	5,000 × 0.15		750		
	5	+ 10,000 × 0.05	=	+ 500	= 2,000	3,000	5,000
	6	+ 15,000 × 0.05		+ 750		
4	0	—				
	1	—				
	2	—				
	3	—				
	4	—				
	5	5,000 × 0.05		250		
	6	+ 10,000 × 0.05	=	+ 500	= 750	4,000	4,750
5	0	—				
	1	—				
	2	—				
	3	—				
	4	—				
	5	—				
	6	5,000 × 0.05	=	250		5,000	5,250
6	0					
	1					
	2					
	3	Nil				6,000	6,000
	4					
	5					
	6					

Probability that all servers are busy in the n-servers Queueing model $\times$ Cost of down-time $=$ Cost of carrying n number of spares

Here, the cost of down-time is the cost incurred whenever an equipment is stranded for spares replacement.

If the cost of non-operation of the failed equipment is related to the length of down-time, then we may compute the average waiting time for the n-servers' model and use it thus:

Average waiting time × Down-time cost per unit of time = Cost of carrying n spares

SOLVED PROBLEMS

1. A special capacitor component in critically important flight electronic equipment system costs Rs. 300,000. The requirement of the component follows a Poisson distribution with a mean of one in five years. The life of the flight electronic equipment system can be taken as ten years and the salvage value is estimated to be nil. The cost of downtime for want of a special capacitor component is considerable and is estimated at Rs. 20,00,000. If there are 20 flight electronic equipment systems, each requiring one special capacitor component, how many of the latter should be stocked?

Answer

There are 20 flight electronic equipment systems.

Therefore, the mean failure rate, $\lambda = 20$ per five years $= 4$ per year.

The number N of special capacitor components (spares) to be stocked should be such that:

$$\sum_{i=1}^{N-1} P_i \leq (C_s - C) / (C_s - S) \leq \sum_{i=1}^{N} P_i$$

Now, $(C_s - C) / (C_s - S) = (20,00,000 - 3,00,000) / (20,00,000 - 0)$

$= 0.850$

Referring to the Poisson distribution table, corresponding to $\lambda = 4$ we have N (i.e. x in the table) = 6 which is the optimal number to stock over the lifetime of all these flight electronic equipment systems.

2. At the aircraft hangar in Kolkata, aircrafts arrive for fitting reconditioned engines at the rate of 20 per month on an average. The damaged engines are repaired at that facility and the reconditioned engines are fitted back on to the aircraft that arrive with faulty engines. The facility has the capacity to recondition an average of 25 damaged engines per month. The cost of downtime (i.e. an aircraft not being available for want of a reconditioned engine) is estimated at Rs. 1 crore per day. The hangar stocks 1 extra engine as a spare in order to minimise the downtime. A spare costs Rs. 10 crore and the cost of stocking the spare is considered to be 30 per cent.

How many spare engines should the hangar stock? Should it stock any spare engines at all?

Answer

As per the data given: $\lambda = 20$ per month, $\mu = 25$ per month. Hence, $\lambda / \mu = 0.80$
For a stocking policy of $s = 1$ (1 spare engine is stocked), we have (referring to the multiple channel single service queuing table given in Chapter 7):
$N_w = 3.200$ which is the mean number waiting (i.e. aircrafts are down for want of a spare engine).
Mean waiting time for the aircrafts = $N_w / \lambda = 3.200 / 20 = 0.16$ month
Hence, cost of downtime = (0.16 month × 25 days per month) × (Rs. 1 crore per day) = Rs. 4 crore
The cost of stocking 1 spare engine for a month = (Rs. 10 crore × 0.30) / (12)
= 0.25 crore
Total relevant cost under this stocking policy = 4 + 0.25 = Rs. 4.25 crore
For a stocking policy of $s = 2$ (i.e. stocking 2 spare engines).
Referring to the above table, we find: $N_w = 0.1523$
Hence, mean waiting time for the aircrafts = $N_w / \lambda = 0.1523 / 20 = 0.00751$ month
So, cost of downtime = (0.00751 × 25 days) × (Rs. 1 crore) = 0.188 crore
Cost of stocking 2 spare engines for 1 month = (2 × Rs. 10 crore × 0.30) / 12
= 0.50 crore
Total relevant cost under this stocking policy = 0.188 + 0.50 = Rs. 0.688 crore
For a stocking policy of $s = 3$ (i.e. stocking 3 spare engines),
we have from the queuing table:
$N_w = 0.0189$
Hence, mean waiting time for the aircrafts = $N_w / \lambda = 0.0189 / 20 = 0.00094$ month
So, cost of downtime = (0.00094 × 25 days) × (Rs. 1 crore) = 0.024 crore
Cost of stocking 3 spare engines for 1 month = (3 × Rs. 10 crore × 0.30) / 12
= 0.75 crore
Total relevant cost under this stocking policy = 0.024 + 0.75 = Rs. 0.774 crore
If no spare is stocked ($s = 0$):
The faulty engine from the aircraft will have to be repaired with an average time of 25 per month of 25 days. That is, the aircraft waits for a mean of 1 day and like these 20 aircrafts will wait during the month.
The downtime for all the arrivals will be = 20 days and will cost Rs. 20 crore. This a huge cost compared to all other options considered above.

Stocking policy (No. of spares)	*Cost of downtime for the aircraft (Rs. Crore)*	*Carrying cost of the spares (Rs. Crore)*	*Total Relevant cost (Rs. Crore)*
0	20	Nil	20
1	4	0.25	4.25
2	0.188	0.50	0.688
3	0.240	0.75	0.774

It is observed that the policy of $s = 2$ (i.e. stocking 2 spare engines) is the most cost effective policy under the given circumstances.

QUESTIONS FOR DISCUSSION

1. In what way is the inventory control of the spare parts different from the control of the regular production items?
2. Under what conditions is Poisson distribution valid for Maintenance Spares?
3. Discuss the effect of maintenance policy on spares inventory control.
4. What are Capital Spares?
5. If you do not have any data on a new equipment, would you buy Insurance/and Capital Spares? On what would you base your purchasing decision?
6. The demand for a certain component can be approximated to a Poisson distribution. The average demand is 12 items per month.
   The cost of shortage for the component is worked out to be Rs. 500 per item. The price of the component is Rs. 50 per unit. The costs of carrying are 25%.
   What buffer stock would you maintain for this component if the lead time for procuring it is 2 months?
7. What 'Spares' can you have in the service industry? Discuss.

15 Work Study

METHOD STUDY AND TIME STUDY

Work Study concerns itself with better ways of doing things and control over the output of those things by setting standards with respect to time. Productivity which is, generally speaking, a ratio of output to input, is of great importance for the smooth running of any organization; it assumes particular importance for developing countries like India who have to compete favourably with other countries in the international market and make optimal use of scarce resources. Although usually the c oncepts of Work Study relate to a manufacturing organization, they are equally valid for other than manufacturing situations where services—if not goods—are generated.

The means of improving ways and means of doing things is called Method Study. the primary purpose of improving 'methods' is to save time, and therefore, effort of labour and machinery. Hence a measurement of the work involved in any job and the setting up of standards (for control purposes) of the time normally expected and the effort involved will be necessary. This aspect of setting work standards for comparison, control and other managerial action purposes is termed as Work Measurement. Since the standards are mentioned in time units required to perform a job, given a particular work setting and method, Work Measurement is also alternatively called Time Study. Method Study and Time Study together comprise Work Study.

The study of 'methods' of accomplishing a job by the movement of human limbs and eyes, etc. is termed as Motion Study. This is a part of Method Study.

FOUNDATION OF WORK STUDY

In fact, early researchers in the field of management were concerned with Motion Study. Frederick W. Taylor, Frank B. Gilbreth and Lillian M. Gilbreth were some of the pioneers in the field of Work Study. Dr. Taylor's conclusion was: "The greatest production results when each worker is given a definite task to be performed in a definite time in a definite manner."* This is the foundation on which modern Work Study stands today.

* Requoted from D.W. Karger and F.H. Bayha, *Engineered Work Measurement*, 2nd edition, 1965, Industrial Press Inc., NY, p.4.

The implication in the above statement of the interrelationship between Methods and Time Studies is important. By knowing the method you may improve the overall time, and by the study of the time taken for the different component tasks involved in the method you may get leads to improve the method.

Subdivision of Work—Therbligs

For a detailed and useful study of method or time, a subdivision of the work into its component elements is necessary. Taylor's division was more broad as compared to the subdivision suggested by Gilbreth, although the latter's study concentrated only on the human body. Gilbreth's elementalization was 'general' in the sense that any work done by hand and body movements could be classified into a few or all of 17 (later 18) 'Therblig' (Gilbreth spelt backwards) work elements. These fundamental motions are given in Table 15.1.

Table 15.1 'Therbligs'—Work Elements for Hand and Body Movements

Therblig	*Description*
Search	: When a hand or body member tries to find or locate an object.
Find	: Different from Search as it involves finding an object by eye movement.
Select	: To locate a specific object from a group of objects.
Grasp	: Gaining control over an object.
Hold	: Holding an object in a fixed position and location; it may amount to prolonged Grasp.
Transport Loaded	: Changing the location of an object.
Position	: Causing a part/object to line-up or orient.
Assemble	: To put two or three parts together.
Use	: Applying a tool or manipulating control.
Disassemble	: Taking objects apart (or causing separation of objects).
Inspect	: Determining the quality of an object by feeling the object.
Pre-position	: Same as Position except that this occurs when the line-up is previous to the use of part or tool in another place.
Release Load	: Letting go of an object.
Transport Empty	: Reaching for something.
Rest for over-coming Fatigue	: Idleness, necessary to overcome fatigue from previous working.
Unavoidable Delay	: Idleness, of a body member, where it is a part of the method.
Avoidable Delay	: Idleness or some movement of a body member, where it is not a part of the method.
Plan	: Deciding on a course of action.

(Adapted from *Handbook of Industrial Engineering and Management*, by Ireson and Grant, 3rd edition, Prentice-Hall of India)

For instance, picking up a glass of water kept on the table in front would involve the therbligs of:

Find, Transport Hand Empty, Grasp, and Transport Loaded (to the mouth).

When both the hand motions are detailed in 'therbligs', the idle time, the unnecessary motions of hands, the long transports, etc. are automatically highlighted for suggesting possible improvements in the methods and implements used for that job.

The general principles of motion economy are given in Table 15.2.

Table 15.2 Principles of Motion Economy†

Use of the Human Body	*Arrangement of the Work Place*	*Design of Tools and Equipment*
The two hands should begin as well as complete their motions at the same time. The two hands should not be idle at the same time except during rest periods. Motions of the arms should be made in opposite and symmetrical directions and simultaneously. Hand motions should be confined to the lowest classification with which it is possible to perform the work satisfactorily. Momentum should be employed to assist the worker wherever possible, and it should be reduced to a minimum if it must be overcome by muscular effort. Smooth continuous motions of the hands are referable to zigzag motions or straight-line motions involving sudden and sharp changes in direction. Ballistic movements are faster, easier and more accurate than restricted or 'controlled' movements. Rhythm is essential to the smooth and automatic performance of an operation, and the work should be arranged to permit easy and natural rhythm wherever possible.	There should be a definite and fixed place for all tools and materials. Tools, materials, and controls should be located close to and directly in front of the operator. Gravity feedbins and containers should be used to deliver materials close to the point of use. Drop deliveries should be used wherever possible. Materials and tools should be located to permit the best sequence of motions. Provisions should be for adequate conditions for seeing. Good illumination is the first requirement of satisfactory visual perception. The height of the workplace and the chair should preferably be arranged so that alternate sitting and standing at work are easily possible. A chair of the type and height to permit good posture should be provided for every worker.	The hands should be relieved of all work that can be done more advantageously by a jig, a fixutre, or a foot-operated device. Two or more tools should be combined wherever possible. Tools and materials should be pre-positioned whenever possible. Where each finger performs some specific movement, such as in typewriting, the load should be distributed in accordance with the inherent capacities of the finger. Handles, such as those used on cranks and large screwdrivers, should be designed to permit as much of the surface of the hand to come in contact with the handle as possible. This is particularly true when considerable force is exerted in using the handle. For light assembly work the screwdriver handle should be so shaped that it is smaller at the bottom than at the top. Levers, crossbars, and handwheels should be located in such positions that the operator can manipulate them with the least change in body position and with the greates mechanical advantage.

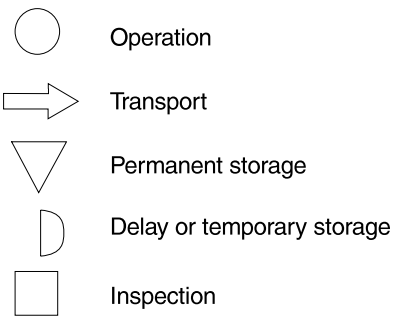
An Example of Application of Motion Economy Principles These principles can be applied to a simple situation (an example) of assembling a nut and a bolt to form an assembly. If the nuts and bolts are kept on the work table on the two sides of the worker, so that they are

† (Requoted from E.E. Adam Jr. and R.J. Ebert, *Production and Operations Management — Concepts, Model and Behaviour*, Prentice-Hall, 1978, p. 291; R.M. Barnes, *Motion and Time Study: Design and Measurement of Work*, 6th edn. John Wiely & Sons, NY, 1968, p. 220. Reprinted by permission of John Wiley & Sons, Inc. © Copyright, 1968, John Wiley.)

kept within easy reach, facilitating smooth curved symmetrical motion of both hands (to be done simultaneously), are stacked or kept in such a way as to eliminate search, a fixture provided to eliminate grasp by a hand while assembling, a chute provided to eliminate transport and release by hand, then we have used some of the above principles to improve the method and productivity.

Process Flow Charts

Just as the motion of hands are studied by classifying into certain fixed categories of micromotions, any job or process can be studied for methods improvement by recording all the events. For the study of the process, therefore, 'process-charts' are used giving the sequence of event occurring in the process from the beginning to the end. The ASME symbols which are universally accepted are:



An example of a Process Chart is given in Fig. 15.1.

Process charts are generally drawn for the material which goes from the raw material stage to the finished goods stage. Sometimes they may refer to the activities performed by the worker in getting a certain process done; in such a case the 'transport' refers to the movement of the man, the 'delay' refers to his waiting involved, etc. Process charts do not refer to the material and man or machine simultaneously.

Such charts give a clear picture of the process and help in analyzing whether the efforts are utilized in accomplishing the job or whether they are wasted. Each one of the activities can then be analyzed to find whether it could be

(i) eliminated, or
(ii) reduced in time, or
(iii) substituted by some other activity, or
(iv) put elsewhere in the sequence of activities, etc.

The ultimate goal is to simplify the procedure to minimize the man/machine effort and reduce avoidable wastage of time resulting in minimization of the process costs.

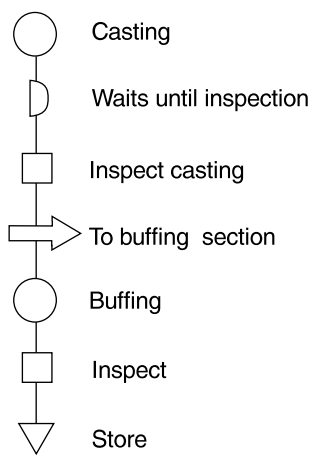


Figure 15.1 Simple Example of Process Chart

Man-Machine Diagrams

Other types of charts used are the man-machine charts, which on a vertical time scale indicate the various activities done by man and machine both on the same chart, for carrying out a certain operation by the man-machine team. An example is given in Fig. 15.2.

Similar graphic charts are sometimes constructed for multiman-machine situations and some to purely show the coordination (or lack of it) between the left and right hands of the operator (called Simo Charts).

The basic idea behind such charts is to visually aid in highlighting the possibility of:

(i) better coordination between man and machine,
(ii) reduction/elimination of idle times of man and machine to improve the utilization, and
(iii) exploration of alternative man-machine arrangements suitable to the plant conditions.

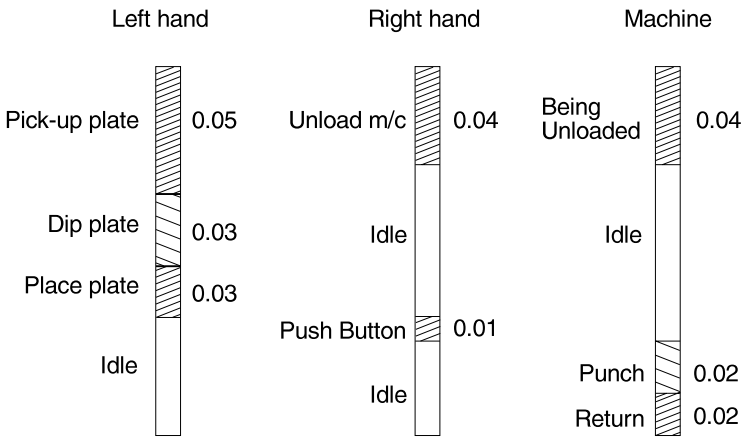


Figure 15.2 An Example for Constructing a Man-Machine Chart, Showing Left and Right Hand and Punching Machine Activities

MAIN COMPONENTS OF METHOD STUDY

The main components in the method study are:

1. Gaining information about and understanding the process, men carrying out the process and their work, machines carrying out the work, the tools, and the working conditions.
2. Information and understanding is to be sought in detail (as much as it makes sense) about the various components of process, and human, material and machine movements. This is preferably put in a graphic or visually simple-to-understand fashion for further analysis.
3. Analyzing critically:

(a)	What? (operations, delays, inspections, or hand-and-body motions, etc.)	Why so?	Alternatives, if any
(b)	Who? (number and skills of person/s doing it)	Why so?	Alternatives, if any
(c)	When? (sequence or time schedule of operations)	Why so?	Alternatives, if any
(d)	Where? (work place)	Why so?	Alternatives, if any
(e)	How? (use of tools, raw materials,etc.)	Why so?	Alternatives, if any

   The questions are to be asked in that order.
4. After the critical examiantion, chalk out improved alternative methods which might be acceptable to the labour and the management.
5. Check acceptance and follow-up implementation to iron out wrinkles if any in the improved methods.
6. Much after the production is undertaken, a reevaluation and maintenance of the method.

Criteria for Methods Improvement

The improvement in method refers to criteria which are relevant to the organization, such as

- improved cost performance,
- improved time or delay performance,

- improved worker satisfaction, or
- improved standardisation of operations and products.

The last two aspects, although mentioned last, are not of less significance; in fact, sometimes the Method Study has much to do with improving the always important industrial relations and with changes in product design (in consultation with marketing and other appropriate departments).

TIME STUDY STANDARDS

Once the method is established, the next thing to do would be to set the standard times for the work. This aspect of work study is called the 'time study'. The 'standard time' by its very meaning should be a consistent and truthful measurement of the time required to perform the job or components of the job with the established method, incorporating established number of adequately skilled and healthy human beings, their actions, machines, materials and work place conditions. The consistency of the time standard should hold good for the same job done day after day without any harmful physical effects.

Uses of Time Study

The utility of the time study comes in:

(i) determining the work content and thereby setting wages and incentives;
(ii) arriving at cost standards per unit of output for the various jobs used for cost control and budgeting for deciding on sales price;
(iii) comparing the work efficiency of different operators;
(iv) arriving at job schedules for production planning purposes;
(v) manpower planning;
(vi) aiding in the method study
  (a) to appropriately sequence the work of an operator and the machines or that of a group of workers,
  (b) to highlight time consuming elements, and
  (c) to compare costs of alternative methods.
(vii) product design by providing basic data on costs of alternative materials and methods required to manufacture the product.

Three Basic Systems of Time Study

The setting of time standards is done basically by following three methods:

(a) Using a stop-watch
(b) Using synthetic time standards
(c) Using statistical sampling.

In the first, the actual performance is studied by collecting data while the worker/s are working, and the data so obtained are synthesised into the time standard. In the second, any work is subdivided into certain standard components for which the standard times are available from previously established time-studies; and these predetermined times are totalled, with appropriate allowances to compute the standard time for the job as a whole. Much of the skill of the time study man lies here in identifying the standard components of a job; the rest is arithmetical computation on paper. The third method is different from the previous two in that it relies on statistical sampling.

Steps Involved in a Stopwatch Time Study

Stopwatch Time Study makes direct observations by means of a simple stopwatch measuring, generally, to the precision of 0.01 minute. The observation equipment consists of the stopwatch, the recording board, the observation sheet and a pencil. The steps involved in such a study are:

1. Subdivide the job into observable and distinct elements.
2. Choose 'acceptable' operator/s for study.
3. Make direct observations of the work elements (while the operator is actually performing the job) and record the time of each element. Make a statistically adequate number of repeated measurements and record each time.
4. Performance rate each element and record.
5. Calculate the 'normal' time.
6. Establish 'allowances'.
7. Compute the 'standard' time.

The key step in a stopwatch time study is that of subdividing the job into component elements. One should take care that the elements are distinct or well defined and therefore amenable to repeated measurements. Also, the elements should be as short as possible without losing accuracy of measurement; the practical minimum is generally 0.02 or 0.03 minute the time required to read and record being 0.027 minutes or 45 TMU (Time Measurement Unit which will be explained subsequently in this chapter). The following are the uses of this breakdown into elements:

(a) It helps in separate performance rating of each of the job elements, instead of performance rating the whole job (which may lead to much error in the Time Standard).

(b) If a job method changes in terms of only one or two elements, the revised time standard can be easily established in the future. Unnecessary time studies are, therefore, eliminated. Standards for similar or related jobs can also be easily established.

(c) It highlights the work element which consumes excessive time, and this can then be subjected to a critical examination to eliminate/substitute the element.

(d) Element/s with large variation in time can be examined for necessary changes in the job design or method.

(e) It highlights the inconsistency in working conditions.

(f) Such division into elements provides a detailed method description which can be used for training new workers.

A few points may be mentioned regarding elementalisation:

1. One must separate the machine time from the worker time. At certain times the worker may appear to be working slow, but in actuality he may be waiting for a machine element to complete. Obviously, the worker cannot be performance rated low for this element.
2. While studying a job, elements of work other than the usual cycle may be encountered frequently. For instance, once in every 10 cycles the operator may clean the tool; or once in every 40 cycles the operator may have to replace the tray filled with finished work-pieces with an empty tray; or he may get the raw material once in a few cycles. These elements have got to be included in the time analysis since they are an integral part of the work. But since these elements are outside the routine cycle, they are called 'foreign' elements. There may be some genuine foreign elements such as when the worker is talking to a fellow employee or some other interruption which is not a part of the work. The Work Study analyst must note all the foreign elements as and when they occur.

3. It may also help if the analyst separates the constant elements from the variable elements.
4. Also, there is no unique method of subdividing a job into elements. Much depends upon the particular job being studied, the type of jobs encountered in the plant, and finally the judgement of the analyst. Only the precautions of distinctiveness and appropriate shortness of elements and of differentiating between constant and variable elements and man-or-machine elements needs to be observed.

For the Time Study one has to choose an 'acceptable' operator. He is one amongst many operators who are trained sufficiently in the job to be performed and are healthy and skilled or capable of performing the job at an acceptable pace day-in and day-out. He is not an abnormally fast or slow worker but one amongst the many who fall in between who might qualify for doing the job. The theme is to:

(i) eliminate the extraordinary (in either sense), and

(ii) to time study only those jobs that have received sufficient learning or training (reaching saturation in terms of 'learning) and in general all the working conditions are well established/settled.

Two Methods of Stopwatch Reading The observation and recording of the element times are done by two methods:

(a) Continuous

(b) Snap-back

In the continuous method the stopwatch is allowed to run continuously and observations on successive elements are recorded. The times for individual elements are obtained later by successive subtractions. The 'snapback' method involves measuring each element separately and snapping the watch back to zero for timing the next element (Fig. 15.3).

One of the criticisms of the snap-back method is that the analyst may forget to take into account any foreign elements. Also the direct recording of the individual elemental times may make the analyst tend towards recording more uniform readings. Moreover, the error due to observing a job and reading a watch simultaneously is not small enough to be ignored in the snap-back method. It is of the extent of 3 to 9% on an element of 0.06 minute duration and the error could be larger if the elemental time is shorter.

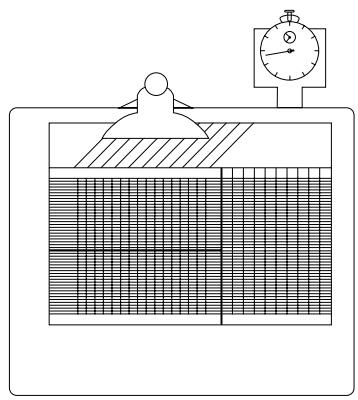


Figure 15.3 Stopwatch Time Study Equipment

Performance Rating Each of the element is performance rated. For this, the analyst's concept of what is the 'normal' pace of working is important. Although this may sound very judgemental, speed rating techniques as used in the Society for Advancement of Management (SAM) rating films and in the Lowry, Maynard and Stegemerten (LMS) system are available to adjust/improve the judgement towards more uniformity amongst various raters. The LMS system gives weights to Skill, Effort, Conditions and Consistency on a Super, Excellent, Good, Average, Poor scale. Of course, the judgmental element or mental concept of what is 'average' is always there.

Each element should be timed repeatedly a number of times before arriving at the usable figure for the elemental times. For this, generally, an arithmetical average of the readings is taken. But,

how many such readings should be taken? or, what is the adequate sample size from which to take an average? This question has been answered by statistical principles. The formula (not derived here; the reader may refer to books on statistics) for having 95 chances out of 100 that observed average will be within ± 5% of the true average for the element for the pace at which it was performed, is

$$N_{reqd} = \left(\frac{40 \cdot \sqrt{N_{taken} \sum X^2 - \left(\sum X \right)^2}}{\sum X} \right)^2$$

where N_{reqd} = Required number of readings or sample size

N_{taken} = Number of readings taken based on which data, the sample size is being determined.

X = Individual reading or elemental time

$\sum$ = Sum of

The sample size computations are done for each element and the element having highest degree of variability, will determine the sample size required for that job.

Computation of Normal Time and Standard Time

The 'normal time' for the job is the sum of the 'normal times' for all of its elements. The normal time for an element is given by:

$$\left(\begin{array}{l} \text{Arithmetical Average of} \\ \text{the Recorded Times} \end{array} \right) \times \left(\begin{array}{l} \text{Performance Rating expressed} \\ \text{in percentage with 100\% as} \\ \text{the 'accepted' performance} \end{array} \right) \div (100)$$

Thus, if an element is rated as 120% and the actual readings are (in minutes):

0.05 0.06 0.05 0.05 0.05 0.06 0.06 0.05 0.06 0.06

(arithmetical average = 0.055)

$$\text{Normal Time for the element} = \frac{0.55 \times 120}{100} = 0.066 \text{ min}$$

This is so, provided the sample size of 10 is the proper one (statistically required). We can check this.

$$N_{reqd} = \left(\frac{40\sqrt{10 \times 305 - 3025}}{55} \right)^2$$

$$= 12.2 \approx 13$$

Therefore, if we take three more readings we have the adequate sample size. Let these be 0.06, 0.06, 0.05 min.

Now, arithmetic average of the 13 readings = 0.0554 min

$$\text{Normal Time for the element} = \frac{0.0554 \times 120}{100}$$

$$= 0.06648 = 0.066 \text{ min}$$

Allowances 'Standard times' are derived from the normal times by applying appropriate 'allowances' for Personal Time, Fatigue and Unavoidable Minor Delays (outside the control of the worker).

A worker needs time to attend to personal physical needs such as drinking water, etc. which is reflected in the Personal allowances added to the Normal Time. These are generally not less than 5%.

At the end of the day a worker tends to work at a slower pace which is due to muscular as well as mental fatigue caused by noise, vibration, need for concentration, rapidly changing directions of motion, heat, etc. This allowance normally is given to the extent of 5 to 10%, but much depends upon the particular conditions of work prevailing.

During the day there are usually some interruptions in the operator's activity over which the operator has no control, for example a delay in the availability of material. Work Study analyst must analyse the extent of such time losses and add appropriate allowance to the Normal Time.

Although to some extent these allowances can be estimated by a proper and extended analysis, these need to be agreed to by the workers' unions.

INVOLVEMENT OF WORKERS' UNIONS

Workers' Unions must be involved in the entire work study activity. New methods cannot be implemented without the cooperation of the workers. Proper time study cannot be done and implemented unless the workers understand and accept the logic behind the division into elements, the performance rating, the allowances provided, etc. Every step in time study can cause doubts in the minds of workers if their confidence is not won. Even the times recorded may not be acceptable. One may say that a good industrial engineer is first a good Industrial Relations person and next a good industrial engineer.

The standard time is calculated from the normal time by the following:

$$\text{Standard Time} = \frac{\text{Normal Time}}{\left(1 - \begin{array}{l}\text{Total Allowance} \\ \text{expressed as a} \\ \text{fraction}\end{array}\right)}$$

Thus, if the total allowances (personal time, fatigue and unavoidable minor delay) are agreed upon as 16% and if the Normal Time is 0.210 minutes, then

$$\text{Standard Time} = \frac{0.210}{(1-0.16)} = 0.250 \text{ min.}$$

Illustrative Problem Continuous Stopwatch Time Study figures for a job are given below: Calculate the Standard Time for the job assuming that the sample size is adequate, and total allowances are 15%.

Element No.	*Description*	*Cycle*	*Cycle Time, min*										*Performance Rating*
			1	2	3	4	5	6	7	8	9	10	
1			0.09	0.49	0.89	1.31	1.70	2.09	2.50	2.88	3.29	3.71	90
2			0.16	0.56	0.95	1.38	1.76	2.16	2.57	2.95	3.36	3.78	110
3			0.28	0.67	1.07	1.49	1.88	2.28	2.68	3.07	3.40	3.90	120
4			0.41	0.80	1.21	1.61	2.00	2.41	2.80	3.20	3.62	4.03	100

Solution

The above are the 'continuous' Watch Study figures. The following is derived from them.

Element No.	*Cycle*	*Element Time, min* 1	2	3	4	5	6	7	8	9	10	*Arithmetic Average*	*'Normal' Time for Element, Minutes*
1		0.09	0.08	0.09	0.10	0.09	0.09	0.09	0.08	0.09	0.09	0.089	0.080
2		0.07	0.07	0.06	0.07	0.06	0.07	0.07	0.07	0.07	0.07	0.068	0.075
3		0.12	0.11	0.12	0.11	0.12	0.12	0.11	0.12	0.13	0.12	0.118	0.142
4		0.13	0.13	0.14	0.12	0.12	0.13	0.12	0.13	0.13	0.13	0.128	0.128
													Total = 0.425 min.

$$\text{Standard Time} = \frac{0.425}{(1-0.15)} = 0.500 \text{ Minutes}$$

An illustration of Time Study entered on an observation sheet is shown in Fig. 15.4.

PREDETERMINED MOTION TIME SYSTEMS (PMTS)

So far we have discussed the Stopwatch Time Study. The other way of establishing time standards is by making use of synthetic time standards for elements of motion. Many such Predetermined Motion Time Systems (PMTS) are available. Some of the important PMTS are MTM standards (Methods Time Measurement) and Work Factor. We shall limit our discussion mainly to MTM, which is used extensively in USA, Canada and other advanced countries and which is gaining some interest in Indian industries in recent times.

Methods Time Measurement (MTM)

MTM was developed by the MTM Association for Standards and Research which now has its headquarters at Ann Arbor, Michigan, and various Chapters and Cooperating National Associations in countries such as England, France, West Germany, Holland, Japan, Norway, Sweden, Switzerland, and various Industrial and Consultant members in Australia, Columbia, Argentina and South Africa. The basic principles of MTM were first put forth by Maynard, Stegemerten and Schwab. The start of MTM application may be put around the year 1948.

The basic MTM approach is to classify the human work motions into certain fixed standard categories such as reach, move, turn, apply pressure, grasp, release, position, eye motions, body-leg-and foot motions, etc. In each of these categories again there are different subclasses or cases of motion. The MTM Association has done extensive and exhaustive studies on the hand and body motions and arrived at normal times for each of these sub-classes of motions. These times or predetermined times for motions are used to synthesize a time standard for a job. A job is therefore observed or visualized to consist of a series of micro-motions from the MTM inventory of standard micro-motions, the times for each of these are looked up from the MTM tables, they are totalled and appropriate allowances added (as in Time Study by Stopwatch) and the result is the standard time for the job. The MTM table (titled MTM-1 Application Data) is reproduced in the Appendix to this chapter.

Since much of the earlier MTM research on the basic elements of motion was done by means of a movie camera with a speed of 16 frames per second, the minimum time that could be observed was 1/16 of a second or 0.0625 second, i.e. 0.00001737 hour. Most of the wage calculations in USA and Canada are done in $ per hour. Taking this also into considerations, it is understandable that

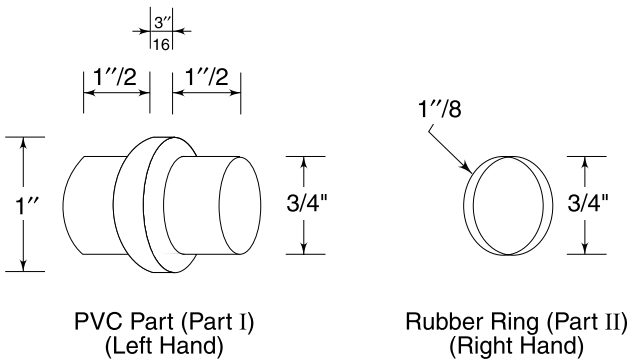


Figure 15.5 MTM Application to the Simple Fitting of Part II on Part I

the originators of MTM used the smallest or basic time measurement unit as 0.00001 hour. This basic unit is called the Time Measurement Unit (TMU).

1 TMU = 0.00001 hour = 0.0006 minute = 0.036 second

Example An example of MTM application is given below. The case is that of fitting a rubber ring (3/4 inch dia) into a plastic part cylindrical in shape. The operator has a stock of each of those parts piled on the table on his left and right hand sides. The assembly is dropped into the centre bin when it is complete. Figure 15.5 will aid the reader.

Solution

MTM Elements			*MTM Elements*		
Left Hand	*TMU*		*Right Hand*		*TMU*
RB 12	12.9		RB 12		12.9
G 4 B	9.1		G 4 B	—	9.1 + 9.1*
—	—		G2	—	5.6
MB 12	13.4	...	MB 12	—	13.4
P2SE	16.2	...	P2 SE	—	16.2 + 16.2*
—	—	...	AP2	—	10.6
RL 1	2.0	...	RL 1	—	2.0
			Total		95.1 TMU

Given that 'allowances' are 16%,

$$\text{Standard Time} = \frac{95.1}{1-0.16} = 113.2 \text{ TMU}$$

$$= 3.47 \text{ sec}$$

Merits and Demerits of MTM

The skill of the work study man lies in consistently and accurately identifying the MTM motions involved in a job. A motion may raise doubts as to whether it belongs to Move or Reach? Position or Move? Whether a Move and a Turn are done combinedly or consecutively? Whether a motion is partly Reach and partly Move or only Move? Whether the Move is of A category or B category?

* Difficult Simultaneous Motion (SIMO); therefore, both times are allowed.

etc. All such cases need a consistent approach besides being as truthful/accurate as possible.

The advantages of MTM over stopwatch time study are:

- It avoids performance rating, thereby eliminating this subjective aspect.
- It can be used for jobs that are yet in the planning stage since it can dispense with direct observation.
- It is a method which has definite breakdown of motion elements thereby enhancing the understandability or verify-ability by two or more analysts.
- It does not have effects of sample-size coming into picture, unlike the stopwatch method.
- It offers the advantage of a detailed method study and time-study combined into one.

One must also mention its disadvantages:

- It is applicable only for the hand, eye and body motions of an individual worker (not for group work or for anything other than hand-eye-body motions). Process times and/or machine times if any, may have to be established by other means.
- Although it offers advantages of clarity of comprehension for trained analysts, it may baffle the ordinary worker with too lengthy details.
- 'Allowances' for other than ordinary working conditions become very important/critical in the calculation of the standard times. The Stopwatch Time Study implicitly takes care of a major fraction of these allowances due to its direct observation technique.
- Jobs involving extremely high degree of control cannot be measured by it.
- The detailed analysis consumes much time and therefore, the economics may not favour measurement of non-repetitive work with this method.

Second Generation MTM

In order to avoid the last given disadvantage, a second generation of MTM has been developed by the Standing Committee for Applied Research of the International MTM Directorate. It is termed as MTM-2. This is derived from the first MTM (heretofore discussed and now called MTM-1) by combining weighted proportions of various MTM-1 motions, so that the number of categories and cases of motions are less and the probable personal interpretations of different analysts are less. Of course, this would mean that the accuracy would be lower, particularly for jobs with a short time cycle. Table 15.3 gives the derivation of MTM-2 from MTM-1.

The MTM-2 table is reproduced in Table 15.4.

MTM-2 usually gives good results with jobs taking more than one minute. For shorter duration jobs the deviations from MTM-1 could be considerably more than 5% and in such cases MTM-1 is more advisable.

Applying MTM-2 to the previous example (just to illustrate its use):

MTM-2 Motion	TMU
GB 12	14
R (Regrasp)	6
GB 12	14
PC 2	21 + 21 (Difficult SIMO)
A	14
GA2	3
Total	93 TMU

(Compare this against the 95.1 TMU by MTM-1)

Table 15.3 Derivation of Second Generation MTM from First Generation

MTM-2 Motion	*Code*	*MTM-1 Motions Combined to Get the Given MTM-2 Motion*
Get	G	R (Reach) G (Grasp) M (Move)
Place	P	M (Move) P (Position)
Apply Pressure	A	APA (Apply Pressure Case A) APB (Apply Pressure Case B)
Re-grasp	R	Re-grasp
Eye Action	E	Eye Travel Eye Focus
Crank	C	Crank
Step Foot Motion	S F	W (Walk) SS (Side Step) TB (Turn Body) FM (Foot Motion) LM (Leg Motion)
Bend and Arise	B	B (Bend) S (Stoop) KOK (Kneel on One Knee) KBK (Kneel on Both Knees) AKOK (Arise Kneel on One Knee) AKBK (Arise Kneel on Both Knees) AB (Arise Bend) AS (Arise Stoop)
Get Weight Place Weight	GW PW	Not from MTM-1

Table 15.4 MTM-2 (Elemental Times in TMU)*

Range	Code	GA	GB	GC	PA	PB	PC
Up to 2"	– 2	3	7	14	3	10	21
Over 2"- 6"	– 6	6	10	19	6	15	26
Over 6"-12"	–12	9	14	23	11	19	30
Over 12"-18"	–18	13	18	27	15	24	36
Over 18"	–32	17	23	32	20	30	41
	GW 1 – per 2 lb				PW 1 – per 10 lb		

A	R	E	C	S	F	B
14	6	7	15	18	9	61

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SIMULTANEOUS MOTIONS

Motion	Get				Place			
	Case	GA	GB	GC	PA	PB (O / W)		PC
Get	GA							
	GB							
	GC							
Place	PA							
	PB							
	PC							

Easy ☐ Practice ☒ Difficult ▨

(Printed with the permission of MTM Association, N.J., U.S.A.) O = Outside; W = Within normal vision

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Third Generation MTM (MTM-3)

Further to MTM-2, a third generation MTM–3 has been developed by the Swedish MTM Association around the year 1970. It consists of only four classes of elements: 'Handle', 'Transport', 'Step' and 'Bend and Arise'. The 'Handle' is a combination of Get and Place of MTM-2 and 'Transport' is a simplified Place, etc. In fact, the entire previous example can be classified as'Handle-Case B-Distance 80 cm' (allow both hands' motion) and accordingly it amounts to (48 + 48) = 96 TMU. Of course, with such broad classification of motions the accuracy in work measurement suffers but the speed is increased. When the jobs are new and of long cycle time and methods are variable, one is justified in applying such broad-and-simplified quicker methods to get a rough estimate of the time required.

Work Factor System

Another PMTS is the Work Factor system, developed by Quick, Shear and Koehler and now a proprietary system of the Work Factor Company Inc. This system, as different from MTM, classifies movements in terms of finger movements, arm movement, leg movement and trunk movement. The movements will take longer times as the difficulty factors of precision of movement, resistance due to weight, directional control or steering, changes in direction, stopping effort by the operator are included. In addition to the distance moved, the analyst has also to estimate the number of difficulty (or work) factors (1, 2, 3 or 4 as the case may be) and read corresponding time from the Work Factor tables. The time measurement unit here is 0.0001 minute. Many industrial corporations in USA have adopted this system.

Data Block from PMTS

The logical extension of PMT systems is to combine elemental movements commonly encountered in not only one plant or an organisation but also common across several industries and organisations. For example, typing a sheet of paper of running matter is common to any organisation anywhere, or changing a gasket for a given size of centrifugal pump is another example. Special Data Blocks have been developed for various such situations. Some of the special Data Systems (a number of such pertinent data blocks making a Data System) are:

(i) Master Clerical Data
(ii) Universal Maintenance Standards (UMS)—both of which are developed by H.B. Maynard & Co., USA
(iii) Standard Sewing Data—used in the garment industry
(iv) Universal Office Controls—developed by Birn Company of USA.

WORK SAMPLING

Besides Stopwatch Time Study and PMTS, Work Sampling is another useful technique for Work Study. This technique is particularly useful to estimate the proportion of delays or stoppages occurring in a plant and attributing the cause for it such as supply failures/delays, machine breakdowns, machine cleaning, manpower idling, etc.; or to give another example, estimating the proportion of time spent by an engineer on telephoning, reading, writing, attending meetings, etc. The same estimation by the Stopwatch method is extremely time-consuming and therefore not feasible; and PMTS also would not be feasible.

Besides this, the Work Sampling technique can also be satisfactorily used to set production standards like those resulting from the Stopwatch Time Study.

As the name suggests, it is a statistical sampling method. It estimates the proportion of time devoted to a given type of activity over a certain period of time by means of a large number of random 'spot' observations.

For example, a sufficiently large number of spot observations at random time intervals throughout a week of a Personal Assistant's (PA) work would give a fair estimate of the time spent by the PA on contacting people on telephone. Of course, the larger the number of observations the better (more accurate) the estimate. Therefore, what should be the adequate sample size (or number of observations)?

If the true proportion of phoning in the entire range of activities (population) is p, and if the sample size is n, then,

$$\text{Standard Deviation (SD)} = \sqrt{\frac{p(1-p)}{n}}$$

Let U denote the mean of the sampled observation. If sampling procedure is undertaken repeatedly: 95% of the values of U will fall between p ± 2 SD; 99.7% of the values of U will fall between p ± 3 SD; and 67% of the values of U will fall between p ± 1 SD. Since the U will have to represent for true p there will be an error and for 95% confidence limits this error, E = 2 SD maximum:

$$\text{i.e.} \qquad E = 2\sqrt{\frac{p(1-p)}{n}} \text{ maximum}$$

$$\text{i.e.} \qquad n = \frac{4p(1-p)}{E^2} \text{ minimum}$$

Note that the error E is expressed here as a fraction of the population.

Problem A preliminary study indicates that the proportion of idle time of a machine is 30%; rest of the time it is working. To get a good estimate of the idle time (as a fraction) with a precision of ± 1% at 95% confidence level what should be the sample size?

Solution

$$\text{Required sample size } n = \frac{4(0.30)(1-0.30)}{(0.01)^2} = 8400$$

Therefore, there should be a minimum of 8400 observations.

Based on these 8400 observations, the idle fraction of time of the machine can be calculated. Say, if 2400 observations are in the category of 'machine idling', the ratio of idle time to total time available is 2400/8400 = 0.29 approximately. If the ratio was found to be significantly different from the earlier estimated 0.30, then the sample size would need to be recalculated to check if additional number of observations are warranted.

Production Standards from Work Sampling The production standards can be established from Work Sampling as follows:

Normal Time for an activity per unit of output

$$= \frac{\text{(Total time of the Study)} \times \text{(Ratio of the number observations of the activity to total sample size)} \times \text{(Average performance rating for the activity)}}{\text{(Total Output of the activity, in measurable units, during the total time of study)}}$$

The above may be illustrated by means of a simple example.

Problem An activity sampling study was undertaken to study the cutting, sealing, finishing and packing operations involved in the money-purse section of Kartik Plastic Works. There are three workers in this section, and the data collected for the finishing operation is as under:

Employee Name	*Rama*	*Bharata*	*Laxmana*
Total hours	40	30	40
Total observations	400	360	340
No. of observations of finishing operation	80	90	85
Average Rating	110	120	80

If 4000 purses equivalent is the output, what is the standard time for the finishing operation? Assume 16% allowances.

Solution Applying the earlier given formula for this case, we have:

$$\text{Normal Time} = \frac{\left(\frac{40\times80}{400}\times\frac{110}{100}\right)+\left(\frac{30\times90}{360}\times\frac{120}{100}\right)+\left(\frac{40\times85}{340}\times\frac{80}{100}\right)}{4000}$$

$$= 0.00645 \text{ hours}$$

$$= 23.22 \text{ sec}$$

Standard Time for the finishing operation

$$= \frac{23.22}{(1-0.16)} = 27.64 \text{ sec}$$

Whether it is time study by Stop-Watch, PMTS or Work Sampling, each has its own merits and should be used in appropriate situations.

APPLICATION OF WORK STUDY TO OFFICE WORK

The principles and techniques of Work Study have been applied to office work also, although with some difficulties. The difficulties are arguably attributed to the following:

(a) Office work involves a significant portion of "mental work". This refers to the decision-making process involved and 'creative thinking' involved in problem-solving which is difficult to measure in terms of time.

(b) Office work is irregular and non-repetitive in nature, unlike the manufacture of a product in a factory. It is possible to visualise an Office Assistant or a Secretary doing a variety of jobs in a variety of permutations and combinations at different times. At one time he/she is making a decision, at another leafing through an office communication, and at yet another talking to a potential customer, etc.

In short, it is argued, and justifiably so, that office work is less amenable to accurate measurement. But much accuracy may not really be necessary and generally ball-park standards of work may be quite adequate. Moreover, not all the above arguments hold much water on closer scrutiny. For instance, in the work of a clerk, the mental work component or decision-making component may not be considerable. For this much of the irregular office work can be made more regular by proper planning and supervision. Work measurement is usually required to investigate whether a section of the office is understaffed or over-staffed and to provide guidelines for future manpower planning; for this purpose a rather broad-based and less precise work measurement would be adequate.

Work sampling has much application; this technique will take care of the irregular or random nature of the office working. Sometimes, PMTS systems such as Master Clerical Data and Universal Office Controls have also been found useful. Stopwatch Time Study *per se* may not be very useful. A system unique to office work is sometimes found useful: making the office personnel maintain *a log* of their daily work which forces them to record briefly the work done at every 15 minutes or so time interval and therefore to record the work as truthfully as possible.

Organisation and Methods (O&M)

Work Study in an office is usually given a different name, Organisation and Methods. The 'Methods' study principles are very much the same as were discussed for the manufacturing situation. Instead of studying and charting the flow of materials, the analyst may chart the flow of papers and forms and that of a complete office procedure. For this purpose, Procedure flow chart, forms flow charts, and sometimes combined forms and procedure flow chart are used. Since much of the office work involves the flow of communication, the methods study in an office in large measure amounts to designing a suitable management information system. Of course, the physical part of the office working can be compared to its counterpart in the manufacturing situation. Improving the information system involves a study and possibly redesign of the organisation and decision-making structure. For this reason, the work study in an office was given the name of organisation and methods. Many organisations in India have O&M cells. However, in most cases, the activities of the cell are confined to the simpler variety of methods improvement rather than studies on information requirements or organisational restructuring. Also, the head of the cell does not rank high in the organisational hierarchy.

Work Study forms the basis of determining job content, changing the job content if necessary, evaluating performance, devising salary and wage structures, designing incentive schemes, and the entire wage and salary administration. We shall look into some of these aspects in the ensuing chapters.

SOLVED PROBLEMS

1. A small section of a factory consists of a drilling machine and a riveting machine. Currently there is one semi-skilled operator posted who drills the metal plates, walks over to the riveting machine and gets the drilled plates riveted and then walks back to the drilling machine to start the second round. The operations are automatic and need only loading and unloading by the operator. The operator does not need to do anything during the operation of the machines.

The work elements for drilling machine can be considered to be: Load (operator loads the machine), Operation (the machine does it by itself once a button is pushed) and the unload-

ing of the machine by the operator. Each work element takes 1 minute. The operator walking over to the riveting machine also takes 1 minute. Similarly, riveting has work elements of Load (operator loads the machine with the drilled plates), Operation (the machine does it by itself once a button is pushed) and Unloading of the machine by the operator. The time required for the elements are: Load 1 minute, Operation 2 minutes and Unload 1 Minute. The operator's walking back to the drilling machine, after unloading the riveting machine, takes 1 minute.

(a) Currently what output can be expected per day of 8 working hours? What are the idle times for the machines and the operator?

(b) If separate operators are provided for the drilling and riveting machines and the drilling machine operator does the job of walking over to deliver the drilled plates to the riveting operator, what may be the improvement, if any, in the daily output? Do the idle times for the machines change? What are the idle times for each of the operators?

(c) If the walking by the drill operator is eliminated by almost instantaneous mechanised transport of the drilled parts to the riveting machine, is there improvement in the daily output? What are the idle times for each machine and each operator?

Answer

Charts depicting machine-man operations will be useful here. The work elements for the two machines and the man are shown in the following charts for each of the cases (a), (b) and (c).

Case (a)

This shows a cycle time of 7 minutes per unit of output. So, in a day of 480 minutes, one can expect an output of 68 units.

Drilling machine is idle for 4 minutes per cycle and riveting machine is idle for 3 minutes per cycle. The operator is idle only when drill machine is under 'operation', i.e. for 1 minute during the 7 minute cycle. Rest of the 6 minutes, he is loading or unloading either of the machines or walking to-and-fro between the two machines. The slanted arrow depicts the 'walk' of the operator from one machine to the other.

Case (b)

Cycle time = 5 minutes. Expected output per day = 480 / 5 = 96 units.

Idle times: Drill machine is idle for 2 minutes, while the riveting machine is idle for 1 minute out of the 5 minutes cycle.

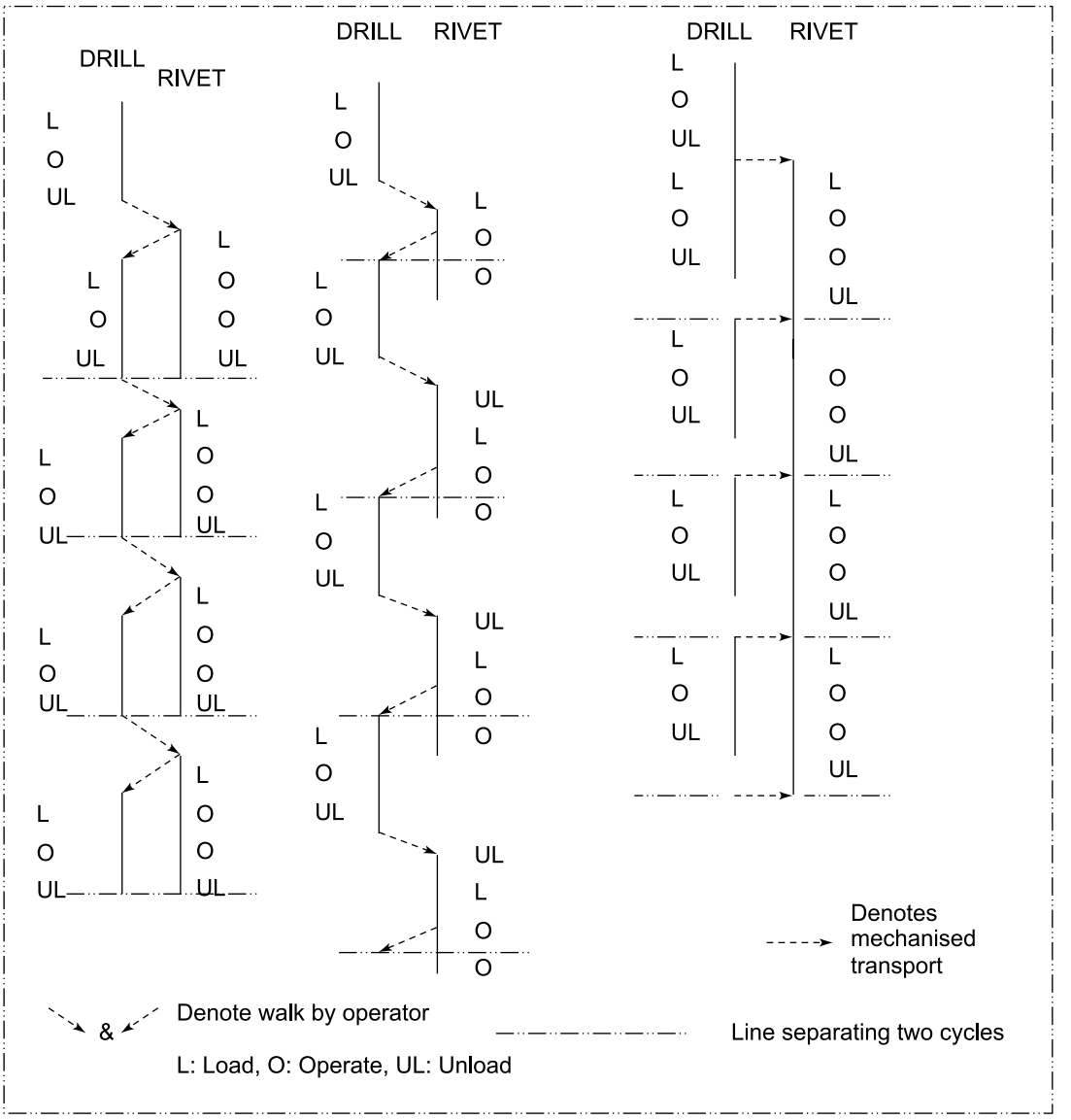
Riveting machine operator is idle between unloading and loading work elements for 1 minute in addition to the 2 minutes when the rivet machine is operating. Drill operator is idle only when the drill is in operation, i.e. for 1 minute per cycle of 5 minutes.

Case (c)

Cycle time = 4 minutes. Expected output = 480/4 = 120 units.

The drilling machine is idle for 1 minute during the cycle, but the riveting machine is always busy. Instant transport improves output and reduces the machine idle times.

The operators are idle when their respective machines are in operation. Hence, drilling machine operator is idle during the operation of the drill. He is also idle – for the duration of 1 minute – after unloading the drilling machine. Thus, he is idle for 2 minutes per cycle. The riveting machine operator is idle during its operation, i.e. for 2 minutes.



Case (b): 2 Operators
cycle of t = 5

machine idle time per cycle
drill: 2 and rivet: 1 minute

man idle time per cycle
drill: 1 and rivet: 3

Case (a): 1 Operator
cycle of t = 7

machine idle time per cycle
drill: 4 and rivet: 3 mins

man idle time per cycle
1 minute

Case (c): 2 Operators & Mechanised Transport
cycle of t = 4

machine idle time per cycle
drill: 1 and rivet: 0 mins.

man idle time per cycle
drill: 2 and rivet: 2 mins.

2. A stop-watch time study is performed on the work of a despatch assistant in the business communications cell of a hotel. The assistant's work is divided into distinct observable 'elements'. The time for each element is recorded over five cycles of observations and each of the elements is performance rated, as shown below.

Job Element	*Times recorded in different cycles (Minutes)* Cycle #					*Performance Rating*
	1	2	3	4	5	
1	2.2	2.7	1.9	2.5	2.2	110
2	4.8	4.4	5.0	4.2	4.6	90
3	7.3	7.0	6.8	7.5	7.4	110

If 10 per cent allowances are given:

(a) Compute the normal time.

(b) Compute the standard time.

(c) What is the output in a day of 8 hours (480 minutes)?

Answer

(a) Normal times for each of the job elements are as follows.

(Arithmetical average of the recorded times) × (Performance rating) / 100

For Element 1:

[(2.2 + 2.7 + 1.9 + 2.5 + 2.2) / 5][110 / 100] = 2.53 minutes

For Element 2:

[(4.8 + 4.4 + 5.0 + 4.2 + 4.6) / 5][90 / 100] = 4.14 minutes

For Element 3:

[(7.3 + 7.0 + 6.8 + 7.5 + 7.4) / 5][110 / 100] = 7.92 minutes

Total: 14.59 minutes

Normal time is, therefore, 14.59 minutes.

(b) Standard time = Normal time / (1 - Allowances expressed as a fraction)

= 14.59 / (1 – 0.1) = 16.21 minutes

(c) Output expected in 480 minutes = 480 / 16.21 = 29.61 units.

This may be approximated to 30 units per day after discussing with the employees. In the first place, it needs to be checked, if the number of cycles (5 here) is adequate for giving the desired percent confidence level. The solved problem was presented only to illustrate the concept of normal and standard times.

3. The despatch assistant in the office is sticking labels to envelopes. An MTM method is being used. While listing the elements, simultaneous motions have been considered and the resultant left hand and right hand elements of motion have been identified as given below. (That is, the reader need not specially consider simultaneous motions. It has already been done.)

Given the data, what is the normal time to stick a label to an envelope?

If an allowance of 10 per cent is to be given, what is the output expected (i.e. number of envelopes with stuck labels) per hour?

Left Hand Element	*TMU*	*Right Hand Element*	*TMU*
Reach (RB 12)	12.9	Reach (RC 18)	18.4
Grasp (1A)	2.0	Grasp (1B)	3.5
Move (MA 12)	12.9	Move (MC 18)	20.4
Position (P2SE)	16.2		
		Position (P2SD)	21.8
		Release (RL1)	2.0
		Move (MA 4) × 4	24.4 (= 6.1 × 4)
Move (MA12)	12.9		
Release	2.0		

Answer

The totals for the left and right hands are 58.9 TMU and 90.5 TMU, respectively. So, the right hand's times prevail.
Therefore, normal time = 90.5 TMU = 0.000905 hour = 3.258 seconds.
Giving allowance of 10 per cent we have:
Standard time = (0.000905) / (1 – 0.10) = 0.001005 hour = 3.62 seconds.
Therefore, expected output per hour = 1 / (0.001005) = 995 envelopes.

4. Kitchen Air Limited supplies standard packed meals to a large domestic airline. It has its meal packing operations near the airport and sample observations have been conducted on a lady packing assistant. During the 40 hours of the work study, in the week when the observations were carried out, the assistant packed 450 meal packets. The work study analyst assessed her performance rating for this packing operation at 90. The packing assistant performed two other operations – collecting supplies and taking instructions from her supervisor – but 70 per cent of the observations showed her busy in the packing operation. Allowances for work at Kitchen Air amount to 8 per cent.
What is the standard time for the packing operation?

Answer

Normal time for the packing operation =

$$\frac{\text{(Total time of the study)} \times \text{(Fraction of observations) in packing} \times \text{(Average performance rating for packing operation /100)}}{\text{(Total output of the packing operation during total time of study)}}$$

$$= \frac{(40 \text{ hr.}) \times (0.70) \times (90/100)}{(450)}$$

= 0.0560 hour per meal packet = 3.360 minutes per meal packet.

Standard time= (Normal time) / (1 – allowances expressed in fraction)

= 0.0560 hr. / (1 – 0.08)

= 0.06086 hr.

= 3.652 minutes per meal packet.

5. Dr. Rustagi, the owner of a pathology laboratory wants to know the extent of clerical work done by his lab technicians. His well considered estimate is that they do it for 40 per cent of the time. Dr. Rustagi initiates a work sampling study for this purpose.
How many observations need to be made to be 95.4 per cent confident that the results are not more than 2 per cent away from the true result?

Answer

For 95.4 per cent confidence level, we have:

$$n = 4p\,(1 - p) / E^2$$

We have $p = 0.40$ (as per Dr. Rustagi's estimate); also the error E is (+/–) 0.02 expressed as a fraction of the population. Therefore, the minimum number of observations required (n) is:

$$n = 4\,(0.40)(1 - 0.40) / (0.02)^2$$

= 2400 observations.

QUESTIONS FOR DISCUSSION

1. Explain the relationship between method study and time study.
2. Get the pen from your shirt pocket and start writing your answer to Question 1 on a sheet of paper. What are the 'therbligs' involved?
3. You are to sign a stack of copies of the same letter. What principles of motion economy might you apply?
4. Write a Left-hand–Right-hand chart for Question 3.
5. Take any simple office procedure, such as the sanctioning of a medical reimbursement claim, and write the process flow chart for the same.
6. What is the purpose of dividing a job into elements?
7. How can work study be used for arriving at (i) Manufacturing Budget, (ii) Production Plan, (iii) Personnel Policies, (iv) Materials Planning? Explain your answer.
8. You may read about value engineering described in another chapter in this book. Are there any similarities/commonalities between work study and value engineering? If so, what are they?
9. Method Study is mostly, commonsense applied systematically. What are these 'systematic' elements?
10. Good industrial engineering begins with good industrial relations. Do you agree with this statement? Explain why.
11. Can time study be applied to indirect labour such as cleaners or sweepers? Explain. Can it be applied to Supervisors?
12. A good work study should be followed by good supervision, for getting good results. Can you explain or elaborate on this statement?
13. Mention two work situations, where in one, a Stopwatch Time-Study, and in another, PMTS is useful. Can stopwatch time study be useful in the service Industry? Discussion.

14. You are sitting for breakfast at the dining table. You want to put salt and pepper on your omelette by means of salt and pepper shakers kept on the table. Write the (i) Simo chart, (ii) MTM-1 motions. Find the approximate time required for this operation if you give 10 shakes each to the shakers.

15. A managing director of a public sector corporation was delivering a speech to the young officers about improving industrial productivity: 'All these techniques such as method study, time study, etc. are for *fine* tuning.' What might be the coarser tuning required first, that the MD was referring to?

16. 'Time Study, by any method—even MTM, should not be left in the hands of a novice.' Support this statement.

17. Explain the advantage of second generation PMTS system? What are the limitations?

18. What is/are the special advantage/s of Work Sampling over the Stopwatch method? Is one more helpful is service operations while the other is more helpful in manufacturing.

19. R.S. Sharma, an industrial engineer made random 'snap' observations of the work of four clerk-cum-typists (CT, for short) in his branch office over a period of ten days. The three typists were present for all the days during this observation. Clerk-cum-typists engage in various activities, one of which is typing. Sharma's observations are given below:

Day	*No. of Observations*				*No. of Typing Observations*			
	CT-1	*CT-2*	*CT-3*	*CT-4*	*CT-1*	*CT-2*	*CT-3*	*CT-4*
1	10	10	10	10	3	2	4	1
2	15	15	15	15	8	7	3	8
3	8	8	8	8	2	4	1	4
4	18	18	18	18	5	6	9	4
5	11	11	11	11	3	4	3	3
6	9	9	9	9	4	2	3	1
7	14	14	14	14	2	5	3	6
8	13	13	13	13	3	2	5	4
9	10	10	10	10	3	5	2	4
10	9	9	9	9	4	3	3	2

Overall ratings of the CTs in the 'typing' activity, as estimated by Sharma, were 80, 90, 120, 100 respectively.

If Sharma found 306 pages of material typed during the ten days, what might be the standard time per page if the observations are assumed to be adequate and allowances are given as 15%. (*Note*: The total working time per day is $6\frac{1}{2}$ hours.)

ASSIGNMENT QUESTION

1. Take any operation that you encounter frequently and you feel is being performed less efficiently than desired by you. Study it in detail using Work Study principles and present your observations and recommendations.

APPENDIX

Methods-Time Measurement MTM-1 Application Data*

1 TMU = .00001 hour = .0006 minute = .036 seconds

1 hour = 100,000.0 TMU

1 minute = 1,666.7 TMU

1 second = 27.8 TMU

Do not attempt to use this chart or apply Methods-Time Measurement in any way unless you understand the proper application of the data. This statement is included as a word of caution to prevent difficulties resulting from misapplication of the data.

Table I Reach—R

Distance Moved Inches	*Time TMU*				*Hand in Motion*		*Case and Description*
	A	*B*	*C or D*	*E*	*A*	*B*	
$\frac{3}{4}$ or less	2.0	2.0	2.0	2.0	1.6	1.6	A Reach to object in fixed location, or to object in other hand or on which other hand rests.
1	2.5	2.5	3.6	2.4	2.3	2.3	
2	4.0	4.0	5.9	3.8	3.5	2.7	
3	5.3	5.3	7.3	5.3	4.5	3.6	B Reach to single object in location which may vary slightly from cycle to cycle.
4	6.1	6.4	8.4	6.8	4.9	4.3	
5	6.5	7.8	9.4	7.4	5.3	5.0	
6	7.0	8.6	10.1	8.0	5.7	5.7	
7	7.4	9.3	10.8	8.7	6.1	6.5	C Reach to object jumbled with other objects in a group so that search and select occur.
8	7.9	10.1	11.5	9.3	6.5	7.2	
9	8.3	10.8	12.2	9.9	6.9	7.9	
10	8.7	11.5	12.9	10.5	7.3	8.6	
12	9.6	12.9	14.2	11.8	8.1	10.1	
14	10.5	14.4	15.6	13.0	8.9	11.5	D Reach to a very small object or where accurate grasp is required.
16	11.4	15.8	17.0	14.2	9.7	12.9	
18	12.3	17.2	18.4	15.5	10.5	14.4	
20	13.1	18.6	19.8	16.7	11.3	15.8	
22	14.0	20.1	21.2	18.0	12.1	17.3	E Reach to indefinite location to get hand in position for body balance or next motion or out of way.
24	14.9	21.5	22.5	19.2	12.9	18.8	
26	15.8	22.9	23.9	20.4	13.7	20.2	
28	16.7	24.4	25.3	21.7	14.5	21.7	
30	17.5	25.8	26.7	22.9	15.3	23.2	
Additional	0.4	0.7	0.7	0.6			TMU per inch over 30 inches

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Table II Move—M

Distance Moved Inches	*Time TMU*				*Wt. Allowance*			*Case and Description*
	A	*B*	*C*	*Hand in Motion B*	*Wt. (lb.) up to*	*Dynamic Factor*	*Static Constant TMU*	
$\frac{3}{4}$ or less	2.0	2.0	2.0	1.7				
1	2.5	2.9	3.4	2.3	2.5	1.00	0	
2	3.6	4.6	5.2	2.9				A Move object to other hand or against stop.
3	4.9	5.7	6.7	3.6	7.5	1.06	2.2	
4	6.1	6.9	8.0	4.3				
5	7.3	8.0	9.2	5.0	12.5	1.11	3.9	
6	8.1	8.9	10.3	5.7				
7	8.9	9.7	11.1	6.5	17.5	1.17	5.6	
8	9.7	10.6	11.8	7.2				B Move object to approximate or indefinite location.
9	10.5	11.5	12.7	7.9	22.5	1.22	7.4	
10	11.3	12.2	13.5	8.6				
12	12.9	13.4	15.2	10.0	27.5	1.28	9.1	
14	14.4	14.6	16.9	11.4				
16	16.0	15.8	18.7	12.8	32.5	1.33	10.8	
18	17.6	17.0	20.4	14.2				
20	19.2	18.2	22.1	15.6	37.5	1.39	12.5	
22	20.8	19.4	23.8	17.0				C Move object to exact location.
24	22.4	20.6	25.5	18.4	42.5	1.44	14.3	
26	24.0	21.8	27.3	19.8				
28	25.5	23.1	29.0	21.2	47.5	1.50	16.0	
30	27.1	24.3	30.7	22.7				
Additional	0.8	0.6	0.85		TMU per inch over 30 inches			

Table III A Turn—T

Weight	*Time TMU for Degrees Turned*										
	30°	*45°*	*60°*	*75°*	*90°*	*105°*	*120°*	*135°*	*150°*	*165°*	*180°*
Small–0 to 2 Pounds	2.8	3.5	4.1	4.8	5.4	6.1	6.8	7.4	8.1	8.7	9.4
Medium–2.1 to 10 Pounds	4.4	5.5	6.5	7.5	8.5	9.6	10.6	11.6	12.7	13.7	14.8
Large–10.1 to 35 Pounds	8.4	10.5	12.3	14.4	16.2	18.3	20.4	22.2	24.3	26.1	28.2

Table III B Apply Pressure—AP

Full-Cycle			*Components*		
Symbol	*TMU*	*Description*	*Symbol*	*TMU*	*Description*
APA	10.6	AF + DM + RLF	AF	3.4	Apply force
			DM	4.2	Dwell, Minimum
APB	16.2	APA + G2	RLF	3.0	Release force

Table IV Grasp—G

Type of Grasp	*Case*	*Time TMU*	*Description*	
	1A	2.0	Any size object by itself, easily grasped.	
	1B	3.5	Object very small or lying close against a flat surface.	
Pick-up	1C1	7.3	Diameter larger than 1/2″	Interference with Grasp on bottom and one side of nearly cylindrical object.
	1C2	8.7	Diameter 1/4″ to 1/2″	
	1C3	10.8	Diameter less than1/4″	
Regrasp	2	5.6	Change grasp without relinquishing control.	
Transfer	3	5.6	Control transferred from one hand to the other.	
Select	4A	7.3	Larger than 1″ × 1″ × 1″	Object jumbled with other objects so that search and select occur.
	4B	9.1	1/4″ × 1/4″ × 1/8″ to 1″ × 1″ × 1″	
	4C	12.9	Smaller than 1/4″ × 1/4″ × 1/8″	
Contact	5	0	Contact, Sliding or Hook Grasp	

Effective Net Weight

	No. of Hands	*Spatial*	*Sliding*
Effective Net Weight (ENW)	1	W	$W \times F_c$
	2	W/2	$W/2 \times F_c$
W = Weight in Pounds F_C = Coefficient of Friction			

Table V Position*—P

Class of Fit		*Symmetry*	*Easy to Handle*	*Difficult to Handle*
1-Loose	No pressure required	S	5.6	11.2
		SS	9.1	14.7
		NS	10.4	16.0
2-Close	Light pressure required	S	16.2	21.8
		SS	19.7	25.3
		NS	21.0	26.6
3-Exact	Heavy pressure required	S	43.0	48.6
		SS	46.5	52.1
		NS	47.8	53.4
SUPPLEMENTARY RULE FOR SURFACE ALIGNMENT				
P1SE per alignment: > 1/16 ≤ 1/4″			P2SE per alignment: ≤ 1/16″	

*Distance moved to engage 1″ or less.

Table VI Release—RL

Case	*Time TMU*	*Description*
1	2.0	Normal release performed by opening fingers as independent motion.
2	0	Contact release.

Table VII Disengage—D

Class of Fit	*Height of Recoil*	*Easy to Handle*	*Difficult to Handle*
1–Loose–Very slight effort, blends with subsequent move.	Up to 1″	4.0	5.7
2–Close–Normal effort, slight recoil.	Over 1″ to 5″	7.5	11.8
3–Tight–Considerable effort, hand recoils markedly.	Over 5″ to 12″	22.9	34.7

SUPPLEMENTARY

Class of Fit	*Care in Handling*	*Binding*
1–Loose	Allow Class 2	_____
2–Close	Allow Class 3	One G2 per Bind
3–Tight	Change Method	One APB per Bind

Table VIII Eye Travel and Eye Focus—ET and EF

Eye Travel Time $= 15.2 \times \frac{T}{D}$ TMU, with a maximum value of 20 TMU

where T = the distance between points from and to which the eye travels,

D = the perpendicular distance from the eye to the line of travel T.

Eye Focus Time = 7.3 TMU.

SUPPLEMENTARY INFORMATION

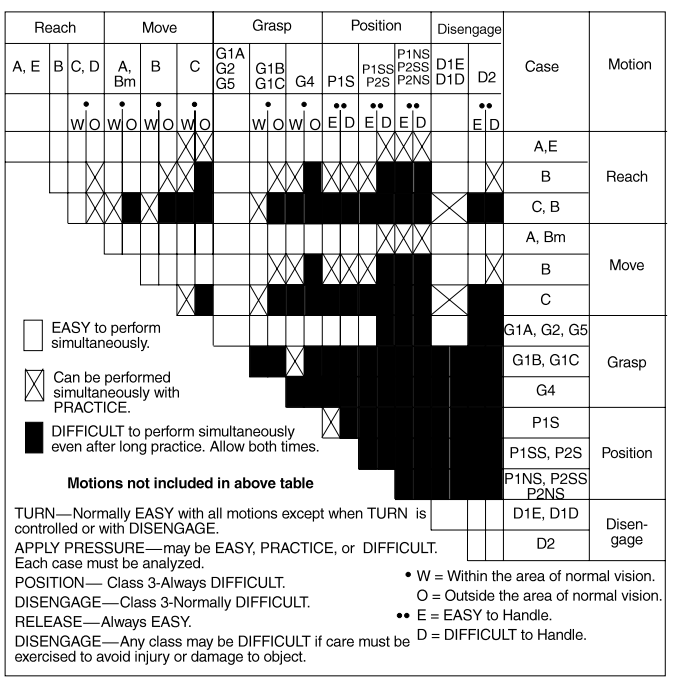
—Area of Normal Vision = Circle 4″ in Diameter 16″ from Eyes

—Reading Formula = 5.05N where N = The Number of Words

Table IX Body, Leg and Foot Motion

	Type	Symbol	TMU	Distance	Description
	Leg-Foot Motion	FM	8.5	To 4″	Hinged at ankle.
		FMP	19.1	To 4″	With heavy pressure.
		LM–	7.1	To 6″	Hinged at knee or hip in any direction.
			1.2	Ea. addn'l inch	
Horizontal Motion	Side Step		*	< 12″	Use Reach or Move time when less than 12″. Complete when leading leg contacts floor.
		SS–C1	17.0	12″	
			0.6	Ea. addn'l inch	
		SS–C2	34.1	12″	Lagging leg must contact floor before next motion can be made.
			1.1	Ea. addn'l inch	
	Turn Body	TBC1	18.6	–	Complete when leading leg contacts floor.
		TBC2	37.2	–	Lagging leg must contact floor before next motion can be made.
	Walk	W–FT	5.3	Per Foot	Unobstructed.
		W–P	15.0	Per Pace	Unobstructed.
		W–PO	17.0	Per Pace	When obstructed or with weight.
	Vertical Motion	SIT	34.7	–	From standing position.
		STD	43.4	–	From sitting position.
		B,S, KOK	29.0	–	Bend, Stoop, Kneel on One Knee.
		AB, AS, AKOK	31.9	–	Arise from Bend, Stoop, Kneel on One Knee.
		KBK	69.4	–	Kneel on Both Knees.
		AKBK	76.7	–	Arise from Kneel on Both Knees.

Table X Simultaneous Motions



SUPPLEMENTARY MTM DATA

Table 1 Position—P

Class of Fit and Clearance	*Case of* † *Symmetry*	*Align Only*	*Depth of Insertion (per 1/4″)*			
			0	2	4	6
			> 0 ≤ 1/8″	> 1/8≤ $\frac{3}{4}$	> $\frac{3}{4}$ ≤ 1 $\frac{1}{4}$	> 1 $\frac{1}{4}$ ≤ 1 $\frac{3}{4}$
21	S	3.0	3.4	6.6	7.7	8.8
.150≤–.350″	SS	3.0	10.3	13.5	14.6	15.7
	NS	4.8	15.5	18.7	19.8	20.9
22	S	7.2	7.2	11.9	13.0	14.2
.025″–.149″	SS	8.0	14.9	19.6	20.7	21.9
	NS	9.5	20.2	24.9	26.0	27.2
23*	S	9.5	9.5	16.3	18.7	21.0
.005″–.024″	SS	10.4	17.3	24.1	26.5	28.8
	NS	12.2	22.9	29.7	32.1	34.4

* BINDING–Add observed number of Apply Pressures.
DIFFICULT HANDLING–Add observed number of G2's.

† Determine symmetry by geometric properties, except use S case when object is oriented prior to preceding Move.

Table 1A Secondary Engage—E2

Class of Fit	*Depth of Insertion (Per 1/4″)*		
	2	4	6
21	3.2	4.3	5.4
22	4.7	5.8	7.0
23	6.8	9.2	11.5

Table 2 Crank (Light Resistance)—C

Diameter of Cranking (Inches)	*TMU (T) Per Revolution*	*Diameter of Cranking (Inches)*	*TMU (T) Per Revolution*
1	8.5	9	14.0
2	9.7	10	14.4
3	10.6	11	14.7
4	11.4	12	15.0
5	12.1	14	15.5
6	12.7	16	16.0
7	13.2	18	16.4
8	13.6	20	16.7

FORMULAE:

A. CONTINUOUS CRANKING (Start at beginning and stop at end of cycle only)

$$TMU = [(N \times T) + 5.2] \cdot F + C$$

B. INTERMITTENT CRANKING (Start at beginning and stop at end of each revolution

$$TMU = [(T + 5.2)\ F + C] \cdot N$$

C = Static component TMU weight allowance constant from move table

F = Dynamic component weight allowance factor from move table

N = Number of revolutions

T = TMU per revolution (Type III Motion)

5.2 = TMU for start and stop

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Date 31.1.85
Study No. 10
Sheet No. 1

Number		1		2		3		4		5		6		7		8		9		10	
Notes	Line																				
	1	0.11	0.11	0.10	0.21	0.07	0.28	0.16	0.44	0.05	0.49										
	2	0.10	0.59	0.10	0.69	0.08	0.77	0.15	0.92	0.06	0.98										
	3	0.11	1.09	0.12	1.21	0.08	1.29	0.14	1.43	0.07	1.50										
	4	0.12	1.62	0.11	1.73	0.06	1.79	0.16	1.95	0.07	2.02										
	5	0.11	A 2.43	0.12	2.55	0.08	2.63	0.14	B 2.93	0.06	2.99										
	6	0.11	3.10	0.10	3.20	0.07	3.27	0.16	3.43	0.07	3.50										
	7	0.12	3.62	0.10	3.72	0.07	3.79	0.13	3.92	0.05	3.97										
	8	0.10	C 4.28	0.11	4.39	⌒	M	0.14	0.14	0.06	0.20										
	9	0.11	D 0.54	0.12	0.66	0.07	0.73	0.16	0.89	0.07	0.96										
	10	0.11	1.07	0.10	E 1.27	0.06	1.33	0.16	1.49	0.05	1.54										

Summary

Totals "T"	*1.12*	*1.08*	*0.64*	*1.50*	*0.61*
No. of Observations	*10*	*10*	*9*	*10*	*10*
Avg. "T"	*0.112*	*0.108*	*0.071*	*0.150*	*0.061*
Min. "T"	*0.10*	*0.10*	*0.06*	*0.13*	*0.05*
Max. "T"	*0.12*	*0.12*	*0.08*	*0.16*	*0.07*
Rating		*C1,*	*B2,*	*C,*	*D* Overall
Levelling factor (L.F.)	*1.16*				
L.F. × Avg. "T"	*0.130*	*0.125*	*0.082*	*0.174*	*0.071*
% Allowances	*20 %*				
Time allowed	*0.162*	*0.156*	*0.103*	*0.217*	*0.088*

Elements: Pull tape from roll: go upto end of table: stick end of tape to roller; Return to roll of tape, cut tape; Get 3" dia card board core, fix it on fixture, affix cut tape on core.; Rotate handle and roll tape on core; Remove wound tape from fixture, put in collecting box

Foreign elements: 0.08

SYM	R	T	Description
A	*2.32 / 2.02*	0.30	Talk to a colleague
B	*2.79 / 2.63*	0.16	*Tighten the nut of the rotation handle*
C	*4.18 / 3.97*	*0.21*	Replace roll with a fresh one
D	*0.43 / 0.20*	*0.23*	Replace filled box with an empty one
E	*1.17 / 1.07*	*0.10*	Talk to the cleaner boy
F			

	Skill			Effort	
	A1	Superior		A1	Excessive
	A2			A2	
	B1	Excellent		B1	Excellent
	B2		✓	B2	
✓	C1	Good		C1	Good
	C2			C2	
	D	Average		D	Average
	E1	Fair		E1	Fair
	E2			E2	
	F1	Poor		F1	Poor
	F2			F2	

	Conditions		Consistency	
	A	Ideal	A	Perfect
	B	Excellent	B	Excellent
✓	C	Good	C	Good
	D	Average	✓ D	Average
	E	Fair	E	Fair
	F	Poor	F	Poor

General rating for the study	Skill	Eff.	Cond.	Consist
	+ 0.06	+ 0.08	+ 0.02	0.00

Study started	Study completed	Overall time
10 : 08 AM	10 : 15 AM	7 min.

(Contd.)

Figure 15.4 Observations Sheet

Study N. 10 Date 31.1.85
Operation: 99

Description of piece: 2.5 cm. width waterproof insulation tape. 5 M long
Code N. 59771

Dept: ADH, Finishing

Worker NAME C. SUMA No. 252

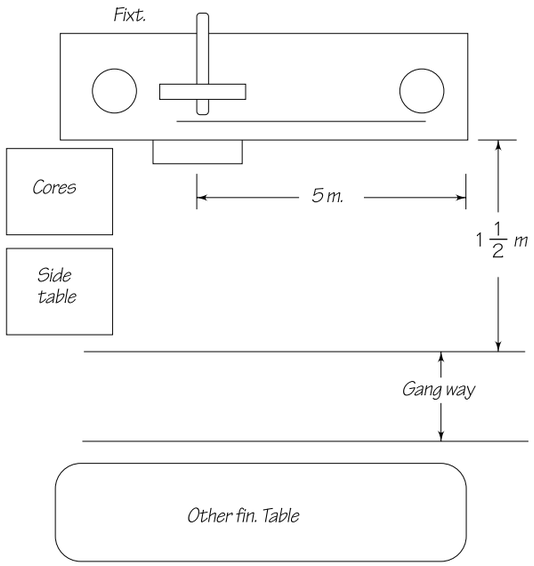
Equipment used

Finishing table, cutting fixture (No 1), tape winder, side table

Working Conditions

Name of Analyst: Sathya Muni

ROUGH DIAGRAM OF WORK-PLACE LAYOUT:



ELEMENT NO.	Elements description	Elemental time allowed (from reverse side of form)	Occurrence per piece or per cycle	Elemental time allowed
1.	Pull tape from roll (Code No. 03884). Go upto end of table, stick			
	end of tape to roller at 5 M.	0.162	1	0.162
2.	Return to roll (03884), Cut tape on cutting fixture (No. 1)	0.156	1	0.156
3.	Get 7.6 cm dia card board core from Box, fix it on the tape winder, affix cut tape - end on			
	core	0.103	1	0.103
4.	Rotate handle of tape winder and roll tape on core	0.217	1	0.217
5.	Remove wound tape from winder, and put in the			
	collecting box	0.088	1	0.088
C.	Replace Roll (No. 03884) with a fresh one	0.210	20	0.011
D.	Remove the filled box, keep on the side table, replace			
	with empty box	0.230	50	0.005
	Time allowed in for each piece:		Total:	0.742

Remarks:

(1) Foreign element `B' observed very rarely. But, check with maintenance secn.

(2) Check with methods secn. about Improvement in element No. 1.

16 Job Evaluation

While Work Study discussed in Chapter 15 is concerned with finding better methods of doing jobs and setting the time standards for job outputs, Job Evaluation concerns itself with bringing internal equity between the job content and the pay.

Work Study and in particular time study stipulates the expectations of work output with respect to time; Job evaluation attempts to equitably relate the demands made by a job in its 'normal' performance (not the work output) and the position of the job in the hierarchical pay structure of the organization. Sometimes in addition to internal equity, market equity (external market pay rates) considerations have also to be brought in. In some other cases, for example in managerial jobs, the relative ranking of the jobs may be as important as the pay. Thus, in general, Job Evaluation is a disciplined attempt at establishing a justifiable 'ranking order' of the various jobs in an organization.

WHAT IS JOB EVALUATION AND WHAT IT IS NOT

1. Job evaluation is concerned with job contents or demands of the job and not the 'value' of the job to the organisation.
2. Job evaluation rates the job and not the man.
3. Job evaluation, despite any quantification, is a disciplined judgement about the hierarchical positioning of jobs.

NEED FOR JOB EVALUATION

The need for job evaluation arises due to the changes that consciously or unnoticeably take place in the job contents over a period of time due to a number of reasons including changes in technology, methods, procedures, systems and structure of the organisation. With the recent rate of advances in technology, such as automation and computerisation in various industrial and non-industrial operations, the conditions for work and the nature of work in many jobs may vary significantly in the future necessitating a job evaluation exercise. Moreover, the expectations of the people change and various economic, social and cultural factors (and values) change over the years. The concepts of 'job difficulties', 'equitable pay' and 'equitable rank' may, therefore, change significantly.

BASIC SYSTEMS

Job evaluation can be basically of two types:

1. Comparing a whole job against other jobs; and
2. Comparing compensable elements of the jobs to a predetermined yardstick.

Under the category of comparing a whole job, there are two basic methods:

(a) Ranking System
(b) Grading or Classification System

In the category of comparing compensable elements there are two important systems:

(c) Points System
(d) Factor Comparison System

We shall cover these four systems in some detail. Before that a point needs to be made: The basic input to job evaluation is a good *analysis* of the various jobs and job descriptions derived therefrom. Therefore, before we start the job evaluation procedure, it is essential to understand all the relevant factors, working conditions, and other nuances of the jobs which are to be evaluated. Comprehensive, truthful and acceptable *job descriptions* is the foundation for a job evaluation procedure.

Ranking System

The method under this system is as follows:

1. Given the job descriptions, decide which job will have the highest rank, which will have the lowest rank and which job will fall around the middle level. Since two extremes and one middle level job are to be identified, this should not be difficult. (Figure 16.1 calls the jobs A, B and C.)
2. Next pick up any other job description and check whether it falls in the range AC or CB. Accordingly, its position is noted. (Refer to Fig. 16.2 for the position of job D.)
3. Pick up one more job description E (Fig.16.3) and compare it with the earlier placed jobs to find out whether it falls in the Zone AD, DC or CB and note accordingly.
4. The procedure is continued till all jobs in the list are exhausted (*Note*: Each time the number of reference points gets larger.)
5. Review the rankings, to iron out any wrinkles in the system.

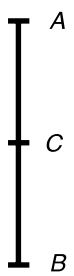


Figure 16.1

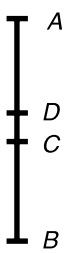


Figure 16.2

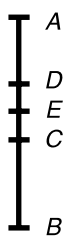


Figure 16.3

Paired Comparison A simpler method of ranking is Paired Comparison. Compare a pair of jobs at a time and decide which one is the higher rank job (denoted H) and which one is the lower (denoted L). This pairing is done randomly, and the comparison (within a pair) is continued till one exhausts all the possible job pairs. The number of times a job has received H determines its rank in the top-to-down order.

For instance, if A, B, C, D, E, F, G were the jobs in the list, the pairs and the 'higher' job in a pair are shown in Table 16.1.

Table 16.1 Paired Comparison

Pair	*Higher Job in the Pair*	*Pair*	*Higher Job in the Pair*
AB	A	CE	E
AC	C	CF	C
AD	D	CG	C
AE	E	DE	D
AF	A	DF	D
AG	A	DG	D
BC	C	EF	F
BD	D	FG	E
BE	E	FG	G
BF	F		
BG	G		
CD	D		

Thus, the number of Hs received by each job are: D:6, E:5, C:4, A:3, G:2, F:1, B:0. The jobs are ranked accordingly.

Drawbacks of the Ranking System It should be noted that the pairs, while doing the ranking exercise, should be drawn at random. This minimises the bias which might creep in if the jobs are sequenced as given in Table 16.1.

The ranking system is no doubt quite simple and this is one of its advantages. It is easily understandable by the workers and the costs of this system are low. Some of the drawbacks of the system are:

1. The rank order does not spell out how close or how far apart each job is in terms of its evaluation. One cannot construct a graduated evaluation scale from this system. For instance, in Fig. 16.4 on a quantitative scale job X is very close to job Y and far removed from job Z. But the ranking method would only place job X as lower than Y but higher than Z. This may, perhaps, lead to anomalies in relating pay with the hierarchical position.*

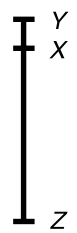


Figure 16.4

* Really speaking, even the so called 'quantitative' job evaluation methods are significantly judgemental in nature. Perhaps, they involve more *refined judgement*.

2. Since a whole job is compared with another whole job, when the number of jobs to be evaluated is very large, questions may arise regarding the evaluators' familiarity with all the jobs and hence about the ranking itself.

It may be noted that even though a whole job is compared with another, the comparison in the evaluator's mind would necessarily be in terms of certain criteria which may not have been explicitly spelt out. But, at least these criteria need to be implicitly decided upon or thought out in order to bring in some measure of consistency (between different evaluators) and a measure of objectivity to the ranking done.

As the objective standards for comparison are lacking in this system, it may be worth-while to repeat the ranking exercise several weeks or months later as a check-up on the earlier exercise and in order to iron out any deviation. Another way of bringing such safeguards into the ranking system would be to get two or three different evaluators to do the ranking independently and then iron out any deviations. A team-approach to ranking is generally preferred.

Grading or Classification System

In this evaluation procedure, the jobs are sorted out as belonging to one of several grades (such as Grade-I, Grade-II, Grade-III. etc.). The number of such grades and the characteristics distinguishing one grade from the other will have been earlier determined.

Procedure for Grading System The procedure, in short, is as follows:

1. Decide on the jobs which are to be evaluated by this system, e.g. Will it cover only managerial jobs or non-managerial jobs or both? (Since the grades directly relate to the pay scale, this first step is very necessary for the system.)
2. Similarly, since the number of grades determine the number of pay scales, it would be necessary to decide on the approximate number of grades.
3. In order to help sorting of the jobs into different grades, every grade should be accompanied by a brief description of the distinguishing job characteristics; this description is a general one, without referring to any particular job, and applies to all the relevant jobs. This description should be **(i)** comprehensive enough to cover all relevant (i.e. same grade) jobs and at the same time be **(ii)** distinctly different from one grade to another. Key phrases describing the unique characteristics of the grades are generally included in the grade, description, supplemented with brief examples to elaborate the same. Sometimes, one or two key jobs are mentioned as belonging to a particular grade; this is meant to illustrate the particular grade description.
4. The job descriptions are now studied and sorted out into various grades according to the match between the job descriptions and the grade descriptions.

Limitations of the Grading System This method is quite simple, deceptively so, for several reasons.

- It is not very easy to come up with grade descriptions which distinguish one grade from another and at the same time find commonalities between a number of jobs belonging to a particular grade. This difficulty increases as the number of jobs increases.
- Also, it is not easy to interpret the grade descriptions and sort out the jobs, particularly for new jobs which have to be fitted into the given grading system.

- One of the major drawbacks of this system is that the grade description and the key phrases used therein determine the grade and therfore the pay. Therefore, the grading system of job evaluation may be misused by manipulating either the grade description or the job description through the introduction of 'suitable' key phrases.

In spite of the above drawbacks, this system at least makes a conscious attempt at bringing in some objectivity through the 'distinguishing characteristics' separating one grade from another. The grading system is quite popular with government departments (in India and abroad) and public sector corporations.

Points System

This method falls in the category of 'comparing compensable elements', as mentioned earlier.

Procedure for the Points System

1. Select the relevant 'factors', i.e. comparable compensable elemets, against which the set of jobs are to be evaluated.
2. Define the weightage points for each 'factor' in the overall evaluation process.
3. Within these weightage points for a factor, design a calibrated scale for different 'degrees' (levels) of requirement of that factor. Thus, depending upon the weightage of a factor and the relevant degree, the corresponding 'point' values may be established.
4. Check each job against a factor to determine the required 'degree'; note down the 'points'. For each job, add all 'points' corresponding to all factors to get a 'total points value for the job'.
5. The span of 'total points' values, obtained by the entire set of jobs, in now divided into suitable 'ranges' of point values so that each range corresponds to a grade.

Example Let the 'factors' and their weightages be as given below:

Factor	*Weightage Points*
Mental Requirement	100
Skills Requirement	100
Physical Effort Required	50
Responsibilities	50

Let the 'degrees' within a factor be, very high, high, moderate, low and very low. The factors with the degrees are depicted in Fig. 16.5.

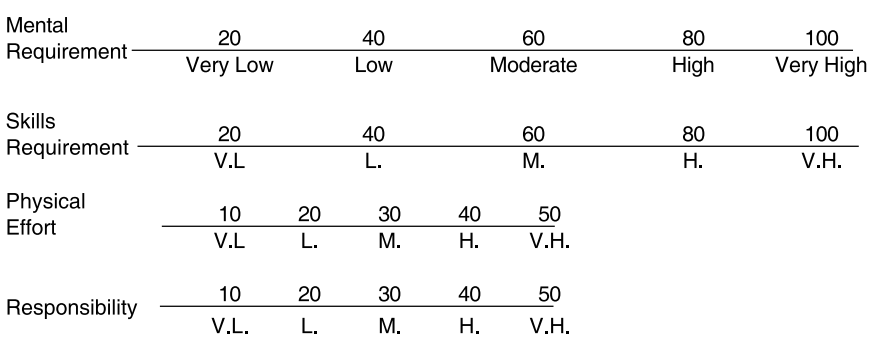


Figure 16.5 An Example of Factors with Degrees and Corresponding Point Values

Based on Fig. 16.5, the jobs are evaluated as shown in Table 16.2.

Table 16.2 Points Evaluations for a Set of Jobs

Job	*Mental Reqt.*	*Skills Reqt.*	*Phys. Eff. Reqt.*	*Responsibility*	*Total Points*
Machinist	100	80	20	50	250
Lab. Attender	60	40	10	30	140
Press machine operator	20	60	20	20	120
Fitter	80	80	40	40	240
Janitor	20	20	50	10	100
Packer	40	20	40	30	130
Wireman	80	40	30	40	190
Oiler	40	20	10	30	100
Stores person	80	40	30	50	200
Assembler	80	80	30	40	230
Materials handler	60	40	40	30	170

For the above hypothetical example, the total points vary from 100 to 250. This range may be divided into four grades:

Grade-I 100–139 points
Grade-II 140–179 points
Grade-III 180–219 points
Grade-IV 220–259 points

Points System and Wage Administration

This completes the job evaluation process. Fixing wages or salaries is an altogether different matter. However, since in many cases, job evaluation leads to the fixing of wage scales, we shall proceed with our example further.

The wages expressed as a median daily rate can be plotted on the y-axis and the total 'points' on the x-axis. This is done for all the jobs. (Refer to Fig. 16.6.) (Alternatively, the wage rates of all the workers could be plotted on the graph.) A straight line or a second degree curve of best fit is passed through the set of points. This is called the wage line or wage curve. Since a good wage policy should seek not only internal equity but also be compatible with the market rates of pay, the latter may also be included in the analysis.

The wage line is important when evolving a suitable new wage policy. Figure 16.6 shows four pay-scales, each pay-scale being 25% wider than the previous one, but at the same time showing an overlap of the scales of about 50%. The points-ranges are the same as mentioned earlier.

It may be noted that:

- The points-ranges need not necessarily be equal. Some judge that the jobs can be stratified more easily at lower point-values where job difficulties are less than for higher point-values. So, the point-classes could be narrower at lower values and broader at higher values.
- Similarly, the pay-scale (wage rate) spreads need not always be equal.

- Even the per cent increase in the successive pay-ranges need not be constant.
- Also, one may or may not have overlapping pay-scales. It all depends upon the nature of the wage-line obtained and other factors influencing the wage policy. Of course, one justification that could be given for the overlapping wages is that this takes care of the seniority, so that, those with long service records have higher wages, falling partly into the next grade.

While designing the pay-scales as many points as possible are fitted into the pay-scale and points-range 'boxes'. Those points that fall below or above are cases of jobs which are under-paid or over-paid. While the under-paid ones need to be elevated in their pay-scales, the over-paid ones cannot be given a cut in their pay. One has to either tolerate this anomaly or try to gradually shift such workers into jobs requiring higher level of skills.

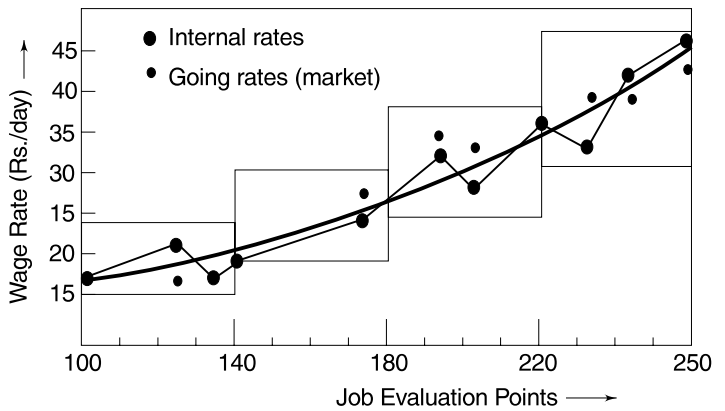


Figure 16.6 Wage Curve and Derived Proposed Wage Ranges

Conditions for Good Evaluation As seen earlier, the Point System depends upon (i) the factors used, (ii) the weightages given and (iii) the degrees defined. The job evaluation exercise, by the point system, can be more reliable and truthful if:

(a) the factors are so chosen that they are common to all the jobs and yet bring out the differences between one job and the other. There should not be any overlaps between the factors; each factor should be distinct from the other. Moreover, the analysis should not omit any relevant factors, i.e. the factors should be comprehensive.
(b) Weightages for factors are a disciplined, group-judgement.
(c) The degrees or levels within the factors are defined clearly.

Factor Comparison System

This method combines the features of the ranking system and points system. The steps involved are as follows:

1. The 'factors' are selected and defined as in the points system but, there are no degrees.
2. Few 'key' jobs (or Benchmark Jobs) are selected and ranked under each factor. A 'key' job is one which has no dispute regarding the wage rates. Generally, 10–15 key jobs will suffice.

3. The average wage rate of each key job is now converted into points, by multiplying the wage rate by an arbitrary number (in order to mask the wage rate).
4. For a key job, the points so obtained are allocated under each factor according to its importance for the job. Do this for all the jobs. While doing this do not bother about the 'ranks' given in step (2).
5. Based on the allocated points, derive new rankings for the jobs under each factor. Compare the new ranks with the original ranks. Wherever they do not tally, remove those jobs from the list of key-jobs.
6. Repeat this process till there is no disagreement between the original and new rankings.
7. Use the key jobs positioned under each factor for comparing and positioning the remaining jobs under each factor. The total points for a job can be easily arrived at by adding the point values for the job under each factor. The points can be reconverted to the pay-rate, or used to determine the overall hierarchy of jobs.

Example Let A, B, C, D, E, F and G be the key jobs selected as shown in Table 16.3. If the average wage rates for them are Rs. 10, 14, 16, 11, 20, 13 and 16 respectively, we convert these into point values by multiplying by an arbitrary number, say 23.

$$\begin{aligned} A &= 10 \times 23 = 230 \text{ points} \\ B &= 14 \times 23 = 322 \text{ points} \\ C &= 16 \times 23 = 368 \text{ points} \\ D &= 11 \times 23 = 253 \text{ points} \\ E &= 20 \times 23 = 460 \text{ points} \\ F &= 13 \times 23 = 299 \text{ points} \\ G &= 16 \times 23 = 368 \text{ points} \end{aligned}$$

The ranking of the jobs is done under each factor. This is the original ranking.

Next, for a job the point values are distributed under each factor. For Key Job A, our distribution would be 60, 85, 25, 40 and 20 points under mental requirement, skills, working conditions, responsibility and physical effort factors, respectively. This is our assessment of the relative importance of each factor for Job A. We do this for all the key jobs. Based on the points noted for each key job under a factor, compute the new rankings under that factor. This is followed for all factors. Tables 16.3 and 16.4 depict the entire procedure.

The same could be expressed in the form of a calibrated scale for each factor, as depicted in Fig. 16.7.

In actual practice, depending upon the total number of jobs being evaluated, a few more supplementary jobs may be added to the key jobs so that the scales under each factor are clear and spread out.

The other jobs can then be positioned in the scale under each factor by comparing with the key jobs.

It may be mentioned that the key jobs, in addition to being non-disputable, should preferably cover as wide a range of points as possible under each factor. They should include in themselves a wide range of existing pay-scales including the highest and lowest paid jobs.

Merits and Demerits of Factor Comparison System One of the advantages of the Factor Comparison system is that the evaluation is based on benchmark or key jobs about which there is no dispute. Everything is in comparison to these key jobs which constitute the steps of the rating scales. Moreover, because of the very same fact, the rating scales are tailor-made so to say, for an organisation.

Table 16.3 Original and Points Ranks for Initially Selected Key Jobs

	Mental Requirement			*Skill*			*Working Conditions*			*Responsibility*			*Physical Effort*			*Total Points*
	Original Rank (O.R.)	*Points*	*Points Rank (P.R.)*	*O.R.*	*Points*	*P.R.*	*O.R.*	*Points*	*P.R.*	*O.R.*	*Points*	*P.R,*	*O.R.*	*Points*	*P.R.*	
Job A	3	60	4	3	85	4	6	25	7	5	40	6	7	20	7	230
B	6	40	6	4	90	3	3	60	3	4	76	4	3	56	4	322
C	1	90	1	5	80	5	4	50	4.5	6	58	5	1	90	1	368
D	7	30	7	6	53	7	7	30	6	2	100	2	5	40	5	253
E	2	80	2	2	100	2	1	90	1	1	120	1	2	70	2	460
F	4	75	3	7	75	6	5	50	4.5	7	34	7	4	65	3	299
G	5	55	5	1	120	1	2	80	2	3	83	3	6	30	6	368

We notice that there is discrepancy in the original and points rankings for key jobs A and F. These two are, therefore, removed from the list of key jobs. The rankings for the remaining key jobs are as in Table 16.4.

Table 16.4 Discrepancies in the Rankings Removed

	Mental Requirement			*Skill*			*Working Conditions*			*Responsibility*			*Physical Effort*		
	Original Rank (O.R.)	*Points*	*Points Rank (P.R.)*	*O.R.*	*Points*	*P.R.*	*O.R.*	*Points*	*P.R.*	*O.R.*	*Points*	*P.R.*	*O.R.*	*Points*	*P.R.*
Job B	4	40	4	3	90	3	3	60	3	4	76	4	3	56	3
C	1	90	1	4	80	4	4	50	4	5	58	5	1	90	1
D	5	30	5	5	53	5	5	30	5	2	100	2	4	40	4
E	2	80	2	2	100	2	1	90	1	1	120	1	2	70	2
G	3	55	3	1	120	1	2	80	2	3	83	3	5	30	5

But what leaves a ring of suspicion about this system is its feature of using monetary points for arriving at these rating scales. Due to this, many feel that this system may perpetuate existing inequalities thus negating the purpose of the job evaluation.

OTHER SYSTEM OF JOB EVALUATION

There are many other systems of job evaluation, many of them used for special purposes, e.g. the Clerical Task Inventory, used (obviously) for clerical and office related jobs. This lists 130 'tasks' that may be performed while doing such jobs. These tasks have been rated as an 'Index of Relative Monetary Worth' by psychologists. In the job evaluation process, rating is given for the 'importance of each task to the job being evaluated'. The sum of the product of these two ratings gives the weighted value of the job.

$$\Sigma \text{ (Importance rating of the task)} \times \text{(Index of Relative Monetary Worth of the task)} = \text{Weighted value of the Job}$$

	Mental Requirement	*Skill*	*Working Conditions*	*Responsibility*		*Physical Effort*
120		G		E		
110						
100		E		D		
90	C	B	E			C
80	E	C	G	G		
70				B		E
60			B			
50	G	D	C	C		B
40	B					D
30	D		D		—	G
20						
10						

Figure 16.7 Calibrated Scale with Key Jobs—Factor Comparison Method

Some other systems could be more useful for supervisory and managerial job evaluation. For instance, Jacques' Time Span of Discretion (TSD) concept believes that there is a good correlation between the TSD and what people consider as a fair pay for any job. TSD is the time available to a subordinate to use his discretion before the superior decides to effect control. A Chief Executive of an organisation may have the discretionary time of a year or more before the Board can decide whether his actions are right or wrong and so effect necessary control action, whereas, a first-line supervisor may have only a few hours before his discretionary actions are judged.

Hay's Guide Chart-Profile method is especially meant for managerial and professional jobs. It consists of comparing the jobs, basically, under three factors.

(a) Know-how **(b)** Problem-solving **(c)** Accountability

HUMAN ELEMENT IN JOB EVALUATION

Thus, job evaluation is an exercise to bring in more equity and improved logic in the pay structures of an organisation, so that there are few grievances left regarding wage or salary differentials. How-

ever, the labour unions sometimes take a view that this curtails their prerogative of negotiating and collective bargaining. Also, it is criticised on the grounds that it is too much of a levelling exercise which does not do justice to an employee's seniority, loyalty or ability. Of course, these arguments could be countered, and errors if any could be rectified, but the fact remains that the employees' confidence cannot be gained by logic alone and, as always, human psychology plays an important role.

INHERENT LIMITATIONS OF JOB EVALUATION

There are a few inherent limitations in job evaluation:

(a) If the technology changes, then the job difficulties, training requirements, etc. may change considerably, necessitating a second look at the evaluations done in the past. Thus, job evaluations are valid for a longer or shorter period depending upon the rate of advance of technology in the organisation.

(b) Job evaluation cannot always iron out inequities in pay because it cannot do anything against the irrationalities in the external market. If job X is paid a high wage in the outside market, whatever the evaluation exercise might say, job X has to be paid a similar high wage within the organisation as well.

(c) However logical or quantitative the evaluation exercise be, there is still a good deal of judgement involved in selecting, defining and measuring against factors or degrees or other variables. Job evaluation is significantly subjective in character.

(d) Also, Job evaluation generally entails increased financial burden to the organisation.

QUESTIONS FOR DISCUSSION

1. What is the purpose of job evaluation?
2. Can job evaluation be alternatively called job ranking?
3. Is there any relation between work study and job evaluation? Is work study, in any way, useful to job evaluation?
4. How does one ensure that 'job evaluation evaluates the job and not the man'?
5. Does the job evaluation process differ for blue collar, white collar, supervisory and managerial jobs? Discuss.
6. Some say that we need a 'national level job evaluation' in India. Can you envisage the issues involved? Is it possible to do such a national level exercise? How would you proceed in this regard?
7. What might be the objections to job evaluation from the labour unions?
8. Mention two possible drawbacks of the factor comparison method.
9. Where would collective bargaining be useful in a job evaluation programme?
10. Should job evaluation be subordinate to collective bargaining?
11. Should the frequency with which a particular skill or knowledge is required, be a criterion for job evaluation?
12. Find out what merit rating is and discuss the differences between job evaluation and merit rating.

ASSIGNMENT QUESTION

1. Apply 'Job Evaluation' at a national level for various categories of professions. Suggest national policy measures based on your evaluation.

17 Incentive Schemes

The basic premise underlying incentive wage schemes is that money can be used to induce effort on the part of the employee. The objective is to improve the productivity and this is expected to be achieved by relating increased wage payment with increased productivity.

TYPES OF INCENTIVE SCHEMES

Incentive wage schemes could broadly be classified into Individual, Group and Plant-wide/Company-wide incentive schemes. This classification and further subclassification arise from the differences in work situations, the differences in the assumed motivational principles, and from different measures of productivity used.

INDIVIDUAL INCENTIVE SCHEMES

The individual incentive scheme has two distinct subclassifications: (a) Payment by results (PBR) system, and (b) Measured Day Work (or Payment by Time) system.

Payment by Results System

The PBR system has a continuous relation between money and results (output); therefore, different results would fetch different wages. Although, theoretically the PBR schemes should follow Fig. 17.1, the schemes are modified to accommodate the modern day requirement that the worker should be guaranteed a minimum flat wage rate. This is shown in Fig. 17.2.

Acceptable Productivity Level The level of output rate or productivity above which the incentive wage payment starts is called the Acceptable Productivity Level (APL). This is the pace of work which is considered as 'normal' or 'fair' and can be expected from an unmotived but otherwise conscientious, and fit workers. Since there are, so many assumptions of 'normality' or fairness', the APL is generally established jointly by management and labour (or by management alone but with implicit approval of the labour).

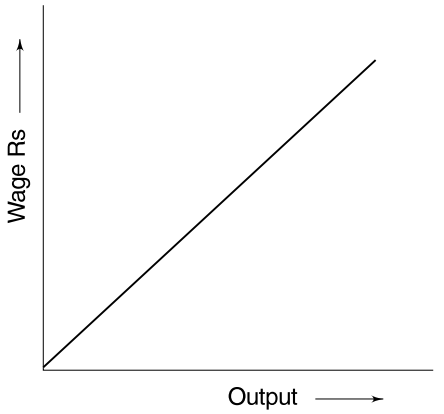


Figure 17.1

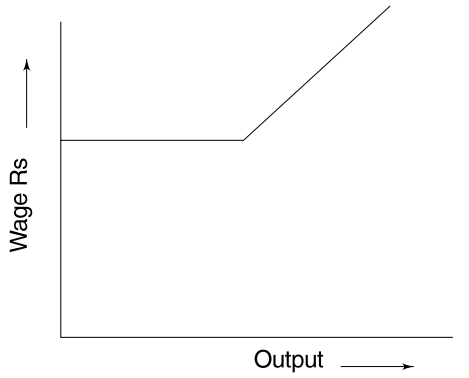


Figure 17.2

Motivated Productivity Level Management is more interested in the Motivated Productivity Level (MPL) which is the incentive pace which can be maintained day after day without any harmful effect on the worker. As with APL, the worker is a 'normal' worker, but he is now 'financially motivated'.

MPL is a function of human ability and of management's expectations—about an average worker's productivity—derived therefrom. With the expenditure of a certain amount of additional money management desires to raise the current productivity level to the practicable motivated productivity level. Since the human work ability has a limit and the extra wage costs also have a limit, MPL is used for establishing the APL (with the concurrence of labour).

Participation Ratio Depending upon the MPL and APL, therefore, the Participation Ratio (i.e. per cent increase in wages for one per cent increase in productivity) can be established. Note that MPL and APL are physiological and psychological norms, and therefore, the employees can bargain, with management, about these norms. The generally presumed relationship is that MPL is one-third more than APL (MPL = 4/3 APL), but management and labour may arrive at a different figure. Similarly, the difference in wages at MPL and APL (which is termed Incentive Expectancy) is generally taken as 33% in a large number of countries.

Example An illustration is given to clarify some of these concepts: Suppose the management has decided to have one-third (33.3%) Incentive Expectancy at the MPL of 100 pieces per hour. If the Participation Ratio is 100%, then the APL works out to be 75 (i.e. $100 \times \frac{3}{4}$) pieces. If the current production rate is 60 pieces per hour, then, under this plan, the workers will start receiving the incentive benefits only after the production rate goes up from 60 to 75, which is a substantial gap. Such a scheme may not be acceptable to the workers. Therefore, another design of the incentive plan could be APL = 60 and Participation Ratio = 50% (MPL and Incentive Expectancy remain the same).

Ceilings on Incentive Earnings The PBR system mentioned so far has incentive payment directly proportional to the increase in productivity. An employee can produce more than the MPL of 100

and earn higher wages. There is, literally, no limit to an employee's earnings. But, this situation, many a time may lead to problems in the administration of the incentive schemes:

- Employees may surreptitiously bring in changes in the methods and increase the output; where there is no such scope for method changes, that set of employees will be disgruntled.
- Employees may also employ various other devious methods to increase the incentive earnings by the clever use of the pen.
- The wide disparity between income levels of individuals may produce tension and conflict amongst employees—potentially not a happy situation for the organisation in the long run.
- The earnings of the individual worker itself may vary over different periods of time. Instability in earnings (although higher) may not be very desirable from the individual's point of view, from the motivational angle, and from the company's angle in terms of the wide fluctuations in the production output of different operations at different times (problems of coordination of one operation with the other).

So, having a ceiling on the incentive earnings might be a good idea (see Fig. 17.3). Some of the incentive plans, such as the Rowan Plan limit the earnings:

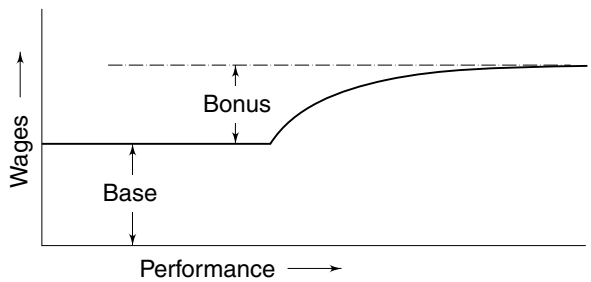


Figure 17.3 Limiting Differential System

$$\text{Bonus Payment} = \text{Base wage} \times \frac{\text{Timed allowed} - \text{Time taken}}{\text{Time allowed}}$$

Tangible and Intangible Costs of a PBR System The introduction of a PBR scheme places a heavy responsibility on the management and comes with a few costs:

- The onus is on the management to provide materials and well-maintained machines on time, in order to reduce the 'waiting times'.
- The management should always ask itself the question; 'Output at what cost?' Amongst the tangible costs could be the costs of deterioration in quality, increased materials usage, and improper handling (and usage) of the machines.
- Amongst the intangible costs are the costs of (a) depersonalisation of relations and hardening of attitudes between the supervisor and workers; and (b) expenditure of the management time on various disputes about the new wages and time, instead of handling more constructive issues such as methods changes, inventory policies, etc.
- Wage anomalies may arise due to imperfect work measurements or due to varying bargaining capacities of individuals. A good worker but a bad bargainer may therefore suffer.
- Management should also be aware, that with an incentive scheme operating, the workers will resist deployment changes from one section to another. This flexibility is lost to a great extent.
- The workers may even resist method change or technology change, particularly in a job which has a 'loose' rate. In general, incentives engender an attitude inimical to improvements in methods and technology.

- The management, in a way, loses control over the output of the employees. This also has the effect on production control in terms of aligning different operations which are linked with one another.
- Since the direct worker is on incentive but the indirect one such as the materials handler, stores worker, laboratory technician, office worker, maintenance mechanic, etc. is not on incentive pay, the management may find it difficult to integrate the work of the incentive and non-incentive employees. This leads to many imbalances in the working of the plant.
- PBR scheme may also mean a fluctuating income for a worker since (a) the work may not be there all the time, and (b) the worker himself may not be able to work at the same high pace all the time.

Measures to Overcome Problems Related to the PBR System In order to overcome some of these difficulties, following are some of the measures that could be taken within the Payment by Results system:

Protection of Quality Generally, one should pay only for the output that meets set quality standards.

In some instances, quality is of extreme importance such as in the products catering to the nuclear power stations, highly safety-oriented mechanisms, products dealing with human health, products of art, etc. The output-oriented incentive scheme is not very suitable for such cases. But, where the incentive schemes can still be installed, they have to be accompanied by the condition that every defective unit of output is severely penalised in terms of a drastic reduction in the incentive bonus.

Protection Against Wastage In cases where materials usage is of much importance (due to the high costs of materials themselves, and their reworking), the incentive payment can be tailored to two parameters:

(i) Output, and (ii) Materials usage.

Any output above the basic output level is given incentive pay which reduces as the materials wastage gets higher. Thus, as the output increases the incentive pay increases, but, also concurrently, as the materials wastage increases the incentive pay decreases.

Indirect Workers and Incentives The term 'indirect' need not mean that the contribution of these workers to the enhanced productivity is any less than the so-called 'direct' workers. In some industries, the indirect workers such as the maintenance technicians, the machine-setters etc., play a very major role in having a high degree of machinery availability. Their role is all the more evident where the production is significantly machinery-controlled.

But, since the measurement of the work of the indirect workers is somewhat difficult, many managements pay them an incentive bonus that is tied with the incentive earnings of the direct workers. For instance, they may pay them the average of their department or group.

Such a simplistic solution may not always be justified. The stop-watch Time Study, the Predetermined Motion Time Systems, the Standard Data Blocks, the Multiple Regression Analyses combined with Work Sampling could be of use in the measurement of indirect work.

The Multiple regression analysis correlates several criteria for the measure of the work (called 'predictors') with the time required to perform a job. Thus,

Standard Time to perform a job, $T = a_0 + a_1 x_1 + a_2 x_2 + \ldots + a_i x_i$

where $x_1, x_2, \ldots, x_i$ are the different predictors and
$a_0, a_1, a_2, \ldots, a_i$ are constants.

If by means of a Work Sampling study enough data is collected on the various *Ts* and corresponding *xs*, this data can be used to run a regression and find out the various correlation coefficients in order to choose from the different predictors earlier hypothesised. An applicable formula can then be arrived at. This can, then, be used to measure the productivity.

Measured Day Work (MDW) System

This system takes care of two of the drawbacks of the Payment by Results System, viz.

1. Considerable fluctuations in earnings for the employee, particularly if the PBR scheme is poorly designed and administered; and
2. Loss of control, by the management, over the level of output; and therefore, the consequent difficulties in aligning different operations which are linked with one another.

Under this system, an employee opts to maintain an agreed higher target level of output in order to secure a stable higher wage rate (Fig. 17.4).

The employee's performance is monitored and if it falls below the target level for a period, he is given a warning. In spite of this, if the level of output during the next period also is below the target level, then the employee is downgraded to the basic wage rate.

In essence, MDW means two levels of wages —an agreed higher level of wages for a specified higher level of consistent performance and the basic wage for lower levels of performance. Basically, MDW is a Payment by Time system.

Under this scheme the worker has no incentive to improve on the target level of performance; he just needs to maintain his current level of productivity. But then, the thought underlying this system seems to be that every worker has a characteristic norm for pace of work and application which can be changed very little on the whole by the Payment by Results scheme.

Premium Pay Plan There are different modifications of the above stabilised output incentive scheme. Under the Premium Pay Plan, for different specified levels of performance there are corresponding different levels of wage rates starting from basic to higher and higher premium pay rates (Fig. 17.5).

If the objectives of the MDW is to stabilize the output and bring in a measure of control by the management, the Premium Pay Plans, with their numerous output levels, would tend to defeat the purpose. In fact, they come closer to the PBR system.

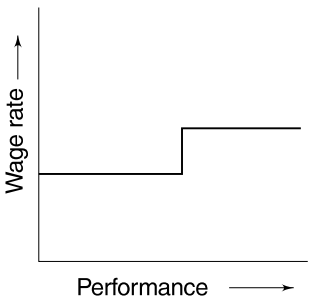


Figure 17.4 Measured Day Work System

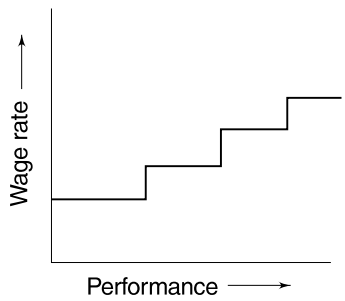


Figure 17.5 Premium Pay Plan

Group Incentive Scheme

Motivating only individual workers does not always result in sustained increase in the ultimate collective productivity from a section or department. Many a time an individual's output is very much linked with the output/performance of another individual. It is not even possible, in many of these cases, to measure precisely the contribution of each individual. This being the case with the direct workers, having the indirect workers of a section also contributing to the performance will make matters even more difficult for the design of an individual-based incentive scheme. In such cases, a Group system of incentives is resorted to, where the enhanced earnings of the group are distributed amongst the members in an equitable manner (e.g., with consideration of the basic wage rate of the worker and the number of hours worked by him) agreed upon earlier.

Commonality of Interests and Group Size Behavioural theory tells us that some of the needs of human beings are the need for security and a sense of belonging to a group. In places where the individual incentive scheme (PBR) is on, it has been observed that many workers limit their own incentive earnings so that they do not face alienation from other workers of their working group. Thus, the idea underlying the group system is to have a financial incentive system which does not pose a threat to the workers' group solidarity and their social satisfaction; in fact, it purports to increase such satisfactions. And, as a group, they are expected to behave like an individual when responding to the increased earnings with increased output performance.

There is no doubt that situations like the assembly line or maintenance crew or construction work crew call for a group system of incentives as against individual incentives, if incentives are to be used in an organization. Installation of the group system of incentives requires a commonality of interests within that group.

As a corollary to the last point, it follows that in the design of a group the Group Size is important. There cannot be any numerical guidelines on the best or optimal group size. Optimal group size is the one that considers the commonality of interest, promotes cooperation, and enhances the ultimate performance. The nature of the tasks involved, the inter linkages, the production system in operation, the physical layout, etc. are some of the factors to be taken into consideration in forming a group.

Merits of the Group System The advantages of a group system, where employees function 'as a group', are:

- There may be better camaraderie and better sharing and linking-up of work resulting in overall increase in productivity.
- Perhaps there is better interchecking of quality of product in a group working situation, and therefore quality of product performance may show improvement.
- Supervising, time-keeping and incentive accounting are simplified.
- The problem of including indirect workers in an incentive system are also taken care of to an extent.

Demerits A Group System may have certain disadvantages, too.

- There may be a levelling effect, that is every one works at about average performance level of the group; an excellent worker and a not-so-good a worker both may work at the same performance level.

- If in a group the workers perform different tasks, then the question arises as to how-and-whether to distribute the group's incentive pool according to the individual contributions (that is, the first two points in demerits question the socialistic pattern of the group system in contributing to enhanced productivity).
- The group makes its own decisions about group output and therefore the management would have very little control over the output leading to difficulties in planning of various production and related activities. (Note: this was a problem in the PBR system, too.)

COMPANYWIDE BONUS SCHEMES

Many companies like to retain the principle of motivation by financial incentives but at the same time like to do away with the number of problems which a PBR or a group system pose. More importantly, the underlying thought is that the ultimate objective is to enhance the overall productivity of the plant or company. This calls for working in an integrated manner with cooperation from all the departments/sections of the company. Yet, this integration and cooperation is to be achieved through the use of financial incentives. A suitable measure of productivity is established, by agreement between the management and the workers, and this is used to distribute the labour-cost savings amongst all the workers of the company.

Choice of a Relevant Productivity Measure

The success of this scheme depends, amongst other things, on the relevance of this productivity measure to the work of the employees. The more the productivity measure depends on the work done by the employees (and less on other externalities) the more is the expected motivation and application by the workers. This is because, there could be a number of factors over which the workers have no control, such as the selling price and product-mix which could affect the productivity as measured by the chosen measure. Some of the measures and their sensitivity are mentioned below:*

	Labour Productivity Measure	*Sensitive to*
1.	$\frac{\text{Work content of production}}{\text{Time worked by labour}}$	Definition of 'Work Content'
2.	$\frac{\text{Physical production}}{\text{Time worked by labour}}$	Changes in product-mix
3.	$\frac{\text{Physical production}}{\text{Cost of labour}}$	Changes in product-mix and wage-rates
4.	$\frac{\text{Added value}}{\text{Cost of labour}}$	Changes in product-mix, finished goods inventory, sales prices and wage rates.

Some of the companywide incentive systems are the well-known Scanlon Plan and Rucker Plan. While, the latter uses the ratio 'added value to cost of labour' as a measure of productivity, the former believes in establishing a suitable measure individually for any company. One of the important aspects of the Scanlon Plan is the establishment of productivity committees and through them the frequent interaction between the management and the workers. This scheme can be described as one of the many methods of the labour's participation

* Adapted from Angela M. Bowey, *Handbook of Salary and Wage Systems*, Gower Press, UK, 1975.

in the management of the company; because, through productivity committees many aspects of the company policies such as marketing, purchasing, quality management, etc. get discussed as they affect the overall productivity. Perhaps this worker participation in anagement, although in a different garb, is the reason for the positive results achieved earlier through the Scanlon and other company-wide incentive plans.

Merits of the Company-wide Incentive Plans In a manufact using industry an advantage of these plans lies in the relative ease with which technology and method changes can be brought in, whereas, in the PBR or Group Schemes technology/methods changes mean changes in the time standards and hence the resistance to change from the affected employees.

But, the success of the companywide incentive schemes lies in how much the workers feel a part of the company and come up with extra efforts and novel suggestions to increase the overall productivity.* It is in the hands of the company management as to how they use this financial motivation, by creating the right atmosphere and conditions, to usher in companywide fellow-feeling and unity of purpose.**

In any case, an annual review of the incentive plan and adjustments to the productivity measure to reflect as truly as possible the changes in the productivity and the contribution by the labour in it, are necessary adjuncts.

A large percentage of the success of service organisations relies on team-work and coordination between various functions within the organisation. Company-wide incentive scheme makes more sense in such organisations.

BEHAVIOURAL ASPECTS OF INCENTIVES

Incentive schemes, whether PBR or group or companywide system, rely on the presumption that every man is a capitalist at heart. Human behaviour is, however, much more complex. Firstly, it is well known through the theories of behaviourists that money is most often only a 'hygiene' factor or that the lack of it is a 'dissatisfier'. Money could perhaps be used as a motivator provided various other 'dissatisfiers' are minimised, which means:

(i) supervisory and other social relationships at work are good;
(ii) the worker feels secure, physically and emotionally; and
(iii) working conditions are adequately satisfactory.

Then the financial reward could work as a 'recognition' for the accomplishments of the employee/s. There are many other motivators such as

(i) interesting, varied and challenging job,
(ii) responsibility over one's own job,
(iii) advancement in status, and
(iv) continued growth and learning opportunities.

At best, the PBR and group system of incentives seem to deal with only one of the several motivating factors. The companywide incentive scheme with labour participation in management

* Some Indian cases on companywide incentive schemes have been mentioned in *Management Information Services, Note No. 15,* All India Management Association, New Delhi.

** The objectives of companywide fellow-feeling and unity of purpose could perhaps be achieved with less difficulty in small- or medium-size organisations.

perhaps goes a little further. Therefore, if a company is facing a problem of low labour productivity there are more things to be done than just resorting under the financial incentive scheme.

FINANCIAL INCENTIVES

We may recapitulate a few other points about financial incentive schemes:

1. The time-study ratings are much less accurate than normally thought,* and the incentive schemes are based on the time-studies. This leaves much room for labour-management bargaining. This further leads to the observation that only a good bargainer benefits and a good worker may not be a good bargainer. And, more often, not-so-good workers benefit from the scheme most. It should also be noted that the time-study analyst is under much social pressure in cases where time-study is linked with monetary gains.
2. Financial incentives, particularly of the PBR and Group kind, have in-built in them (so to say) a resistance to technological/equipment/method change. Even when such changes take place gradually over time, they only cause a 'wage drift' which means enhanced wage payments without the labour contribution to productivity really changing. Thus, incentive schemes, once thought to be good for the company, may perpetuate old technologies and practices, which is harmful to the company in the long-run.
3. Many incentive schemes, particularly the multifactor schemes, may be difficult for the comprehension of the employees. This may defeat the very purpose of financial incentive.
4. In addition to the grey area in the time-study, many a time, quality of the output is a judgemental issue. Plus, quality depends on various motivational factors and needs an integrated company-wide outlook, which is lacking in most of the financial incentive schemes.
5. Management loses much of its control over the performance/output of the employees. This poses many problems in planning of production, marketing and other operations.
6. Moreover, management will be saddled with the additional burden of providing materials, supplies, good-working equipment to the production workers on a more or less continual basis.
7. In short, management may lose authority and control over labour (having given it away to the 'money') and be burdened with disputes over rates, wage payment calculations and the like which fritter away precious managerial time which could have otherwise been used for various vital planning issues.
8. Many incentive schemes which do not cover properly all employees, direct and indirect, will face disgruntlement from a section of employees.
9. Moreover there is the crucial issue whether the productivity of a worker can be substantially altered with monetary incentives and how long it will stay at that level in the long-run.

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* 12% variation range—with same observer;
32% variation range—for different observers with same training;
76% variation range—for different observers with different training.

Source: Tom Lupton, *Money for Effort*, Ministry of Technology, *Problems of Progress in Industry*—11, Her Majesty's Stationery Office, London 1961 (Reprinted 1968), p. 18. Quoted in this book as taken from: W. Rogers, and J.M. Hammersley, 'The Consistency of Stop-watch Time-Study Practitioners', *Occupational Psychology*, 1954, 28(2).

Human motivation is a complex phenomenon which depends upon the various 'satisfiers', 'dissatisfiers' within and outside the factory. Over the latter, management has no control. Over the former, management must ponder in all seriousness. Prof. Douglas McGregor* says: 'If, the *total* costs of administering the incentive programme—both direct and indirect—were calculated, it would often turn out that they add up to more than the total gains from increased productivity.' One may or may not completely share Prof. McGregor's view, but undoubtedly financial incentives are, at best, only one of the many ways of enhancing sagging employee productivity.

SOLVED PROBLEMS

1. In a fabrication shop, a Payment by Results (PBR) system of incentive payments is being introduced. The standard time for producing an item is 10.8 minutes. The current average level of productivity, measured by this standard, is 60 per cent. If the PBR should start at the current average productivity level and if Incentive Expectancy is to be 1/3rd (33.33 per cent): What should an operator in the basic wage rate of Rs. 40 per hour earn as total wages including incentives for an 8-hour (400 minutes only) per day, if he produces 30 units? 40 units? 60 units?

Answer

Motivated productivity level (MPL) corresponds to the standard time.
MPL ≡ 10.8 minutes per unit.
Now, APL = 60 per cent of MPL = (10.8) / (0.6) = 18 minutes per unit = Time allowed t_a.
When the productivity goes up from APL of 60 per cent to MPL (= 100 per cent), i.e. when there is an increase of 40/60 = 66.66 per cent in output, the increase in wages (i.e. incentive) is to be 33.33 per cent. Hence, we have:
Participation Ratio (increase in wages to increase in productivity)
=33.33/66.66 = 0.50 or ½.
Therefore, the total wage inclusive of incentive bonus, to be paid to a worker is:
Total wage = (Output) × (Basic wage rate) × (time taken per unit of output + ½ time saved per unit)
It is given that basic wage rate is:
=[Rs. 40 × 8 hrs/day] / 400 mins. = Rs. 0.80 per minute.
Let us now compute the total wages to be received at different outputs.

For an output of 30 units a day

Time taken per unit t_t = 400/30 = 13.33 mins.
Time saved per unit t_s = 18 – 13.33 = 4.66 mins.
So, total wage =(30) × (0.80) × (13.33 + ½ × 4.66) = Rs. 375.84

For an output of 40 units a day

Time taken per unit t_t = 400/40 = 10 mins.
Time saved per unit t_s = 18 – 10 = 8 mins.
So, total wage = (40) × (0.80) × (10 + ½ × 8) = Rs. 448.00

* Douglas McGregor, *The Human Side of Enterprise,* McGraw-Hill, New York, 1960.

For an output of 60 units a day
Time taken per unit t_t = 400/60 = 6.66 mins.
Time saved per unit t_s = 18 – 6.66 = 11.33 mins.
So, total wage = (60) × (0.80) × (6.66 + ½ × 11.33) = Rs. 591.36

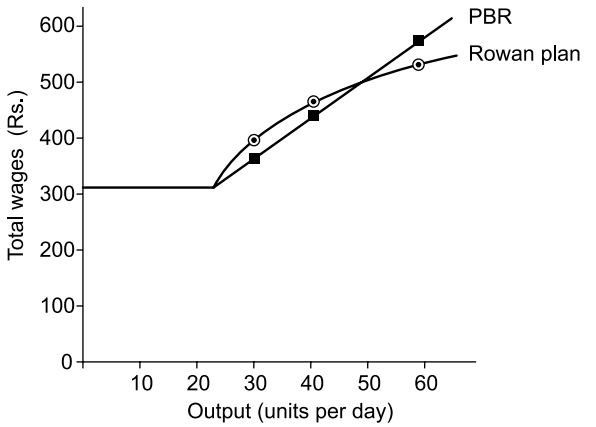
2. If the earlier fabrication shop adopted a Rowan Scheme of incentives payment, what would be the total wages for the same outputs,i.e. 30, 40 and 60 units respectively?

Answer

Under the Rowan Scheme, the incentive bonus is:

= Base wage per day × (Time allowed – Time taken) / Time allowed
= Base wage × Time saved / Time allowed

For an output of 30 units a day
Time taken per unit t_t = 400/30 = 13.33 mins.
For our example, the time allowed t_a = 18 mins. (Corresponds to APL.)
Hence, time saved per unit t_s = 18 – 13.33 = 4.66 mins.
So, incentive bonus = (Rs. 320) × (4.66 / 18) = Rs 82.84
So, total wage to be paid = 320 + 82.84 = 402.84
For an output of 40 units a day
Time taken per unit t_t = 400/40 = 10 mins.
For our example, the time allowed t_a = 18 mins. (Corresponds to APL.)
Hence, time saved per unit t_s = 18 – 10 = 8 mins.
So, incentive bonus = (Rs. 320) × (8 / 18) = Rs. 142.22
So, total wage to be paid = 320 + 142.22 = Rs. 462.22
For an output of 60 units a day
Time taken per unit t_t = 400/60 = 6.66 mins.
For our example, the time allowed t_a = 18 mins. (Corresponds to APL.)
Hence, time saved per unit t_s = 18 – 6.66 = 11.33 mins.
So, incentive bonus = (Rs. 320) × (11.33 / 18) = Rs. 201.42
So, total wage to be paid = 320 + 201.42 = Rs. 521.42



It may be observed that under the Rowan Scheme, the incentive bonus flattens out or plateaus and thus limits the production of huge outputs that could be undesirable for the company from the viewpoints of loss of consistency in quality or loss of management control over production volumes or higher inventory costs or difficulties in planning production of other related items or overloading of equipment causing future major maintenance problems.

QUESTIONS FOR DISCUSSION

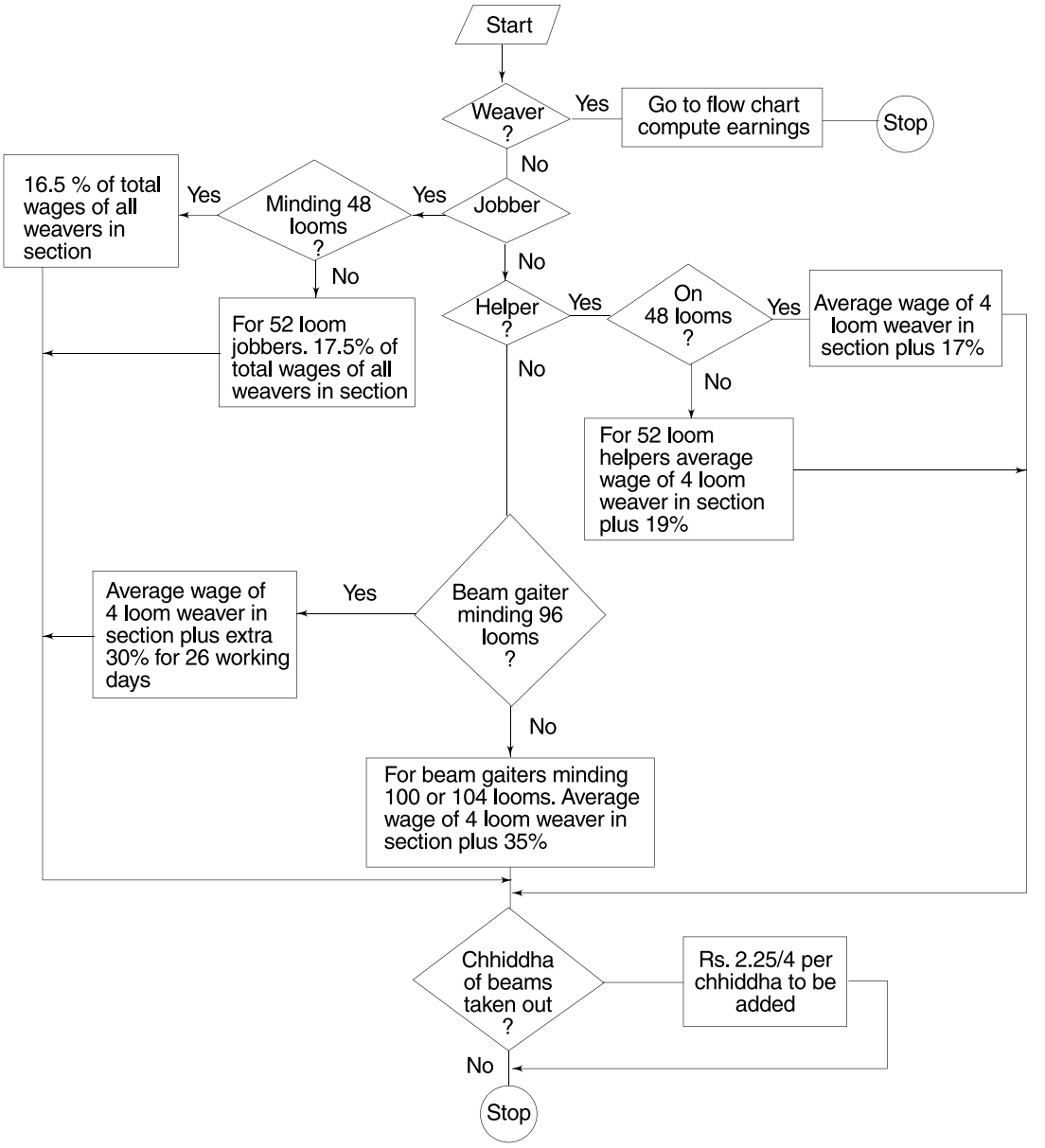
1. Is there any connection between job evaluation and Incentive schemes? Discuss
2. What is the difference between the Scanlon and Rucker plans?
3. What can be the difficulties associated with the productivity measure of Added Value/ Cost of Labour? Give an example and discuss.
4. What is the basic premise of the group system of incentives? Discuss.
5. In some companies, a novel system of incentives called 'flexible time system' is reported. In this system, the timings of work are flexible for a worker and he can choose his own timings, as long as these timing allow for about 3–4 hours overlap with other sections with whom interaction is necessary.
   What, in your view, could be the merits and demerits of such a system? Discuss.
6. What are the limitations of financial incentives, in general? What other avenues would you consider for increasing the labour productivity?
7. It is mentioned in this chapter that 'commonality of interests' is important in the design of a Group System of incentives. What are the factors influencing this? Give examples.
8. How would you put a process control laboratory analyst on financial incentive?
9. Examine the statement: 'Payment by Results System could, perhaps, serve well as a short-term solution to a short-term problem; but it cannot be a long-term solution to a long-term problem.'

ASSIGNMENT QUESTION

1. Visit different industries where financial incentives have been used. Study them in detail and present your report on their impact on the respective organisation. Present common principles that may emerge from your study.

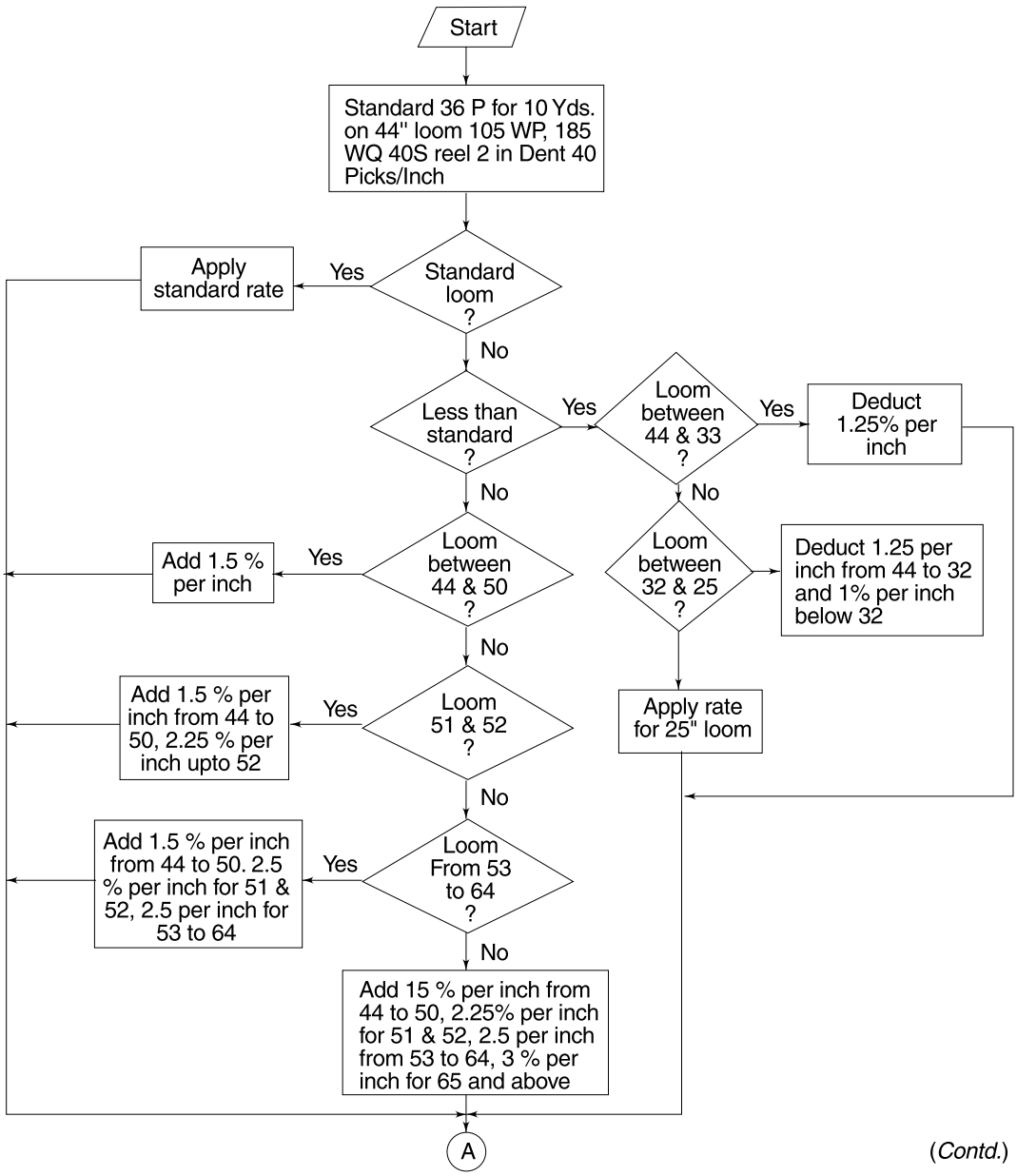
APPENDIX

EXAMPLE OF PIECE-RATE CALCULATIONS FOR THE WEAVING DEPARTMENT OF A TEXTILE COMPANY*



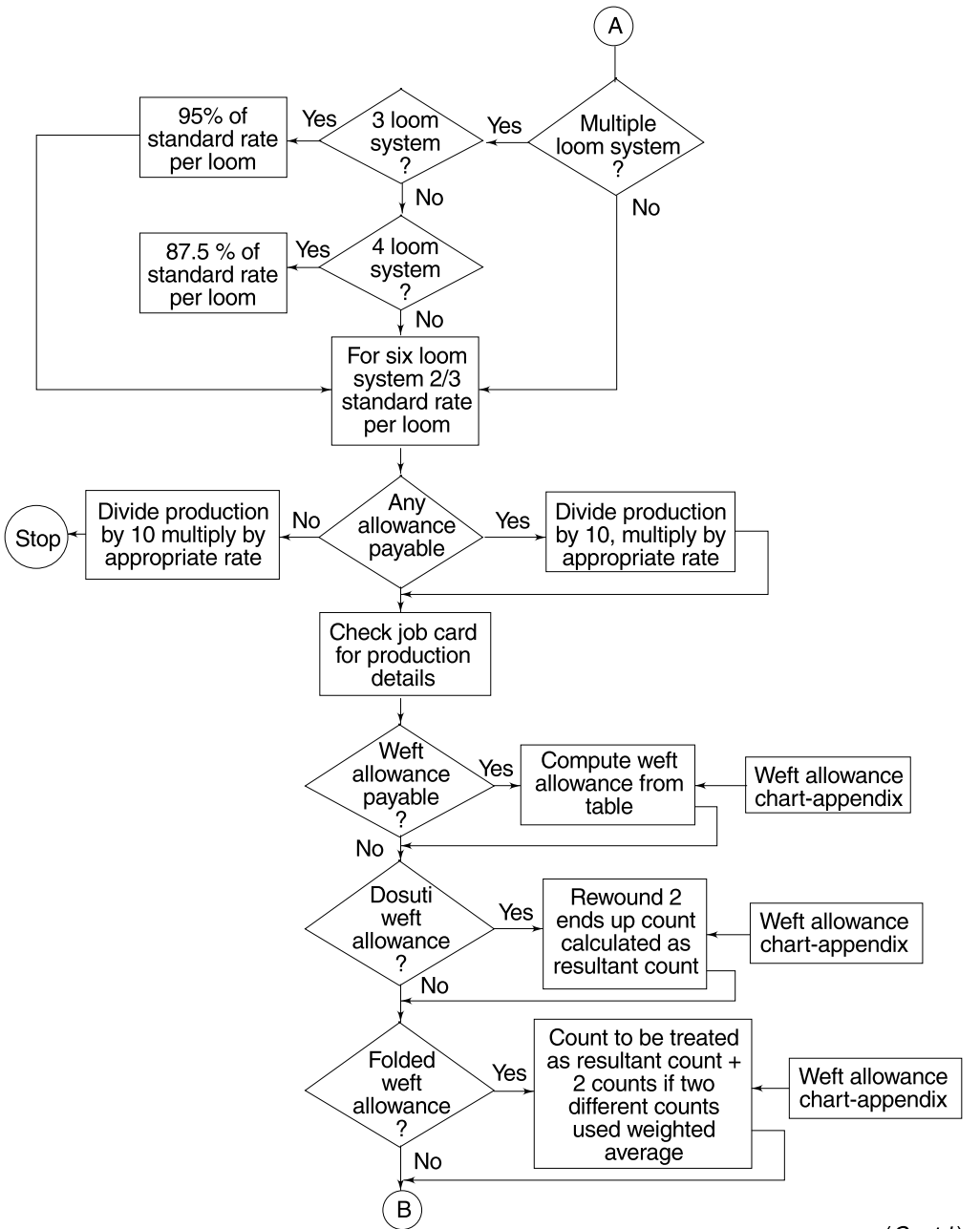
* *Source:* The Mafatlal Fine Spg. & Mfg. Co. Ltd, Unit No. 2, Bombay.

Flow Chart—Piece Rate Calculations—Weaving Deptt. *(Contd.)*



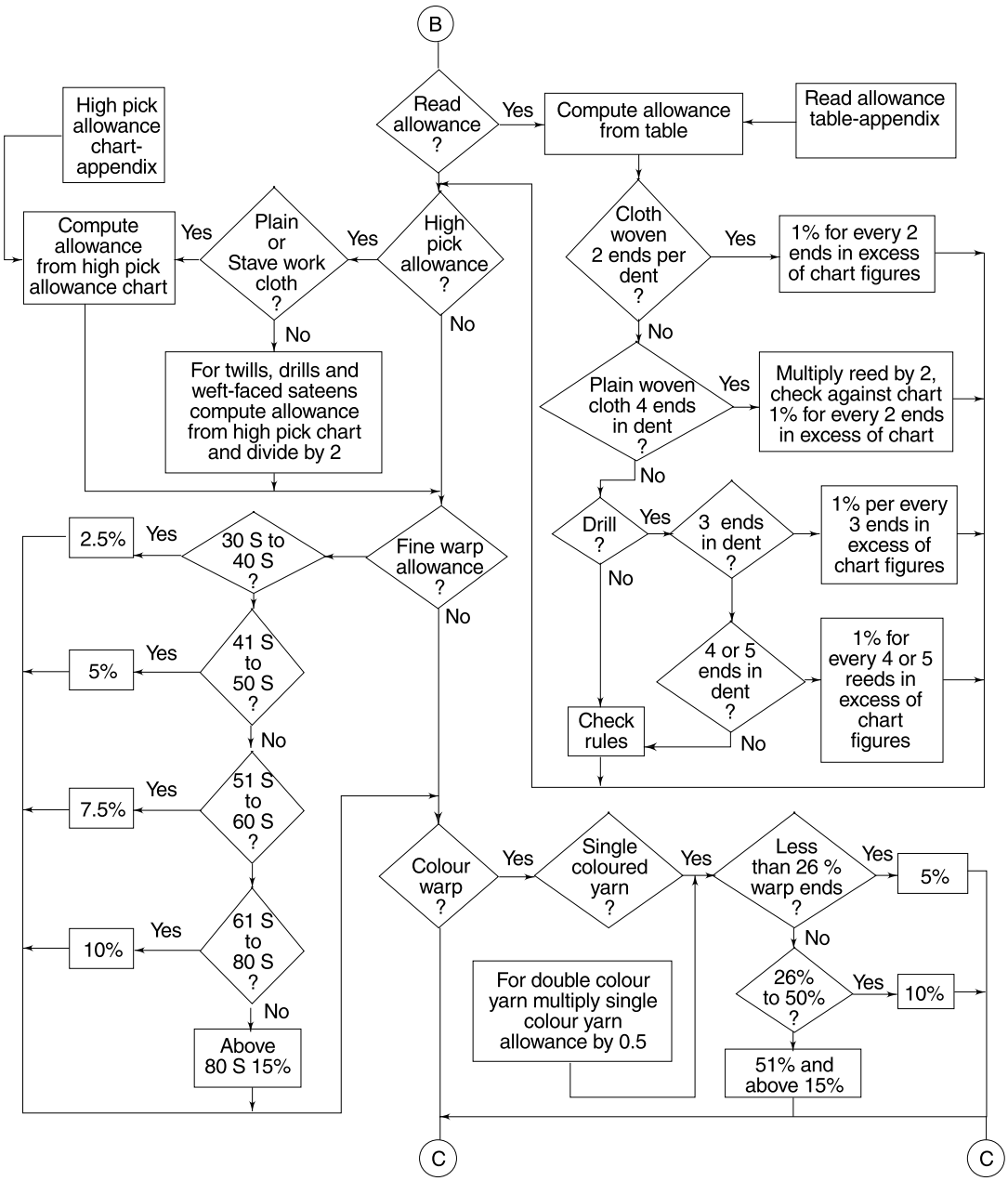
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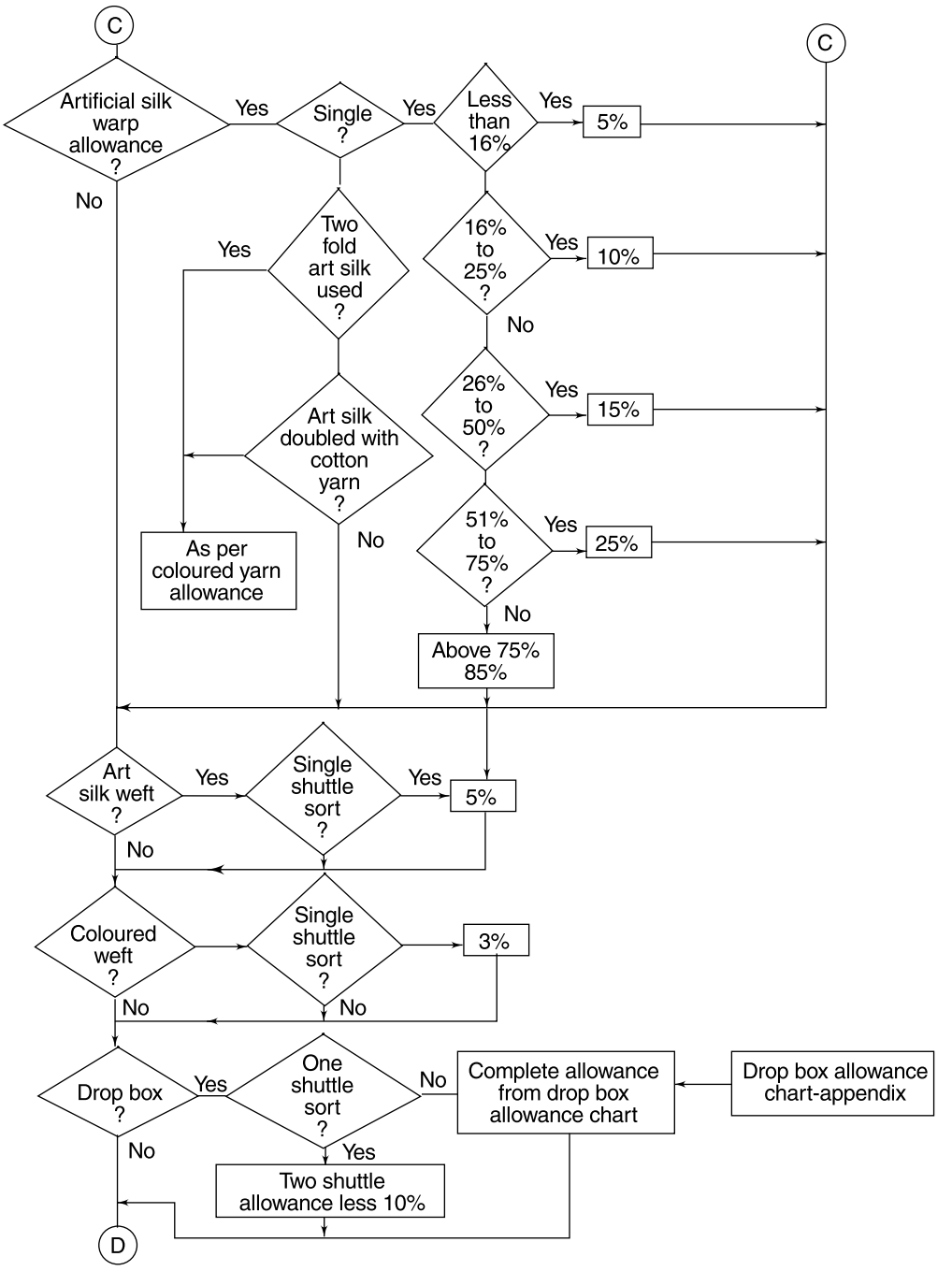


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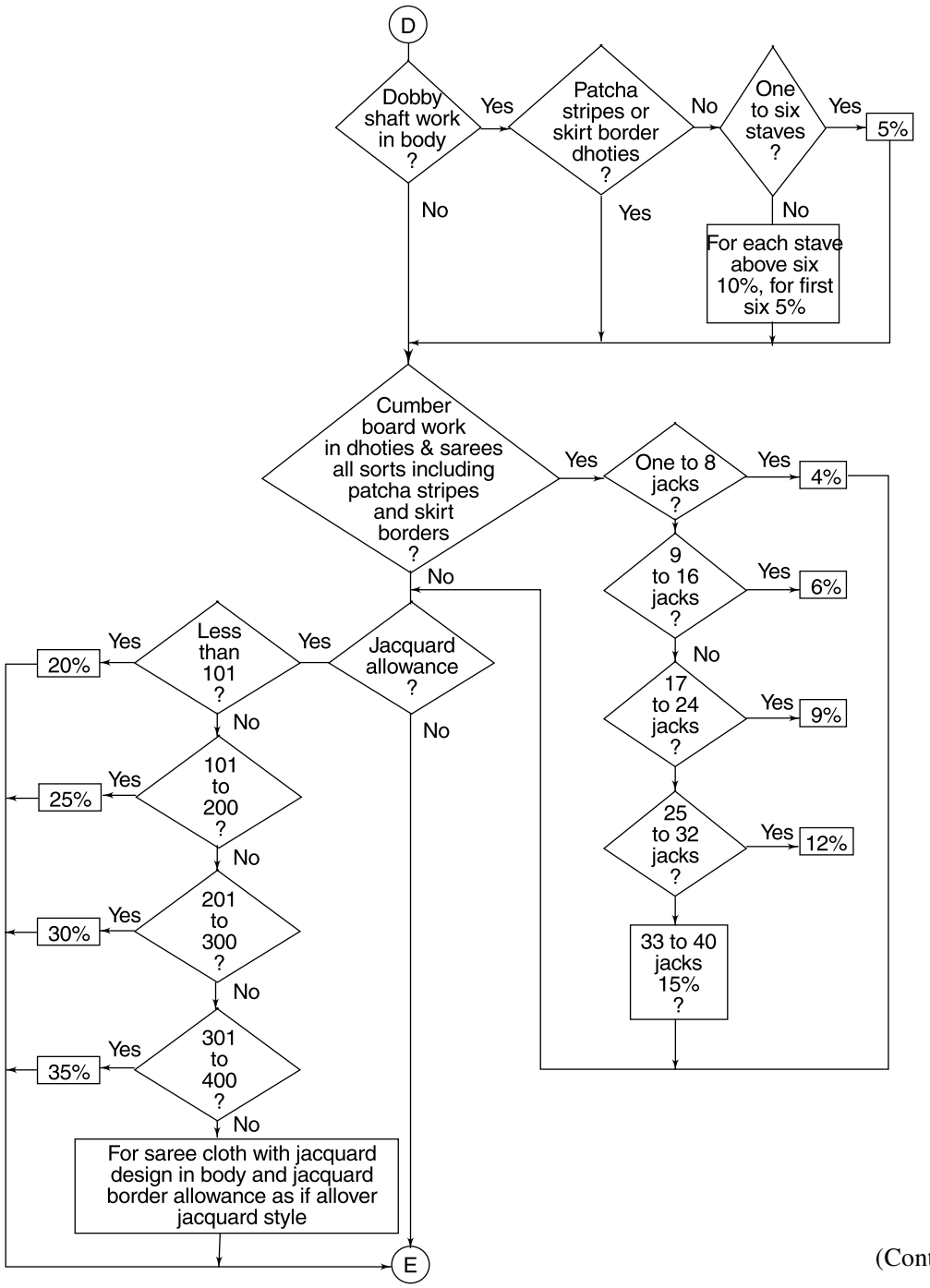


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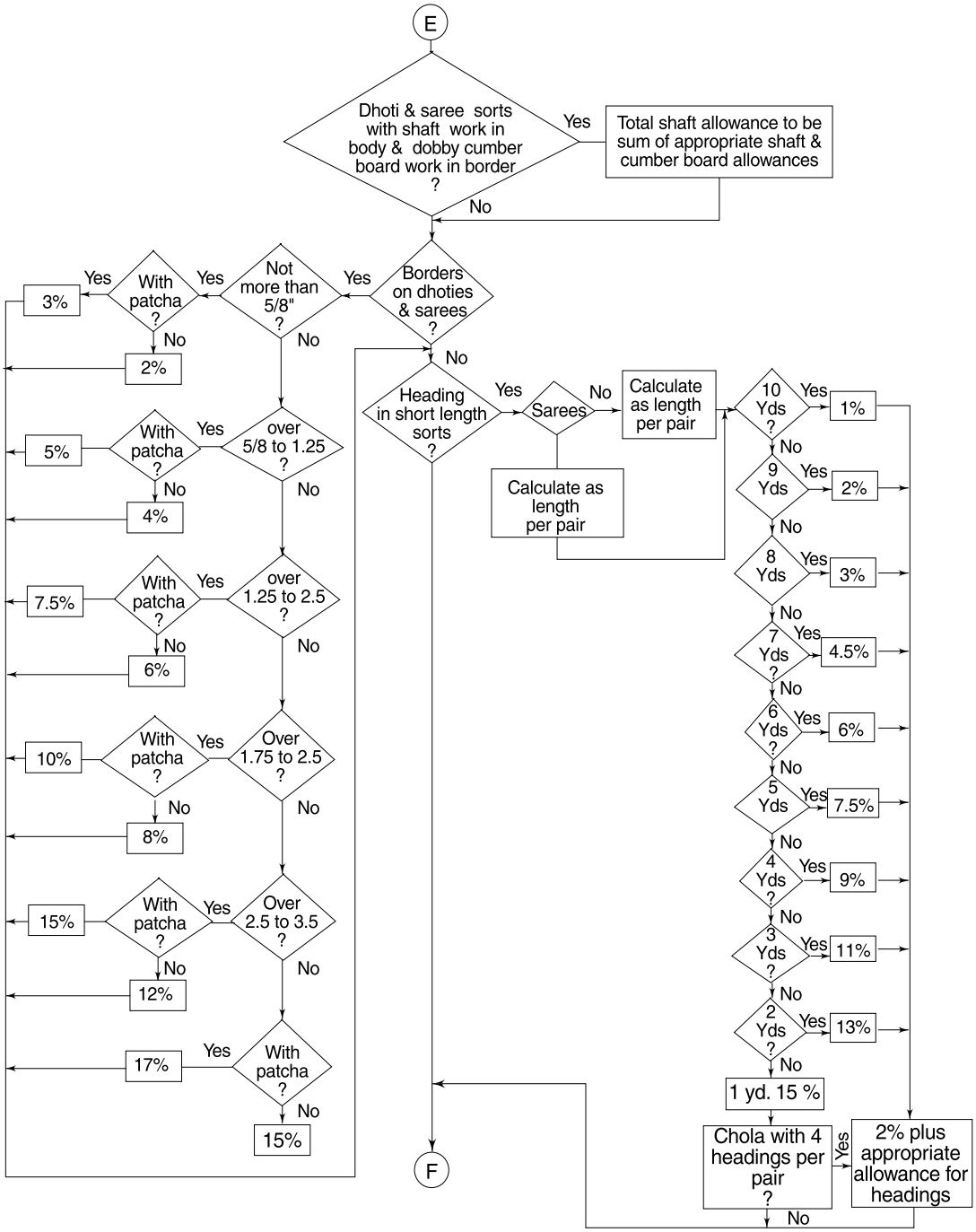
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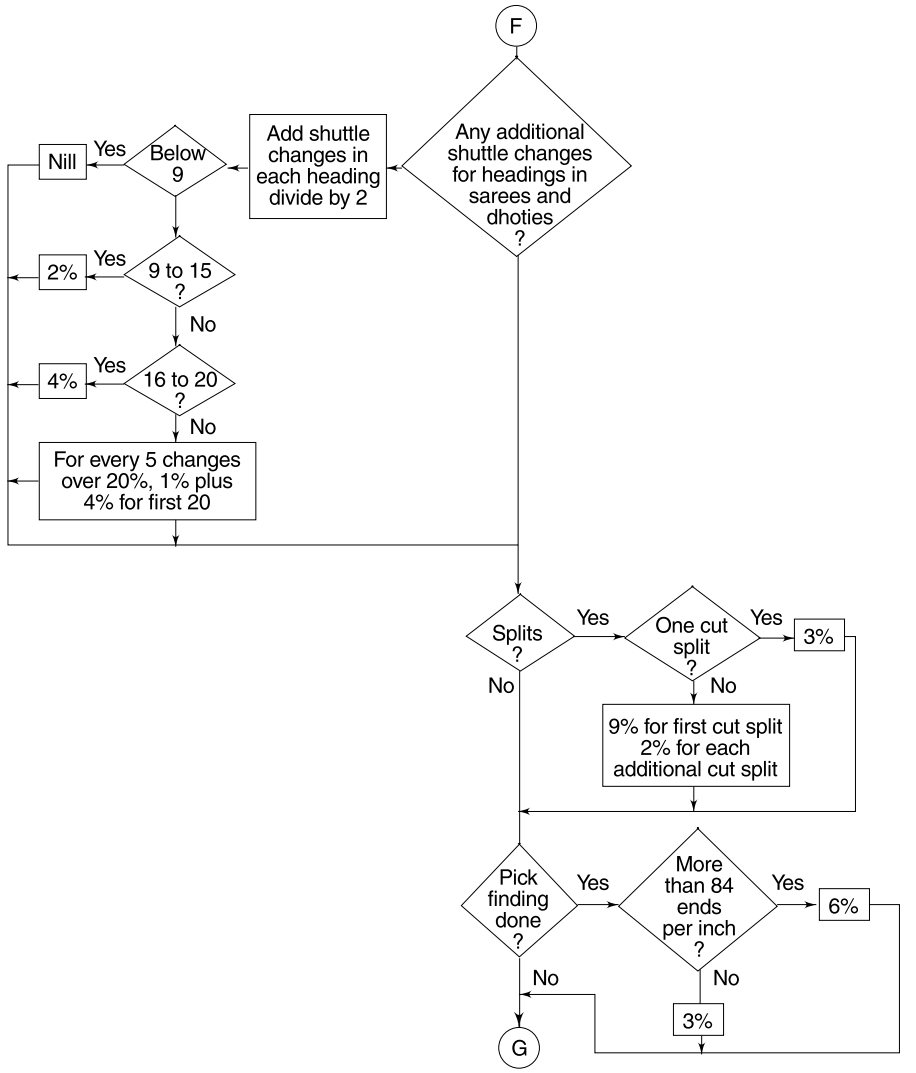
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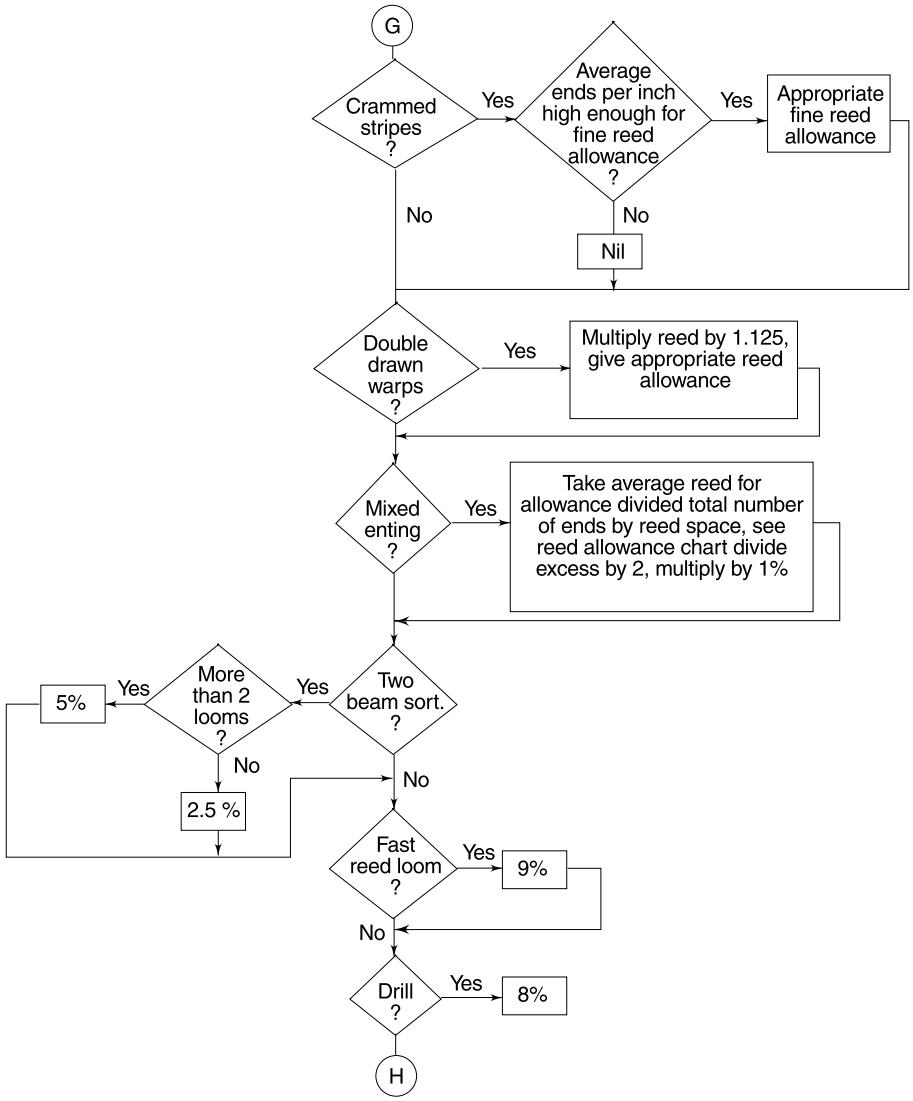
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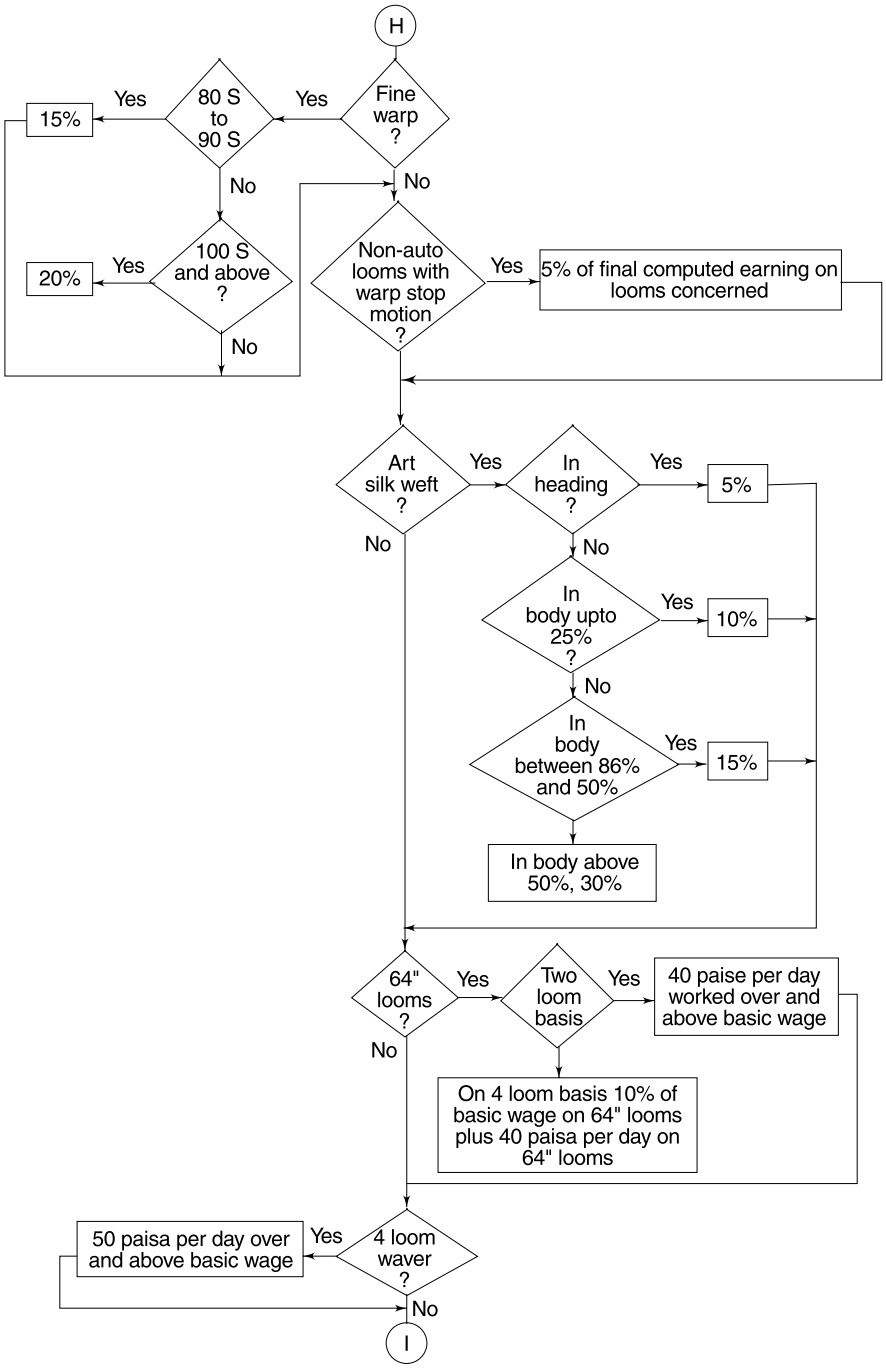
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Flow Chart—Piece Rate Calculations—Weaving Deptt. (*Contd.*)



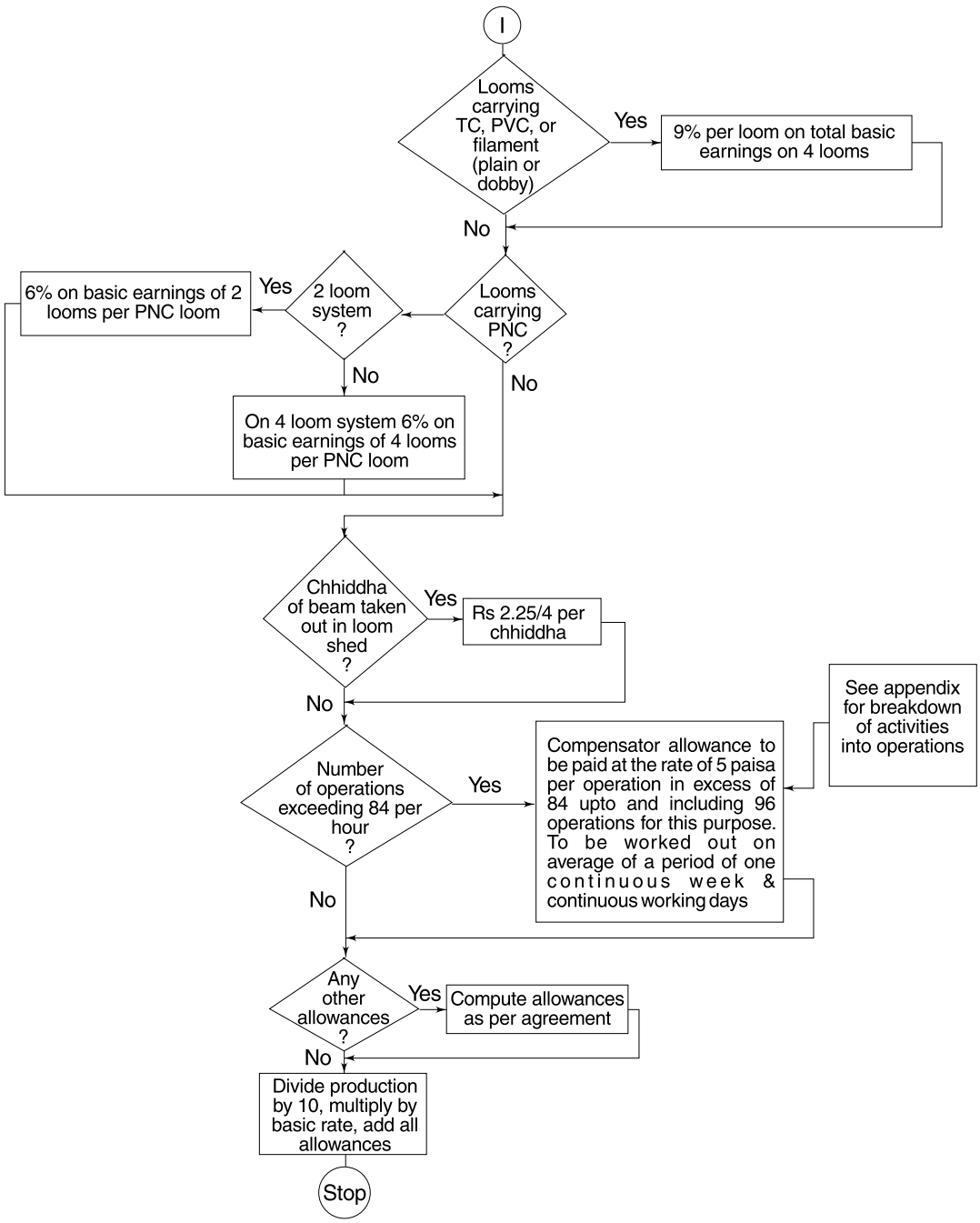
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Flow Chart—Piece Rate Calculations—Weaving Deptt. (*Contd.*)



18

One of the means of increasing the motivation of the workers is through Job Redesign. The concept of job redesign is to make the work itself interesting, varied and challenging.

NEED FOR JOB REDESIGN

Frustration with the job is not uncommon either in our India or elsewhere. It is, perhaps, one of the by-products of increasing mechanisation and automation. Technological advance is inevitable for the survival of industry but if introduced without adequate regard to 'human' aspects it will produce much frustration and anxiety amongst employees. With technological advances an employee may either experience 'growth' or feel reduced to a small cog in the giant technological wheel of progress. Both things are possible and it depends on how the organisation manages the human aspects of 'job redesign' in the context of continually advancing technology.

Typically the Industrial Engineering or the Time-and-Motion Study approach to work design has been, historically, to divide the work into many fragments and increase the efficiency by a high degree of specialisation in a small job fragment. The assembly lines, the learning curves are all aimed at realising cost economies from a high degree of learning in a small period of time. But, a very small job fragment, a narrow area of responsibility and lack of any further learning can lead to much frustration for the employee.

This manifests itself in terms of drop in quality of performance (particularly where quality is a judgemental issue), lack of adaptability to changed circumstances, lack of any creativity, and other numerical indicators such as absenteeism (employees escaping from work) and employee turnover (an employee finds the work unchallenging with respect to his capabilities and therefore seeks a more challenging job elsewhere).

Take for example the case of a general post office that has several counters for dispensing stamps, postcards, inland letters, postal envelopes, etc. In order to improve 'efficiency' an O and M expert introduces a system whereby only one type of material will be available at any counter: it is either only postcards, or only inlands, and so on. All employees are also supplied with a ready reckoner for computations. The result is that the employee has no variety in his job, no different postal materials to handle, no different calculation to make and no fun of having an occasional argument with the customer over the calculation of the payable amount and small change due.

One of the reasons for strikes and industrial relations problems is job frustration. There is no challenge in the job; it has to be sought elsewhere. Demand for higher wages is, perhaps, only a symptom. To some extent one can say that enhancement in pay is demanded as a compensation, for the lack of challenge in the job.

'Bipolarisation' of Jobs

Technological advances produce a 'bipolarisation'—deskilling some lower level jobs and increasing the skill requirements at higher levels of jobs. This condition can only be cured by periodical job redesign considering the abilities of people and by a continuous effort of human resources development.

Job redesign can be of three kinds:

(a) Job Enrichment
(b) Job Enlargement
(c) Job Rotation

Job Enrichment

Job enrichment increases the amount of job 'satisfiers'* in a job. Thus the responsibility level (control by oneself), growth level (continued learning opportunities) and therefore the challenge level could be increased in the job, thus 'enriching' it. Of course, the people should be capable of handling these higher level demands of the "enriched" job.

If technicians in a large central government department are doing simple maintenance jobs such as soldering, fixing, etc. in a section under the detailed instructions of a junior engineer, then the technician's job can be enriched by giving him independent charge of maintaining certain equipment knowing very well that almost all technicians are either 3-year diplomaholders in engineering or science graduates.

One job enrichment leads to another at the higher level (or in the elimination of one of the higher levels). Consequently, in the above example the junior engineers' responsibilities have to be increased to include maintenance planning, and other first line managerial tasks.

The lower level jobs of the technicians could either be retained to retain the 'completeness' of the job or transferred downwards to other jobs making lesser demands at present.

Job Enlargement

It is not always possible to enrich jobs. Instead, one can increase the variety of tasks in a job. All these tasks do not differ significantly in their level of responsibility. This is termed as job enlargement.

For instance, if a Wireman and a Lineman are doing indoor and outdoor jobs of similar level of knowledge and skills, then there is perhaps scope for integrating these jobs and enlarging the base. This would also put the responsibility on one person.

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* Herzberg's Motivators or Satisfiers include:

(a) achievement (b) recognition
(c) work itself (d) responsibility
(e) advancement (f) growth

Job enlargement is gaining much relevance in the manufacture of automobiles, for example, which are traditionally made on an assembly line. The enlargement process, tries to make the jobs as "complete" as possible. The worker, therefore not only has variety but is also held responsible for a 'complete' job. Though the skills/knowledge/decision-making levels have not changed, the identification of the worker with his product is more complete raising his level of (Herzberg's) 'achievement' satisfier and giving him a feeling of having more control over his job.

The job redesign methods will not only produce more motivated workers, less defects in quality and higher productivity, but will also mean less supervision, and less movement of men or materials. Of course, there will be additional costs of training which will be small compared to the benefits gained.

Job Rotation

The third method is that of Job Rotation, whereby at periodic intervals people are posted at jobs of different nature (although of the similar level). For instance, production employees could be rotated in the maintenance department and vice versa. Both production and maintenance workers would have learnt different skills and would appreciate one another's problems. Where job enlargement cannot be done due to physical reasons, the variety and integration is brought in through a carefully planned periodic rotation.

HUMAN RESOURCE DEVELOPMENT

Any redesign means 'changes' for the employees. The resistance to change can only be won over by continual training input and preparing them to face the challenges, good communication between the employees and the management, and preferably employees' participation in the redesigning scheme.

Human resource needs a great deal of care from the management and it is a good manager's job to develop it; so that, what was human 'potential' yesterday becomes a real strength today.

Job Redesign is not just a jugglery of different tasks or levels of jobs. It has to be a commitment on the part of the management towards continuous development of the human potential to meet the newer challenges of the future.

QUESTIONS FOR DISCUSSION

1. What are the similarities between job enlargement and job rotation?
2. What is the impact of technology on jobs?
3. 'Job redesign should take into consideration the social value systems.' Do you agree with this statement? Why?
4. In attempting a job redesign in your organisation, what relevant data will you collect? How will you use it?
5. What are the financial implications of job redesign?
6. What will the implications of job redesign be for personnel policies such as selection and recruitment, promotion, etc.?
7. Discuss the importance of training in the context of job redesign.

8. As a consultant to a large government department, which is experiencing a tremendous growth in technology, with over 3 lakh employees all over India, you are contemplating a job redesign. What objections from (a) management and (b) unions do you visualise?
9. Herzberg mentions salary or money as a 'dissatisfier', whereas some people find money a good motivator. Is it possible to reconcile these two views? If so, how?



19 Productivity

The work study, inclusive of methods study and time study, job evaluation, merit rating, job re-design and financial incentives which were described in the earlier chapters have been known as Productivity Techniques since several decades. 'Productivity', in this context, means a measure of the quantity of output per unit of input. The input could be the man-hours spent on producing that output or it could be the number of machine-hours spent or the amount of material consumed (in number, kg, litre or Rs, etc.). Basically, productivity is known as the ratio between the output and the input:

$$\text{Productivity} = \frac{\text{Amount of output}}{\text{Amount of input}}$$

Since, in the earlier days of industrial management, it was considered very critical to control the labourers, the term productivity generally meant labour productivity. The time study, method study, incentive schemes and the like were seen as ways of managing or controlling the labour. The emphasis was on labour or, more exactly, on the labourers. The managers could understand the machines and could always run them faster or slower, for a longer period or a shorter period, of course within the capabilities of the particular machine or a set of machines. They thought that they could make the machine as productive as it could possibly be: Controlling the machines was easier–after all those were mechanical things; however, humans could not always be trusted to give the desired output. These needed to be monitored, standards to be established for them, prescribing a method, and sometimes being enticed to produce more by giving more money for more than the 'standard' output. After all, human being, in all truthfulness, was only an extension of the machine/equipment he was operating in the production shop. Nevertheless, this 'human machine' seemed to go berserk voluntarily. It was not a very honest machine. It needed standards of time, method and monetary compensation to put it (him/her) in place. These managerial control methods formed a major part of the techniques for productivity.

This is not to say that in the recent times human productivity has lost its importance. Human input is a major input into any business, management, government or society. Management is, after all, by the people and of the people; What is important is that now it is more and more recognised that management is primarily for the people.

Some of the ratios for labour productivity measurement are as follows:

$$\text{Workers' productivity} = \frac{\text{Workers' output expressed in standard hours}}{\text{Number of hours (man-hours) worked by the workers}}$$

$$\text{A Worker's or a group of worker's productivity} = \frac{\text{Number of units of output}}{\text{Number of days taken}}$$

$$\text{Another example of labour productivity} = \frac{\text{Number of toilets cleaned in a shift}}{\text{Number of cleaners}}$$

$$\text{A group of workers' productivity} = \frac{\text{Tonnes (or kg) of output}}{\text{Number of workers}}$$

$$\text{Labour productivity} = \frac{\text{Workers' Output expressed in Rupee Value}}{\text{Workers' Salaries and Wages in Rupees}}$$

Productivity, as measured above, represents the efficiency of the labour. These indices show how efficiently is the labour being utilised. As indicated earlier, these are the engineering indices of labour productivity. That is, labour productivity would be looked at the same way the machinery productivity is viewed.

Though there is nothing wrong conceptually with this viewpoint, it is a limited view. These are 'partial measures' of productivity. Further additions are required in order to get a complete picture of productivity. Before proceeding to a more comprehensive definition, let us look at the 'engineering' or 'efficiency' definition of productivity.

WHAT IS OUTPUT?

While productivity is seen as the ratio of output to input, it needs to be understood as to what constitutes the numerator 'output'. Take the case of a car tyre manufacturing company. If during the financial years 1996–97 and 1997–98 its output has been as follows:

Output	*Year*	
	1996–97	*1997–98*
No. of Tyres produced	16,000	20,000
Life of a Tyre in km.	20,000	15,000
Price of a Tyre in Rupees	2,000	1,600

Has the productivity gone up or down during 1997–98?

Assume that the level of input has been the same during both the years.

If one looks at the number of tyres produced, the year 1997–98 has shown a 25% [(20,000 – 16,000P) ÷16,000] increase in productivity. However, if the output is viewed as tyre-km, then the picture is reversed. The output in the year 1996–97 was 320 million tyre-km as against only 300 million tyre-km in the year 1997–98. So, the productivity, on this count, has gone down by $\frac{320-300}{300} \times 100 = 6.66\%$. If the output is viewed in monetary terms, then there is no change in the output and it is constant at Rs. 32 million.

One has to be, therefore, cautious while speaking about productivity. One or two of the above measures or all the measures may be relevant depending upon the situation at hand. For instance, at present when the competition is very hot, the monetary angle may be less relevant than capturing a sizeable share of the market; in such cases, the number of tyres produced is the most relevant figure. Lowering of the price could only be a short-term tactic to capture a larger slice of the tyre market. At other times, production in terms of its rupee value might be more suitable as a measure of productivity. From the long term point of view, customer satisfaction is vital. It will, therefore, be appropriate to consider the life of the tyre in the productivity calculations. In which case, tyre-km may be one of the suitable measures for measuring productivity.

DIFFERENT INPUTS AND PRODUCTIVITY MEASURES

Input, which is the denominator in the ratio of Productivity, also can be viewed differently at different situations. Inputs are of varied types: human input, material input, machinery input, money input, technology input and time input. Not all can be combined together to be put in the denominator as one entity; for instance, the technology and time inputs. Sometimes, it is better not to combine any; Productivity can then be judged on each of the inputs. Certain inputs are critical and therefore, very important from the productivity point of view.

For instance, if electrical power is scarce and, so is vital, then productivity could be measured with respect to power as the input. This will be a useful measure for the management in comparing it with a benchmark and taking appropriate decision to improve the process with regard to the use of power.

$$\text{Productivity} = \frac{\text{Number of tonnes of Aluminium produced}}{\text{Number of units of power used for the production}}$$

$$\text{or another ratio for Energy Productivity} = \frac{\text{Production value of the metal produced,Rs.}}{\text{Purchased Energy, Rs.}}$$

or for a gas-fired thermal generation of power, where the gas is limited, expensive and, therefore, a critical resource, the productivity of the generation of power would be

$$\text{Productivity} = \frac{\text{Number of units of power generated}}{\text{Number of Kg of gas used up for that generation}}$$

Similarly, one may be interested in productivity as it relates to the input of materials. We can have

$$\text{Materials Productivity} = \frac{\text{Production Output (Value in Rs.)}}{\text{Raw materials + Packaging Materials + Supplies (all in Rs.)}}$$

Even input measurement can sometimes give different pictures of productivity. For example, we can describe the input of labour or staff in terms of either the number of persons or the number of hours/days spent by them or the amount of wages paid to them which can be allocated to the output produced.

$$\text{Productivity} = \frac{\text{Number of units of output}}{\text{Number of persons employed to produce that output}}$$

$$\text{Productivity} = \frac{\text{Number of units produced}}{\text{Number of man-hours worked}}$$

$$\text{Productivity} = \frac{\text{Output at standard price}}{\text{Amount of wages paid in order to produce that output}}$$

Even here, one may ask: Should the denominator consist of only the direct labour or should it also include indirect labour? For, sometimes the contribution of the indirect labour towards the measurable output could be very significant. For instance, a continuous chemical process such as a petrochemical plant depends heavily upon the plant maintenance mechanics; and the maintenance mechanics are categorised under the category 'indirect labour'.

The point is, the use of a productivity measure is situation-dependent. The measure is to help the manager in monitoring and controlling the usage of the relevant inputs.

OTHER PARTIAL AND INDIRECT MEASURES

While labour productivity has been of much importance since the birth of management science, there are other inputs which are also important—for instance, materials, capital, management know-how, technology and time.

$$\text{Capital productivity} = \frac{\text{Value Added}}{\text{Capital employed}}$$

$$\text{Another ratio for Capital Productivity} = \frac{\text{Total sales in Rupees}}{\text{Depreciation of capital assets}}$$

There can be many other ways of describing capital productivity. We have already seen productivity with respect to materials and utilities. Productivity of management and/or technology is difficult to measure directly and performance ratios (indices) which are indirect can be suitably devised.

For instance, a production line manager's productivity is sometimes partly judged by the labour efficiency or material efficiency measures such as

$$\frac{\text{Standard hours}}{\text{Actual hours}}, \frac{\text{Standard material usage}}{\text{Actual material usage}}$$

These are not classic productivity indices, since they do not represent the ratio of output to input. Some other similar indirect measures of managerial productivity are shown below:

$$\frac{\text{Profit Before Tax}}{\text{Net Sales}}, \quad \text{Inventory Turnover} = \frac{\text{Sales (in Rupees)}}{\text{Inventory (in Rupees)}}$$

$$\text{Fixed Assets Turnover} = \frac{\text{Net Sales}}{\text{Fixed Assets}}$$

$$\text{Accounts Receivables Turnover} = \frac{\text{Net Sales}}{\text{Accounts Receivables}}$$

$$\frac{\text{Value addition (in Rupees)}}{\text{Number of employees}}, \frac{\text{Value addition}}{\text{Cost of materials}}$$

$$\frac{\text{Number of back orders}}{\text{Total number of orders}}, \frac{\text{Unscheduled down time}}{\text{Total down time}}$$

$$\frac{\text{Beds filled}}{\text{Number of doctors in the hospital}}$$

Example In Chinchwad Compressors Company for the year 1997–98, the net sales, inventory and accounts receivables have been Rs. 250 crore, Rs. 50 crore and Rs. 100 crore, respectively. Find the related productivity ratios.

$$\text{Inventory turnover} = \frac{\text{Sales}}{\text{Inventory}} = \frac{\text{Rs. 250 crore}}{\text{Rs. 50 crore}} = 5.0$$

$$\text{Accounts Receivable Turnover} = \frac{\text{Sales}}{\text{Accounts Receivables}} = \frac{\text{Rs. 250 crore}}{\text{Rs. 100 crore}} = 2.5$$

Accounts Receivables expressed as Number of Days of Sales

$$\frac{\text{Account Receivables in Rs.}}{\text{Sales in Rs.}} \times 365 \text{ days} = \frac{100}{250} \times 365 = 146 \text{ days}^*$$

MULTIFACTOR PRODUCTIVITY

It is right to say that the productivity measure should represent or reflect the overall capability and not focus on only one set of costs. The reason being that with the single factor productivity measures, it is easy to increase the productivity of one factor by replacing it with another. Labour, capital and materials are all potential substitutes for each other. Thus, in a company where the Just in Time system is improperly implemented, we may find that while the inventory turnover is high, the fixed assets turnover is low; thus, in the case of this company, the inventory is substituted by capital. Or, in another case, the company may decide to outsource heavily by cutting down on its production operations, selling off those machines and laying off some of its workers. In this case, the fixed assets turnover and labour productivity (sales to number of workers) will go up; but, materials productivity may quite likely fall because outsourcing mostly comes at a premium (higher cost). Hence, a multifactor view of productivity would be better.

The Total Factor Productivity (TFP) measure could be

$$\frac{\text{Production at standard price}}{\text{Labour + materials + overhead + k (capital invested)}}$$

where, labour, materials overhead and capital constitute all the input factors. 'k' is a fraction taking values below 1.0.

Example If 180 pieces are produced at a standard price of Rs 500 each, with a labour cost of Rs. 4,000, material cost of Rs. 20,000 and overhead of Rs. 12,000, the multifactor productivity would be

* More the number of days, in this case, would mean less productivity in the area of recovery which might affect the cash inflows.

$$\text{Productivity} = \frac{\text{Quantity at standard price}}{\text{Labour cost + Material cost + Overhead}}$$

$$= \frac{180 \text{ units} \times \text{Rs. } 500 \text{ per unit}}{\text{Rs. } 4{,}000 + \text{Rs. } 20{,}000 + \text{Rs. } 12{,}000} = \frac{\text{Rs. } 90{,}000}{\text{Rs. } 36{,}000} = 2.5$$

While TFP is comprehensive, the partial measures of productivity definitely have their place. These are easy to comprehend and when performance is up for review, people can generally explain what happened easily. From the manager's or the supervisor's angle, it is simpler to tackle each factor of input separately.

The manager selects a measure or measures that capture something that he/she feels is important to the competitiveness of the company. It is not always necessary to have the stereo-type measures of productivity. For instance, in the service sector businesses, it is not always possible to judge the employees actions based upon the output. In the service industry, the quality of the service is sometimes much more important than the physical output. For example, a cook or chef of a hotel cannot be judged by the quantity of the food cooked, but by its taste i.e. quality. Quantity could only be a secondary consideration. Similarly, the productivity of a designer cannot be measured by the number of models completed. If a good design improves efficiencies all over, then the fact that it has been designed by two people instead of one does not mean the designers are half as productive or less productive.

PRODUCTIVITY IN INDIA

Our national picture on productivity has not been and is not good if we compare it with several other industrialised nations. From the available statistics it is seen that the total factor productivity growth (TFPG) in India, during the one score years of 1960 to 1986, has been virtually zero—in fact, – 0.2 per cent (negative) per annum. Many other developing countries seem to fare better. (Refer Table 19.1.)

Table 19.1 Total Factor Productivity Growth, Per Cent Per Annum, Around the Years 1960 to 1985

Korea	4.5	Mexico	0.8
Indonesia	1.9	China	0.7
Egypt	1.7	Hungary	0.6
Turkey	1.5	Yugoslavia	0.4
Argentina	1.5	Philippines	– 0.2
Chile	1.3	India	– 0.2

Source: Adapted from Isher Judge Ahluwalia, *Productivity and Growth in Indian Manufacturing*, Oxford University Press, New Delhi, 1991.

Now, with the liberalisation of the Indian economy it has become all the more urgent that our industrial sector rapidly increases its productivity in order to match international competition. With this one not only has to compete with foreign competitors in the international market but also in our own country for many competitors have arrived, and more are likely to set their shops here.

There may be many viewpoints about the definition of productivity. But, whatever may be the definition, the fact remains that we have to do urgent thinking on productivity and the ways of enhancing it from the abysmal levels that it has been over the past several decades. There is no doubt that in our industries the inventories are of mountainous proportions, averaging from 50–60 days consumption to even several years of consumption or sales. In one of the public sector industries, it has been reported to be of almost 16 years requirement. Our private industry, despite the oft-mentioned 'profit motive', is not very much better. The recoveries are poor (60–90 days being common). Professional management systems are near-absent. If at all, lip-service is given to the latest management jargon. Several private sector companies where the ISO 9000 system for quality is in operation, have not shown any significant improvements in the productivity in the elementary aspects of quality such as reduction in percent defects or defectives, rejection rates, warranty costs, and the like over the past six to seven years. Cycle times for production are very high, so also the cycle times for the development of a product. Delivery times are huge and erratic, almost always in several months.

There is no doubt that the Indian manufacturing industry will benefit by the application of even the elementary management concepts such as ABC & VED analysis, variety reduction and simplification, value engineering, improvements in plant layout and materials handling, simple forecasting and business planning, methods and process improvement, simple market research, etc. In the competition with the multinational companies, these simple measures will help our industries to stay at least at the base-line, if not a little above.

In the technological services sector—IT, BT, R&D and ITES—India holds a clear cost advantage and productivities are good enough to attract service work from overseas (outsourcing)

EFFICIENCY AND EFFECTIVENESS

While the productivity in an organisation can be improved by better application of materials, improved processes and machinery, faster production lines and application of more energy from the workers, however this is not all. The productivity measures mentioned in this chapter so far and the techniques of time study, methods study, production scheduling, inventory control, etc. discussed in other chapters are basically efficiency-oriented.

There is nothing wrong in being efficiency-oriented; however, when the prime motive is efficiency rather than effectiveness, the productivity improvements happen to be generally of a short-term nature. More lasting and more appropriate results can only be produced through a change in the attitudinal aspects of the people in the organisation from the top to the lower level.

The attitude of the top management has to be right in order to give the right direction. The attitude of the lower levels of people has to be tuned to that of the higher levels of management, so that the right message is picked up. A right direction leaves a prolonged impact on productivity. Productivity is a vector and not a scalar quantity.

If emphasis is laid only on increasing efficiency, no doubt there will be more action. Machines will work for long hours, surplus quantity will be produced, more papers will be shuffled or filed, more people will be seen running around, and there will be more of everything that you can see. But, such an effort will in fact be worthless. A well-run organisation improves productivity by eliminating such unnecessary exercises and reassigning the persons to needed work. The following Table 19.2 brings out the difference between efficiency and effectiveness.

Table 19.2 Differences between Efficiency and Effectiveness

	Efficiency	*Effectiveness*
Objective:	To produce quantity and quality	To enhance the value to the customer and, therefore, to the society.
Goal:	To improve the process and/or the product	To determine the right direction for the organisation and the value that needs to be generated.
Questions:	*How* to perform a task (whether in production, marketing or any other area)	*Why* to perform something and, so, *what* to perform.
Satisfaction Measure:	"Is everything running well?"	"Are we aiming right?"

Source: Adapted from: Kurt Hanks, *Up Your Productivity*, Crisp Publications Inc, Menlo Park, California, USA, 1990.

While more output with the same or reduced inputs is good, it must be remembered that all that is 'put out' is not output. A product can be truly termed as an output only if it is marketable; that is, if the customers want it and are ready to buy it. Too much of quantity orientation entails a danger that one will be so submerged in work, that he/she will not be able view, listen or even think about the customer.

After all, it is the customer for whose satisfaction an organisation works hard. Overemphasis on trivia can drown out critical thinking and acting. It takes constant reaffirmation of "what the business is about" in order to stay at the top.

QUANTITY ORIENTATION

Our Indian industry is replete with quantity orientation. There are always AOPs (Annual Operating Plans) or targets to meet. The activity during the year-end (February and March) is feverish. Again, during April and May there is a lull. Obviously, market is not asking for this pattern of production. Production volumes are not driven by the market but by the 'targets' or the numbers themselves. Several managers, from the top to the junior level, are busy saving their skins because, their productivity or performance is measured by the numbers without relating to the ultimate objective of the organisation of providing value to the customer. The real objectives and goals lie in the background and the 'appearance' of managerial productivity takes the front seat. Sometimes even the modern management techniques/procedures become the victim of the following 'appearance' orientation—'In our unit we have been doing 'Business Process Reengineering'. 'We believe more in TQM for which we have begun a Small Group Activity.' 'Through ERP (Enterprise Resource Planing) we are going to cut down our late deliveries by one-third (from the present level of about 80 per cent)'.

While the techniques are good, the 'intent' behind the usage of the buzz-words is missing. Therefore, the application takes place half-hazardly, if at all. The buzz-words have become status symbols of the managerial class in a large number of Indian organisations. In several cases, unnecessary work evolves because of wrong orientation at the top. Efforts to increase productivity need to focus more on managerial work. 'Hard-working' and 'efficient' managers may be really unproductive or, worse. They may create useless work for themselves and others. In order to make an organisation more productive, it becomes wise to reduce the organisational levels or managerial levels. Productivity does not mean production.

It must be emphasised that e1ven if the quantitative measures were implemented in all seriousness, these measures by their own merit shall produce results only upto a limited extent and for a certain duration. Emphasis on mere 'Houskeeping' may divert the organisation's focus from the very purpose of a business, which is to provide value to the customer. More lasting and better results require combining both the approaches viz. efficiency and effectiveness. If any, the latter approach should dominate between the two.

Efficiency, by its very description, is reactive. It cannot be pro-active. It has to be measurable; but, what happens in the future is not measurable. Efficiency has to be more historical. The future of efficiency is designed from the past. It is based on only what is presently known. It deals with things that are present here and now. When the future turns out to be different, efficiency is not of any use. In fact, in some cases it may get the organisation into trouble because the organisation has spent all its time in problem-solving and fire-fighting, rather than on conceptual thinking. It has all along looked at problems and not at seeking and/or creating opportunities. True productivity calls for a managerial 'vision'. Figure 19.1 is illustrative.

BUSINESS PROCESS REENGINEERING

In the recent past, companies have sought to increase organisational productivity through radical changes by means of Business Process Reengineering (BPR). BPR is about taking a hard look at why the organisation does the things the way it does. It involves fundamental rethinking. It is not about incremental or continuous improvements; also, it is not about some work study or process study here and there yielding 5 or 10 per cent improvements. Business process reengineering is about revamping or overhauling the existing processes and redesigning them from a clean slate, in order to achieve significant improvements in critical measures of performance.

BPR requires that the firm gets out of its institutionalised or rigid thinking ('We have always been doing it this way') and do rethinking. The business *process*, which consists of all tasks that create outputs of value to the customer should be looked afresh. The analysis is not limited to

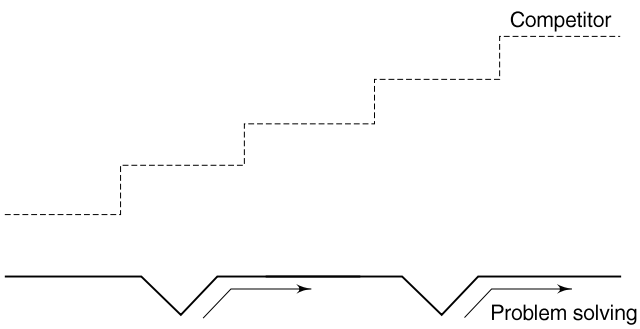


Figure 19.1 'Danger of Thinking only about Problems'

Adapted from Edward de Bono, *Sur/petition*, Indus imprint of HarperCollins Publishers India, New Delhi, 1993, Fig. 1.2, p. 7.

With kind permission from HarperCollins Publishers Ltd, London, UK.

functional areas or to departments. It involves organisational changes, redesign of the work, rationalisation and integration of all the tasks and work-flows, use of information technology to bring in the speed of response, creating the information base and bringing in connectivity between various tasks, functions, areas and departments at different levels so that ultimately the customer benefits through a superior service/value provided to him. In BPR parlance, 'processes' mean all those actions that lead to results in terms of the customer satisfaction. It brings in the people and tasks to achieve the ultimate organisational objective.

The genesis of BPR was in the traditional hierarchical vertical organisations which resulted more often in departmental or function-wise efficiencies but did not always result in the achievement of the ultimate organisational objective. It is a known fact that from getting a customer order to its fulfillment, the processes for the order flow more or less horizontally and across various functions and hierarchical structures. BPR takes this lateral view of the organisation rather than the vertical view (Refer Fig. 19.2). The important things in BPR are the processes, which are different from operations, and thus the customer-oriented changes. Processes concern with results (i.e. organisational objective orientation) whereas operations are function/job oriented. Although, in Indian industry we find firms resorting to BPR only when they have reached a stage where only radical changes are required, the use of BPR need not be restricted to only such 'critical' cases where the companies find themselves in a jam. BPR exercise can also be implemented while a company is sailing smooth. The changes in a BPR exercise need not necessarily be radical. Many a time it is thought that the main component of any BPR is information technology; this, also, is an erroneous view. Many BPR actions need not/do not involve IT. IT is not the panacea for all problems. The emphasis of BPR is and should be outside the organisation—at/for the customer. IT, if inwardly focussed, which is generally the case, and only at the internal problems of the organisation, it produces more of the unnecessary (and, therefore, wrong) data about the inside and nothing much about the happenings outside the organisation. In such a case, IT may possibly do more damage than provide help to the management of the enterprise.

Reengineering literally means to redesign the processes in order to serve the organisation's objectives. TQM also has the same purpose. However, historically speaking, TQM approach seemed to be more gradual, incremental, continuous and bottom-to-top; whereas, BPR approach was

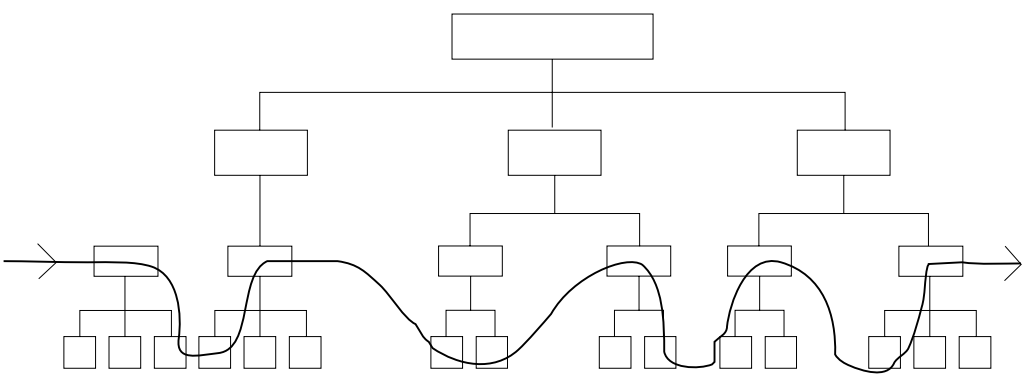


Figure 19.2 Processes Flow Horizontally while the Organisation is Vertical

considered to be more radical, fundamental, surgical or dramatic and top-down. This kind of distinction gained ground because many organisations had accumulated so much of rust and were so confused in their orientation that a radical shift was perceived to be essential prior to any gradual change. But, as is evident, the objective and focus of BPR and TQM are the same i.e. providing the customer the appropriate service.

BENCHMARKING

While carrying out TQM or initiating BPR, the company should have a basis of establishing performance goals. These basis, which should be the best practices in the industry, are called the benchmarks. Such benchmarking should lead the company to superior performance. Xerox Company, USA, which was the leader in the use of benchmarking as a management technique or process, terms benchmarking as, 'the continuous process of measuring our products, services, and business practices against the toughest competitors or those companies recognised as industry leaders.'

Benchmarking is not a new concept. All of us do benchmarking, in our usual lives. We admire some people for the way they speak, for the way they conduct themselves, or for the way they dress and eat. Many of us have some role models whom we try to emulate. This process is also called as benchmarking.

CLASSIFICATION*

Internal Benchmarking

One must know one's own internal processes and compare within units, across units or divisions. This, in fact, should be the first kind of benchmarking any company should do, for it is the easiest, quickest and cheapest type of benchmarking. All the information is available from within one's own company. However, the big limitation is that one is simply looking at one's own processes. Hence there may not be any significant or radical improvements.

Competitive Benchmarking

This involves comparison between specific competitors for the product or function of interest. Obviously, not an easy thing to do; a competitor generally does not give data on his company and its processes. Nevertheless, one may collect the data through secondary sources such as newspapers and magazines, seminars, networks, industry associations, one's suppliers, one's own sales people, customer feedback, consulting firms, clearing houses and government sources such as departments of industry and commerce. By being informed about what one's competitor is doing, one learns how to design, manufacture and market in a better and planned manner.

This benchmarking could be done collaboratively between a group of several competing companies, where there could be a limited exchange of information.

When such collaboration is not possible, companies may do shadow 'benchmarking' i.e. doing benchmarking without one's competitor's knowledge.

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* Camp, Robert C., *Benchmarking*, ASQC Quality Press, Milwaukee, Wisconsin, USA, 1989.

Functional Benchmarking

This involves comparison of similar functions within the same broad industry or with industry leaders. The benchmarking partners, therefore, need not be in direct competition. This analysis seeks ideas that have already succeeded in a compatible area as well as conveys that it is not necessary to concentrate solely on direct product competitors. Within the ambit of the general industry, this procedure helps a company to know how other companies follow inventory reduction, delivery timings, materials handling or packaging practices. Which in fact helps the benchmarking company to suitably adapt their superior practices.

Generic Benchmarking

It is not always necessary to learn only from the firms that are competing or those that fall within ones general industry. Some processes are same regardless of the dissimilarities of industries. For instance, Xerox benchmarked American Express for its process of billing and collections, American Hospital Supply for automated inventory control, Ford Motor Company for their manufacturing floor layout,L.L. Bean for warehouse operations, and Mary Kay Cosmetics for warehouse and distribution efficiency.* A mining company in the interiors of Thar Desert has a dust problem; it wants to eliminate dust that spoils all its in-house machinery. Where should it look for benchmarking? One should not be surprised if it looked at a reputed hospital, particularly its operation theatre for the dust prevention systems. What needs is an adaptation of these systems to suit the mining company's operations. In fact, generic benchmarking would yield the best of best practices.

Benchmarking is not only for processes but also for comparing ourselves against the best in terms of success factors such as customer satisfaction provided (what? how much? how?), cost reduction (what? where? how?), services (what? where? when? how?) provided, finances raised (how much? which areas? how?), products made, items purchased such as the components, raw materials and supplies (what? how much?, where?, when?, how?), and the like. This helps to develop superior competence.

Benchmarking is a must for any good BPR exercise so that a company can analyse the what, why and how of leading companies, so that one can reengineer or change the business practices, processes as also the products that will satisfy the customer and thus generate value to the society.

In any case, it would be appropriate to mention what Gary Hamel and CK Prahalad** have said:

A company surrenders today's business when it gets smaller faster than it gets better.

A company surrenders tomorrow's business when it gets better without getting different.

The message is: be proactive, in addition to getting better. Benchmarking and BPR should serve as triggers for proactivity, in addition to help improve the existing products, services, processes and systems.

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* James G. Patterson, *Benchmarking Basics: Looking for a Better Way*, Crisp Publications Inc., Menlo Park, California, USA, 1996, p. 4.

** Quoted from: 'Business Process Reengineering: The Truth and the Hype', *Analyst*, March 1997, pp. 23–31.

MEASURES TO INCREASE PRODUCTIVITY

So, what needs to be done in order to increase productivity? Here is a partial list:

- Be clear about your organisation's mission i.e. what contribution it wants to/can make to the society. Who your customer is, or should be, depends upon this decision.
- Be customer oriented. Know your customer. Understand your customer.
- Be proactive and chart out organisation's direction to provide service to the customer.
- Communicate this understanding, care and concern for the customer and the organisation's direction to all employees and all those who interact/contribute in the value chain.
- Have goals and values of common consent. Make sure that the needs of the individual and the organisation correlate well with each other. Create a sense of belongingness. Encourage team work.
- Let each employee realize his/her full potential and the potential of the 'family'.
- Empower the people involved.
- Encourage creativity.
- Make value-based decisions.
- Express care and concern for all employees, vendors, dealers and all those who collectively help the company.
- Once the philosophy, values, attitudes, and intent are established, make use of the relevant productivity techniques and measures including the conventional and modern, like BPR and Benchmarking.
- Assign right people for right jobs. Appoint specific people in charge of specific tasks.
- Learn from failures and allow others to learn from experimentation and failures.
- Keep things simple, avoid complexity and confusion.
- Make the organisation as flexible as possible.
- Make the organisation as much a 'learning organisation' as possible.

It is interesting to note that many of the above mentioned dicta sound familiar—as belonging to the service industry. Production management is indeed getting closer and closer to the management of service.

TRANSFORMING THE ORDINARY TO THE EXTRAORDINARY

Productivity is not about using of manpower. That is a wrong or perverse way of looking at productivity. It is a very 'mechanical' view which has prevailed so far, particularly in economies endowed with cheap labour and abundant natural resources. It is generally misunderstood that the advancement of science and technology is going to make the world more mechanical by reducing dependence on labour, staff and the consequent 'problems' that need to be solved. But, contrary to these predictions, the factory of the future will not be a monument to the triumph of technology over human beings. Instead of a zero-sum relationship between technical and social systems, where every advance in technology would require a reduction in human importance, a positive-sum relationship would emerge. Increasing input of technology is supposed to give speed of response and flexibility. But, this speed and flexibility, in turn, requires a work force that is more skilled, more informed, with a better understanding of the organisation's vision, values and direction, and with a much greater empowerment. In order to ensure this they should be trained adequately. Training can also foster team spirit and group effectiveness.

It should also be realised that in the coming future, more and more workers will demand supervisory tasks and supervisors will demand managerial tasks. It is a challenge of the future that while cutting down on the managerial hierarchy, the organisations will have to meet the aspirations of the workers/staff to be the effective managers of the organisations. The 'management' has to let go of a substantial share of its responsibilities to its workforce. As Peter Drucker, the world-renowned management consultant, said: 'The purpose of an organisation is to enable ordinary human beings to do extraordinary things.'* In one of the Human Resources Conferences, the Managing Director of Timex Watches (India) mentioned how in his company young high school dropout women have been trained to do complex computer-based jobs for which normally computer graduates are hired in other organisations.

PURSUIT OF EXCELLENCE

Productivity is taking more and more the meaning of excellence, which has to come about in all types and levels of jobs and responsibilities. Improving productivity would mean encouraging excellence.

As John W. Gardner* said:

An excellent plumber is infinitely more admirable than an incompetent philosopher. The society which scorns excellence in plumbing because plumbing is a humble activity and tolerates shoddiness in philosophy because it is an exalted activity will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water.

A commitment to excellence means to constantly strive for producing the highest possible results. It means continuous improvement. In such a case, 'standards' for productivity may come in the way of pursuing excellence. Because standards prescribe what is 'good enough'; unless a standard is not seen as a rigid concept. Standards should be there for the very purpose of better future transformation. A standard should be the base-line from which further improvements can be made.

We cannot escape the fact that productivity and society are closely linked, just as the organisation and the society are inseparable. The society's, as also the organisation's thinking determines productivity. Productivity is definitely contributed to by improved methods, procedures, techniques and systems but, it is much more than that; as Joji Arai,** Director of Washington, DC, USA office of the Japan Productivity Centre said: 'Productivity is a state of mind'. And the state of mind should be to excel and through this excellence please the customer, contribute to the society while ensuring that the organisation survives and thrives. It should be everybody's endeavour to create that state of mind within self and then in others.

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* As quoted in Kurt Hanks, *Up Your Productivity*, Crisp Publications Inc., Menlo Park, California, USA, 1990.

** Schaffer Robert (Editor), *Managing Productivity*, Jaico Publishing House, Mumbai, 1995, p. 8.

Highlight

A JOURNEY TO EXCELLENCE: TATA BUSINESS EXCELLENCE MODEL

Companies within the Tata Group are required to ensure that they demonstrate consistent corporate leadership in order to build and enhance the Tata brand equity aligned with the group purpose of 'Leadership with Trust'. The signing of the Brand Equity and Business Promotion (BE-BP) agreement by the Group companies with Tata Sons is a significant aspect in this regard.

Consistent corporate leadership is demonstrated through consistent business health and a never-ending quest for business excellence. Achieving world-class levels of performance in all aspects of business is one of the key objectives. However, business excellence needs to be pursued in a highly structured and systematic manner.

Tata Business Excellence Model (TBEM) provides such a common framework for assessment and planning for further improvement across all the Tata Group companies. All the Tata Group companies are required to adopt this framework. Such an assessment would help a company to determine as to where it stands in its journey to excellence. A company is expected to attain and maintain a minimum standard vis-à-vis this model. The quantifiable minimum standard depends upon the number of years since the company signs the BE-BP agreement. TBEM is based on the internationally acclaimed Baldrige Award criteria.

The TBEM criteria for performance excellence are built upon a set of core values and concepts that are embodied in seven categories:

1. Leadership
2. Strategic Planning
3. Customer and Market Focus
4. Measurement Analysis and Knowledge Management
5. Human Resource Focus
6. Process Management
7. Business Results

These are shown in Fig 19.3.

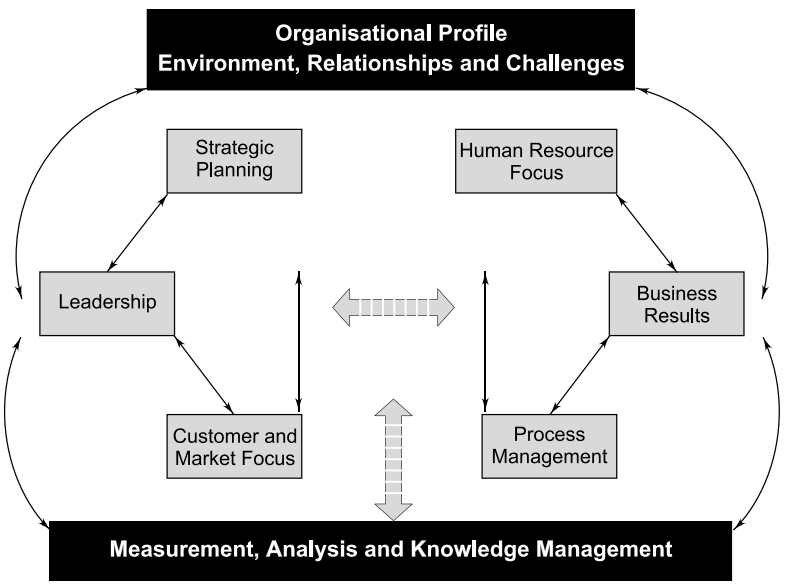


Figure 19.3 Tata Business Excellence Model: Framework

As shown in the model, a company's organisational profile (Environment, Key Working Relationships and the Strategic Challenges) sets the context for the way the company operates.

Leadership, Strategic Planning, and Customer and Market Focus are placed together to emphasise the importance of a leadership focus on strategy and customers. Together, they represent the leadership triad. A company's senior leaders set the direction for the organisation and seek future opportunities for it.

Human Resource Focus, Process Management and Business Results represent the results triad. An organisation's employees and its key processes accomplish the work of the organisation that yields its business results. Business results are a composite of customer, financial, and operational performance results, including human resource results and public responsibility.

The horizontal arrow in the centre links the leadership triad with results triad, a linkage critical to organisational success. Moreover, the arrow indicates the central relationship between leadership and business results. The two-headed arrows indicate the interrelationships and the importance of feedback.

As indicated in the model, Measurement, Analysis and Knowledge Management form the foundation for the performance management system.

Courtesy: Titan Industries Limited, Hosur, Tamil Nadu.

QUESTIONS FOR DISCUSSION

1. 'Productivity improvement is not a one-shot project' Do you agree with this statement? Discuss.
2. What are the difficulties in measuring productivity? Discuss.
3. Is Total Factor Productivity a sum of all partial productivities? Explain your answer.
4. An electrical equipment manufacturing company manufactures AC Motors, DC Motors and Transformers. During the month of December, the production of these items in Rupee terms has been, respectively, Rs. 140 million, Rs. 250 million and Rs. 90 million. The inputs of human resources, capital, materials and power have been as given in the table below:

		Product		
		AC Motors	DC Motors	Transformers
Input Rs. million	Human	14	23	12
	Capital	28	81	14
	Materials	72	108	24
	Power	9	20	10

   What are the partial productivities of each of the inputs?
   What are the total productivities of each of the three products?
   What is the Total Factor Productivity (TFP) of the company?
5. How are partial productivity measures inadequate in monitoring overall productivity of a firm?

6. What is Managerial Productivity? Can you measure it? Discuss.
7. What is Sur/petition as Edward de Bono calls it? Explain.
8. Is there anything wrong with a problem-solving approach? Discuss the right and wrong.
9. What has customer orientation got to do with productivity?
10. What is meant by being proactive? Give two examples in the realm of productivity.
11. Does benchmarking help a firm to be proactive? Explain your answer. Give two examples each of the different types of benchmarking.
12. Can TQM, benchmarking and BPR be related exercises? Discuss the connectivities and the differences.
13. Discuss the role of HRD in organisational productivity improvements, particularly in the light of technological advances and automation in both manufacturing and services industries.
14. India prides itself on its 'Family' culture. Family is the anchor for the Indian society. Can this culture at home be transferred/translated to a similar culture in business/work place? Discuss.
15. Get information on Japanese management. How is it different from traditional Western management? What are the plus and minus points in each? Discuss.
16. How are society and productivity linked? Discuss in relation to the Indian situation.

ASSIGNMENT QUESTION

1. Visit any organisation. Present a detailed report on how productivity can be enhanced by means of a Job Redesign.

SECTION IV

Supply Chain Management

Chapter 20 Purchasing
Chapter 21 Inventory Models and Safety Stocks
Chapter 22 ABC and Other Classification of Materials
Chapter 23 Materials Requirement Planning
Chapter 24 Other Aspects of Materials Management
Chapter 25 Physical Distribution Management
Chapter 26 Materials Management—An Integrated View
Chapter 27 Supply Chain Management
Chapter 28 Outsourcing

Philosophers all over the world and across the ages have often opined that the whole world is interlinked. Indian philosophy stretches it to the extent of *vasudhaiva kutumbakam* meaning 'the whole world is a family'. A light brush of this philosophical thinking is seen in supply chain management. Perhaps, globalisation of business may have been the trigger that caused it.

It is quite obvious to anybody that a manufacturing factory (or even a service centre) needs to coordinate with its suppliers in order to ensure that its production (or other) operations run smoothly and thus it is able to serve its customers. Supply of components, parts and/or services are essential to the running of operations in any business. Such chains of *supplier* to *factory* to *customer of the factory* have

always existed. Even in this 21st century, the traditional tasks will retain their importance as long as a factory (or a service centre) has to cater to its customers.

However, what is new is that, currently a huge emphasis is placed on the linkages or 'chain' aspect of the process. With business getting globalised and with outsourcing and offshoring getting more common, these links of the chain may even be based abroad. It is being increasingly realised that unless these chains are strengthened, a company cannot serve its customers and satisfy them and thus remain competitive for long. The coordination of materials, information and financial flows that is seen today has not been experienced in this magnitude before. Coordination upstream and down stream have been there earlier too, but not to this extent.

Supply chains always existed; what is different today is the 'supply chain thinking'. What happens to the supplier is of as much importance as what happens to the factory itself. So, today one likes to know about his supplier's problems. One would also like to consider the requirements of the customer's customer. Only then could one deliver superior service. One would not only like to know about these, but also do something about it. That is, a company would know as to what its supply chain is and then 'manage' it for optimal results for all the entities constituting the chain (see the following figure).

SUPPLIER'S SUPPLIER → SUPPLIER → MANUFACTURING COMPANY → CUSTOMER → CUSTOMER'S CUSTOMER

Figure: **Supply 'Chain'**

All the companies in the chain have to gain. Neither can it be a solo performance, nor can only a few benefit while the others do not. It has to be a 'win-win' situation for all in the chain. Competitiveness is not only about an individual company's performance, but the entire supply chain. In other words, the competition is no more between individual companies, but between different supply chains.

However, it ought to be emphasised that the traditional functions do not vanish. They do remain. Purchasing has to be there and will be there. Inventory control will be there. Managing depots and warehouses will be there. So, will materials handling, transportation and logistics. What changes is the orientation—a new outlook of teamwork, the way the managers would look at the participants in supply chain. Managers now look at various functions within the company as linked and not as isolated ones. With this new outlook the insular attitude would go and with it would come needed changes in the systems and procedures that would support the new business logic—the logic of mutual dependency, of partnership and of supporting each other for the greater good of the whole.

Since the traditional functions do remain, they will be discussed individually. The techniques, tools and issues described therein would be relevant even now. However, with the supply chain orientation, there would be a change in the way the managers deal with the issues. Supply chain management is all about realising that indeed it is a 'chain' and therefore applying the time-tested techniques and procedures with the 'chain' in view.

20 Purchasing

PRIME FUNCTION

For an organisation, purchasing is a window to the outside world. The prime function of purchasing, is that of being sensitive to the external supply market situation and also of feeding back this information to the other functions of the organisation. However, it is usually understood to be to get the right quantity of material of the right quality at the right time, at the right place, from the right source and at the right cost.

Quite often it is not understood, by even top executives, that a considerable profit potential exists in the purchasing activity. In fact, it has been quoted that 20–30% of a company's profits can come from savings generated in the purchasing department. Suppose a company's output volume is Rs. 20 crore and the cost component of materials is say 50% (that is Rs. 100 crore for materials). If the profit margin is taken as 15%, the gross profits will be Rs. 30 crore. With a 20% increase in the output volume, the profits will increase by Rs. 6.0 crore. The same increase in profits can be achieved by 6% savings in the purchase costs. This example is given to illustrate that there is a lot more potential in reducing the purchasing costs as compared to increasing the sales turnover. Moreover, the increased savings in purchasing require only one or two purchasing executives doing a proper study and analysis of the external market. Whereas an increase in sales volume usually means an increased capital outlay on equipment, an increased sales and marketing expense through increased advertising and promotional expenses, and much more leg work by the salesmen. All this means more efforts, expenses and risks. Compare this with the efforts required in generating equal profit contribution from the purchasing department and one will realise that the latter does not require such enhanced management effort and risk. A point to be noted is that the cost of materials in the production cost of an item, on an average, in the Indian manufacturing industry takes a lion's share of almost 65%. For some industries this component could be even higher. This only highlights the importance of the attention needed for the purchasing activity.

LINKS WITH OTHER ORGANISATIONAL FUNCTIONS

Purchasing has important links with most of the organisational functions. The Production Planning and Control or Materials Control sections might have a say in the inventory of raw materials and bought out parts; but the purchasing executive has a first hand knowledge of the market situ-

ation for the supply of these items. For instance (1) Is there going to be any shortage in the near future? (2) How will the shortage escalate the prices? (3) Are there any good substitutes available? (4) Will there be an industrial relations problem in the important supplier's company and how will this affect the company's production? (5) Which supplier can supply better quality material and better quality component parts at the same or less price? (6) Which are the potentially good vendors who could be developed into reliable suppliers and loyal partners sharing the concerns in the business? All such information regarding the outside market is of much importance to the production, marketing, finance and other departments. If a company buys component parts which are incorporated into its own products, the purchasing manager will have to play a role which can perhaps, be described as 'External Manufacturing Manager'.

Increasing the sales does not always result in increasing profit. Sometimes increase in sales may mean a decrease in profits, because with an increase in volume, the cost of input materials may also rise. This is where the purchasing department's feedback information is useful. It can apprise the management of what an increase in sales activity will entail. The marketing/sales and purchasing departments have to work hand-in-hand in order to take care of such situations. Purchasing is as much in contact with the external market as the sales department is. The sales department may be concerned with the customer market, whereas the purchase department may be looking at the supply market. In fact, both are looking at the external environment and therefore, exchanging of notes between the two departments is important to the organisation.

In cases where the Inventory control or production planning and control (PPC) departments set certain inventory levels for raw materials, these norms for stocking levels are for average situations. When the external market is other than usual, the purchasing executive's feel of the supply market should provide valuable input to PPC or inventory control. The normal stocking levels and service levels do not mean much in such situations. Purchasing can also provide valuable information regarding substitutes which may be cheaper and functionally better or at least as good.

The purchasing executive may also spot certain extraordinary opportunities to get the raw material at a low cost. The point is that an organisation can make use of the valuable market information provided by the purchasing department, and consider it not merely as a department processing purchase requisitions but as a vital link between the external environment and the organisation. A purchasing manager should provide this link consistently. This is as much true for a service organisation as that for a manufacturing organisation.

OBJECTIVES

The objectives of the purchasing department can be stated as follows:

1. To ensure availability of proper quantities of materials for smooth functioning of the production department.
2. To procure materials at reasonably low costs (not necessarily low prices) for the company.
3. To ensure supply of quality materials.
4. To select the proper source/s of supply in order to ensure the above points (1, 2 and 3).
5. To keep abreast of various substitute materials available in the supply market, their prices and utility to the organisation; to pass or discuss such information with the various other departments of the company such as design, production, sales, finance, etc.
6. To study or research possible substitutes for the raw materials and boughtout component parts; for this, the technique of Value Analysis/Value Engineering will be useful.

7. In order to ensure the continuity of quantity and quality of the supplied raw materials (at competitive prices), to develop new vendors and maintain good relations with existing vendors. Vendor relations, vendor monitoring or vendor evaluation and development of new vendors is an integral part of the purchasing executive's job.
8. To develop good procedures and systems for the purchasing department, so that the various purchasing objectives do not remain personalised but become institutionalised.
9. To coordinate with other functional departments to achieve continuity of information flow and integration between different departments as much as possible. For this purpose, it becomes essential for the purchasing executives to keep in touch with the various functions of the company such as Design, Production, Sales, Finance, etc.

The *Wall Street Journal* had quoted W.F. Rockwell Jr., President of the Rockwell Manufacturing Company, USA, stating that a purchasing executive's job is not simply to buy a product at the lowest possible price rather he should be one of the most knowledgeable managers in his company who understands Design, Engineering, Production, Marketing and other related functions in sufficient detail. In short, a Purchasing Executive's role is not restricted to procuring the requisitioned goods at a low price and at proper time, but is also to be knowledgeable and informed about not only *what* is being bought, but also about *why* it is being bought. The role of a Purchasing Manager is that of being well informed about the internal operations of the company as also about the external supply market, and to combine these two in procuring materials at the right quantity, quality, time and cost, so that the organisation/firm as a whole benefits on a sustained basis.

MANAGEMENT OF SUPPLY: AN INTEGRATED APPROACH

However, the Purchasing Manager is not always the final decision-making authority regarding the quality, quantity, time or cost of the materials. It may be so in some organisations, and not so in many others. What we said earlier emphasises the integrated approach towards the management of supply of materials by being sensitive to the internal and external environment, and being one of a team of decision-makers for the input materials. The Purchasing Manager should serve as a link for the various internal departments and external environment. He should be an advisor, informer to various departments and a consolidator of various conflicting objectives/opinions inside and outside the company. Often this is misunderstood to mean that the purchasing executive should have an authority over all the segments of the function of procuring the input materials. Such authority may not exist in most of the cases. A purchasing executive has to produce results by advising and coordinating his activities with that of various other internal departments and the external market.

BAYESIAN ANALYSIS

Let us see how a purchasing executive might provide his knowledge of the outside environment to help the functional departments within the company. Suppose a company is buying a petroleum derivative as raw material. The purchasing executive feels that there might be a meeting of the OPEC countries in the near future resulting in an increase in petroleum prices which in turn will result in increase in the price of its raw materials. He also figures out that even if the meeting does not materialise, the supplying company may increase the price of the raw material due to escalation of the cost of various other inputs. Of course, the price increases in the latter event will be lower

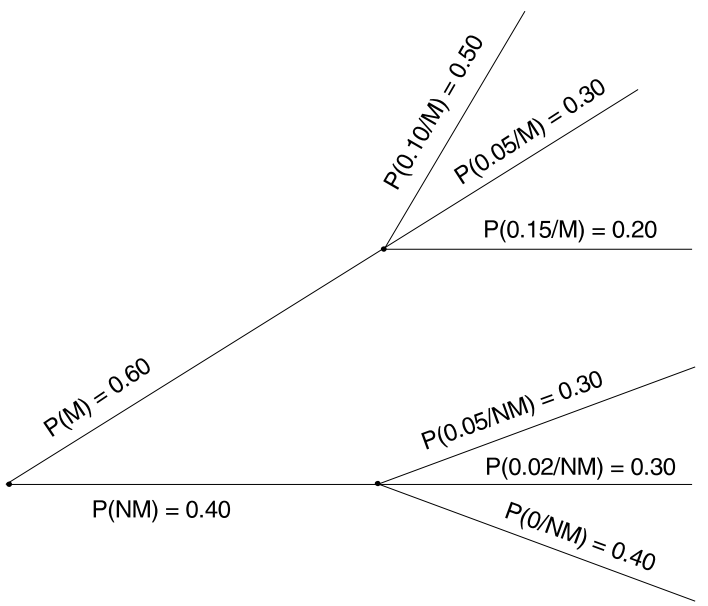
than the price increase in the former event. The Purchasing Manager, therefore, based on qualitative and quantitative data gathered, estimates the probabilities of the petroleum price hike by the petroleum producing countries. The following are his estimates of various probabilities:

1. He estimates that the probability of the OPEC meeting materializing is 60%.
2. If this materialises, he estimates an increase of 10% in the price of his company's input material at a probability level of 50%. Moreover there is 30% chance that the price may increase by 5%, and 20% chances that the price may increase by as much as 15%.
3. Even if the OPEC countries postpone their meeting, he estimates that the probability of price rise for the raw material is 30% for a price rise of 5%, 30% for a price rise of 2% and 40% for no change in the prices.

The purchasing manager is assessing the impact this information may have on the requirement of finance for the procurement of this material. At present, the company is buying Rs. 1,00,00,000/ = worth of this input material.

Figure 20.1 shows the decision-making process used by the purchasing manager.

We can use Bayesian Analysis to determine the impact of various possibilities on the ultimate financial needs. The Bayesian Theorem states that the probability of a certain event occurring, if it is conditional on the occurrence of a previous event, is given by the product of the probability of the previous event and that of the present event. For instance, the probability of 10% price rise, given that the event of OPEC meeting occurs, is computed to be: $P(M) \times P\ (0.10/M) = 0.60 \times 0.50 = 0.30$.



NOTE: M ≡ OPEC meeting takes place.
NM ≡ No meeting of the OPEC.
P ≡ Probability

Figure 20.1 Bayesian Analysis for Purchasing

Likewise, the probabilities of various events can be calculated as given below:

Probability (0.05) = (0.60 × 0.30) + (0.40 × 0.30) = 0.30

Probability (0.15) = (0.60 × 0.20) = 0.12

Probability (0.02) = (0.40 × 0.30) = 0.12

Probability (0) = (0.40 × 0.40) = 0.16

Based on the above probabilities, the following calculations are made for the expected price to be paid for the same quantity of the input material:

Rs. 1,10,00,000 × 0.30 = Rs. 33,00,000

Rs. 1,05,00,000 × 0.30 = Rs. 31,50,000

Rs. 1.15,00,000 × 0.12 = Rs. 13,80,000

Rs. 1,02,00,000 × 0.12 = Rs. 12,24,000

Rs. 1,00,00,000 × 0.16 = Rs. 16,00,000

Expected Value = Rs. 1,06,54,000

Therefore, the purchasing executive informs the finance department of the need for extra funds worth Rs. 6,54,000 for the purchase of the petroleum derivative.

Such Bayesian Analysis is of much utility for the purchasing function. One may not be able to hit the probability figures right on the dot; but if this analysis is done, one may not be caught totally unprepared for the financial and other implications to follow. Instead of taking a broad level or general hunch for the total increase in the financial outlay, one may approach the problem more scientifically.

VALUE ANALYSIS/VALUE ENGINEERING

Another important job of the purchasing executive, as mentioned earlier, is that of finding proper substitutes for raw materials. For this, a management technique developed during the Second World War period called value analysis (VA) or value engineering (VE) might be of much help. It is a systematic method of thinking about substitutes. It basically consists of studying in detail the 'value' of the material. The value could be due to the functional characteristics (i.e. performance) of the product or due to other considerations of value such as the 'esteem' value. In organizational purchasing we largely do not encounter the latter kind of value. The idea behind value analysis is to find a substitute giving the same functional value, yet costing the same or less.

In general, we can divide the value analysis into the following steps:

Step 1—Information Stage

Here, all the relevant information regarding raw material and the finished product in which it is incorporated, such as the cost, the manufacturing method, the performance characteristics, etc.

is gathered. The more detailed the information gathered in this initial stage, the better will be the value analysis. Here one may ask questions in detail, such as what, where, when, how and why (for each of them).

Step 2—Functional Analysis

At this stage, the functions that the material performs are listed in terms of basic function and secondary functions. It is advised that the functions be described in two words—a verb and a noun—as far as possible. This is to avoid long winding descriptions of the functions. After having listed the functions, each of these functions is given the value points or the weightages in terms of its importance or desirability. If the value (or worth, as it is alternatively called) is expressed in terms of 0–100 points, then the total for all the functions of a material should add to 100 points. Alongside, we also mention the cost incurred (or price paid) for each of the functions. Placing the cost and the value points side by side immediately reveals those areas of the material where much money is spent for little value. These high cost-to-worth functions are the focus of our attention in suggesting a substitute design of a bought-out part or a substitute material. If the value of a function is small, then that function can be dropped altogether in the substitute product.

Step 3—Brain Storming

Having done the analysis of the functions and costs of the material, we are now ready to think of various alternative possibilities for the material. The main idea, here, is to encourage creativity. Many of the suggestions may seem like wild guesses. Still, these are recorded even if all suggestions are not feasible. The idea is to break away from rigid thinking and encourage creativity. Some systems of brainstorming start idea-generation from such widely differing 'triggers' as politics and geography, and develop them further so as to apply to the problem at hand (which could be finding an alternative product design). For such idea-generation, a heterogeneous group is preferred.

Step 4—Evaluation Phase

Each of the ideas is evaluated again in terms of a functional analysis, i.e. by finding the various functions that the substitute can perform—to what extent and at what cost for each of those functions. Such an analysis will indicate a few of the alternatives which might offer similar functional value as the earlier material, but at a reduced cost. We may even find some substitutes with enhanced important functional values.

Step 5—Implementation

In this phase, the selected substitutes, or new ideas are discussed with the appropriate departments for their implementability. It is possible that some will be screened out and only one or two ideas might be implementable.

Such a systematic analysis of the functional values of input material along with their cost structure will help the purchasing executive in finding alternative materials of equal functional value or better value while reducing the procurement costs. Value analysis, of course, should be done as a team work since it involves a lot of creative and interdisciplinary thinking. Value analysis can be performed for processes and therefore, it can be of much utility in the service industry as well.

PURCHASING RESEARCH

Another function of purchasing is that of purchasing research. In many large and well-managed organisations there is a group of people doing formal purchasing research. This is not only the study of substitute materials to get over a recent problem of procurement, but *also a long range study* of the requirements of the present as well as anticipated products. Purchasing research, understandably also has the task of studying the trends and future forecasts of the cost of various input materials; and also that of the general economic conditions, industrial conditions, and national and international developments of interest for the task. Purchasing research will have to interact with the R&D and engineering departments of the company on a continual basis. The idea is that when the crunch comes in the future, the company should not crumble under the pressure. The other tasks of purchase research include: make or buy studies, studies of alternative vendors, studies in developing the vendors (in terms of their technical financial capabilities and needs), etc. In short, purchasing research includes short and long-range studies of the internal company requirements and the external supply market. This is an important aspect of purchasing, and all organisations that can afford it, should launch formal purchasing research programmes.

VENDOR RELATIONS

Another important objective in purchasing management is that of maintaining good relations with vendors. A good vendor is an asset to the company; and, therefore, just as customer goodwill is considered important, a good relationship with the vendor should also be treated likewise. A vendor who supplies the proper quality material in proper amounts in proper time is not very easy to find. Moreover, there are many situations where materials are required in a hurry. There are situations where materials are in shortage in the supply market. In all such situations, good relationships with the vendors pay dividends. This may entail: personal relationship, professional relationship:

(a) by helping the vendor in times of stress and strain with financial aid, technical aid, by providing management skills if necessary, and

(b) maintaining a healthy professional relationship by fair negotiations, fair evaluations and fair compensation.

The modern management theory and world-class manufacturing call for a long-term, almost a lifetime, association with the vendors. This also means that there will be fewer vendors but these will be dedicated vendors—almost as a part of the organisational family.

Until the present and even now, the Indian industry has not given/is not giving much attention and importance to vendor relations. The emphasis, if any, has been on vendor selection and on monitoring the performance of the vendors through a vendor rating system. Vendor is an entity that is, generally, taken for granted. The attitude is: All said and done, the vendors for the company may change over a period of time. They may change to another business; some of them may not give the desired performance in quality, delivery and price, and therefore, one should always expect a drop-out rate in the vendors' list of the company.

In any case, a continuous programme of developing vendors and of selecting new vendors, if and where necessary, should be in existence in any organisation. When selecting new vendors what should a buyer look for?

Selection of Vendors

1. The production capabilities of the vendor:
   (a) Capacity to manufacture the required product in desired quantities.
   (b) Possibility of future expansion in capacity.
   (c) The understanding or the knowledge of the vendor regarding the buying company and its needs.
2. The financial soundness of the company:
   (a) The vendor company's capital structure.
   (b) Whether it belongs to a larger group of companies; whether it is a private limited or a public limited company.
   (c) The profitability record of the company in the past.
   (d) Expansion plans of the company in the future.
3. Technical capabilities (these are mostly regarding the quality capabilities):
   (a) Whether the available machines are capable of the required quality of materials? What are the future plans of the vendor?
   (b) Whether there are enough technical skills (skilled manpower) available with the vendor?
   (c) Whether there is proper research, design and development facility available with the vendor?
   (d) What is the record of the vendor in filling the orders of other buying companies in the same business?
   (e) What has been the consistency in the quality produced by the vendor?
   (f) Whether the vendor has appropriate storage and warehouse facilities to retain the quality of the produced product?
   (g) Whether proper quality control procedures are being followed in the vendor company?
4. Other considerations:
   (a) What are the working conditions in the vendor company?
   (b) How are the industrial relations in the vendor company?
   (c) Whether there is any possibility of disruption of the supply of materials in terms of quantity and/or quality due to human relations problem in the vendor company?

While getting this information the Purchasing Executive should take the help of his colleagues in production, engineering, quality control, industrial relations, finance and other functional areas so as to get a proper evaluation of the potential supplier.

Vendor Rating or Performance Monitoring

Although this prior evaluation is necessary, vendors who are already on the regular list should be periodically appraised for their performance. This performance appraisal, which is and should be done as a continuous monitoring exercise, is termed as vendor rating. Vendors can be rated on various characteristics:

1. Delivery (to deliver on time as per order).
2. Quality (to deliver as per the quality specifications).
3. Price (to supply the materials at as low a price as possible).
4. Other factors such as (a) capability to meet emergency orders and (b) help in various other aspects such as supplying useful market information, readyness to try out new designs or new orders, etc.

In the vendor rating system, one usually gives weightage to these various characteristics and measures the performance of vendors periodically on the basis of certain norms or standards. The total of the vendor's performance is thus calculated, and, based on this information, the vendors are coaxed, cajoled or sometimes dropped from the company's list. A formal system of vendor evaluation should exist in every company so that an objective evaluation is done.

In order to illustrate the formal vendor rating system, let us consider the following example: Suppose a buying company gives 40% weightage to 'delivery' on time, 30% to the 'quality' and the rest (30%) to the 'price performance' of the vendor. If the vendor, during the past six months, has made 17 deliveries on time out of 20 orders, has given an average of 5% rejects, and has delivered the items at the performance index of Rs. 110 when the average price performance index is Rs. 100, the rating of the vendor is calculated as follows:

$$0.40 \times 17/20 \times 100 = 34.5 \text{ points}$$
$$0.30 \times 95/100 \times 100 = 28.5 \text{ points}$$
$$0.30 \times 100/110 \times 100 = 27.3 \text{ points}$$
$$\text{Total Rating} = 90.3 \text{ points}$$

The above example gives the vendor rating in terms of his *overall* performance for all the items that he supplies. Although some organisations prefer an overall vendor rating, a few others prefer to rate the vendors for the individual items of supply. A vendor's performance is rated and compared with other vendors supplying the same or similar kinds of items. Sometimes, this gives better flexibility to the buyer organisation in terms of continuing or discontinuing the vendor for only specific items of purchase; a vendor need not be totally dropped, but only one of his products needs to be dropped—one which might be giving a problem to the buying company. However, in general, a vendor rating system should be used constructively. This kind of a vendor rating system should allow a more detailed and better evaluation of the different vendors. The problem areas can then be pin-pointed and rectified with the help of the vendor.

Vendor rating is a beneficial devise not only for the buying company, but also for the supplier company. The supplier company gets information regarding its own performance compared with the performance of its competitors. It is a fair evaluation since the rating is based on fact and not on opinion. The vendor company can know its shortcomings, and can, therefore, try to improve them. Some suppliers even use a good vendor rating, by some of the large reputed companies, as a sort of merit certificate to deal with other companies.

Vendor Development

It has to do with creating or making new vendors (and not *selecting* out of the already established ones in the market). This is a continual and an important activity of the purchasing manager. Traditionally one of the reasons for developing new vendors is to build more competition in the supply market (eliminating monopoly or oligopoly). The company can then buy a material from a number of sources. Another traditional reason for such multiple source buying (and, therefore, also for vendor development) is to spread the risk of non-availability or shortage of input materials over a number of suppliers. In case, one of the supplier's employees go on strike (or if there is an explosion or fire in the supplying company), the other suppliers can be relied upon to compensate for the shortage. Therefore, in traditional organisations, which most Indian organisations are, spreading risk over a number of suppliers is the main motive behind vendor development.

However, international standards are premised on the thinking that single source buying provides some advantages which multiple source buying does not. One of the obvious advantages of single source buying is that of close rapport between the two companies and the loyalty established with the supplier. This goodwill might yield benefits in a number of ways in times of difficulties or crisis for the buying company. Also, the supplying company might even do some information gathering work for the buying company and therefore, keep it appraised of the recent market trends (what may be termed as "intelligence" information). Reliability, lack of uncertainty, quick and faithful response to the needs and, therefore, a general improvement in quality and reduction in inventory and purchase related costs are the long-term benefits for both organisations. However, the present Indian situation is far away from such world class thinking. In the present socioeconomic milieu prevailing in our country, where trust and concern are found somewhat wanting, the Indian companies seem to find more advantages in multiple-source buying. But still the choice between single source or multiple source buying is quite situational. Vendor development can be seen as an attempt to get the advantages of both spreading risk, building competition and at the same time establishing a good rapport. Vendor development involves helping or building up the vendor by various means such as:

1. Lending money for part of his capital equipment, working capital requirement, etc.
2. Lending technical help by making company engineers and technicians available to the vendor to help him tide over the initial technical problems.
3. Help in R&D, by again lending technical help to not only to establish the company, but also to help improve its products and services on a continuous basis.
4. Guaranteeing him a certain amount of business (this is particularly needed during initial stages of setting up the vendor).

Such efforts on the part of the buying company will produce a kind of goodwill and rapport between the two companies. Such a vendor will be willing to listen to the special problems of the buying company and, therefore, will be an asset to the buying company.

Some of the vendor companies may be large and established companies who may not need financial, technical or R&D assistance. But such companies can still be cultivated in many other ways by collaborating with them in various projects of interest to them, jointly investing in a project to produce common raw material required by both the supplying and the buying companies, etc.

The 'supply chain' thinking and benefits of single source buying have been explained in the chapter on Supply Chain Management.

NEGOTIATIONS: A PART OF PURCHASER'S ROUTINE

Negotiations is a part of the buyer's routine task. Although much of this belongs to the behavioural sciences, a great deal of the success of negotiation, hinges upon a good preparation by the purchasing executive before starting any negotiation. Whether the negotiation is for cost, or quality, or for quantity, much homework needs to be done by the purchasing executive prior to the negotiation. He should have detailed cost data and technical data regarding his own company and regarding the supplier companies. He should have information regarding the economic trends in the region or in the country, as also the technological and other trends. Backed by such detailed data the purchaser is in a better position to support his statements or demands. This homework is necessary not only to argue effectively for the buying company, but also to understand the supplying company's difficulties and problems. So that, during the negotiation the buyer does not rub the vendor the wrong way and thus spoil an established relationship. Many effective buyers backed by purchasing

research, are in a position to suggest ways of reducing costs, improving quality, delivery or other performance to the vendor company; and this is appreciated by the supplying company.

Learning Curve Concept

The 'Learning Curve' concept can be of some help in negotiations. When a task is done more and more number of times, the time to complete the task also gradually reduces with increased attempts at it. Similarly, when the number of units produced increases, the direct labour hours required per unit decrease, for a variety of reasons:

(a) Workers become more and more skilled at that particular set of tasks.
(b) Improvement in production methods and tooling takes place.
(c) Improvement in layout and flow takes place.
(d) Perhaps, some organisational improvements also take place.
(e) Economies of scale, in time, are achieved.

Whatever the reason, what is interesting to note is that each time the number of units is doubled, a constant percentage reduction results in the average direct labour hours per unit. It has also been observed, that for similar groups of products (in different enterprises) specific learning rates occur.

Learning is expressed in terms of percentage. For example, with 80% learning rate, the average direct labour hours per unit will be reduced by a factor of 80% when the production volume is doubled. A 100% learning curve means that there is no improvement or learning possible, whereas a 50% learning curve means that when the production quantity is doubled, the second half is produced at no cost—which is not possible. Thus, the learning rates range between 50 to 100%. The useful curves lie in the range of 75–95%. Figure 20.2 depicts the learning phenomenon.

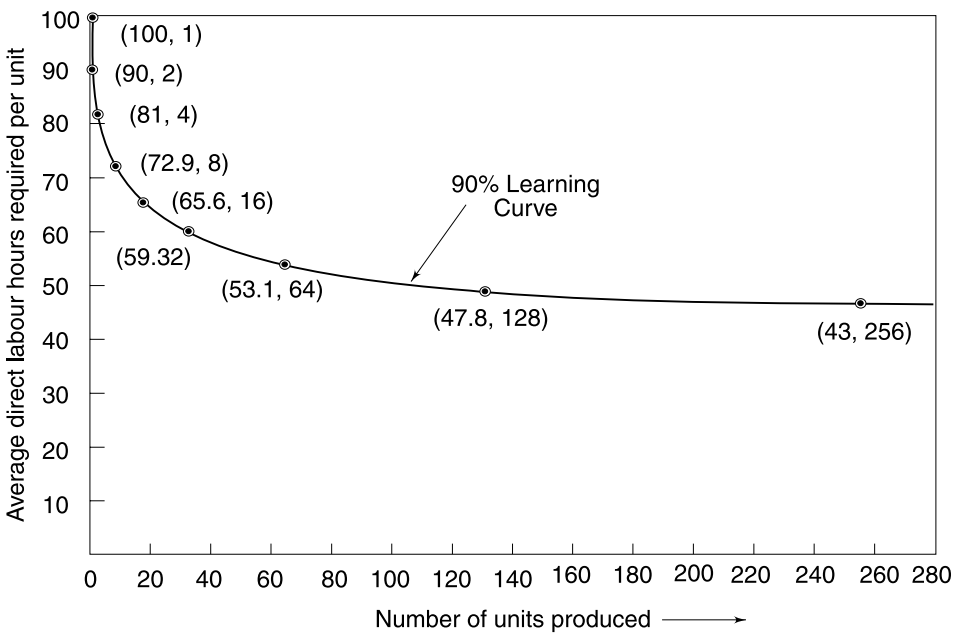


Figure 20.2 Learning Curve

If the average direct labour hours are expressed as cost, the 'learning' can be expressed algebraically as

$$\log C_n = \log C_1 - b \cdot \log n$$

where C_n is the cost for the nth item;
C_1 is the cost for the 1st item;
n is the cumulative output; and
b is a parameter characteristics of the learning rate occurring.

(for example: $b = 0.3220$ for 80% learning; calculate and check for yourselves.)

Learning curves can be used in purchasing and in production

(i) for costing new products;
(ii) for make-or-buy decisions which are so relevant to purchasing;
(iii) to determine the ultimate manpower requirements for the production;
(iv) to determine the delivery schedules; and
(v) for purchase negotiations.

Let us take an example of the use of the learning curve. Suppose a special set of gears is being supplied to our company at Rs. 1,150 each. The cost breakdown for this is:
Material = Rs. 550; Labour = Rs. 200; Overheads = Rs. 250 and Profits at 15% amounting to Rs. 150. If we pay Rs. 1,150 each for the first five gear-sets, what should we pay for five more units, if it is found that a 95% Learning Curve applies?

Applying the 95% Learning Curve and referring to the table in the Appendix to this chapter, 'improvement' corresponding to 10 units is 0.8433.

Therefore, the labour cost for the 10 units will be

$$10 \times 200 \times 0.8433 = \text{Rs. } 1{,}686.60$$

For the first five units, the labour cost has been charged at Rs. 200 per unit. Our company has already paid Rs. 200×5 = Rs. 1000.

Therefore, for the new order of five units, we need to pay:

1,686.60 – 1000 = Rs. 686.60 only towards labour costs. This is equivalent to Rs. 137.32 per unit.

The price per unit should be

	Rs. P	
Material	550.00	
Labour	137.32	
Overheads	250.00	
	937.32	
Profit @ 15%	140.60	
	1077.92	per unit price

PRICE FORECASTING

Cost aspects are useful when dealing with the supplier on a one-to-one basis. However, there are very many situations, particularly regarding raw materials, where the material is subject to a multitude of economic factors which influence the price of the material. It becomes necessary on

the part of the purchasing executive to take cognizance of and understand the price movements. Price forecasting, based upon the time-series methods of computing trends, business cycles and seasonalities, or based upon the understanding of the influence of various economic/business parameters should be of some interest to the purchasing executive who would like to keep the costs low. The objective is to keep the costs of purchases reasonably low, and if the prices of the materials do "run away", then to ensure the availability of supply of the material for the current and near future requirements.

FORWARD BUYING: IS IT ETHICAL OR NOT?

In order to ensure near-future availability, the buyer may have to take recourse to 'Forward Buying' which means buying the quantities now, but for the requirements of a future period of time. However, when the material is bought for 'future' and not for 'current' requirements, it raises questions as to whether this amounts to: (i) hoarding, or (ii) speculative buying. How ethical is the price consideration then? In a scarcity economy such as ours, the question assumes much importance. If the intention to purchase is solely to assure supplies to production, and not making a speculative profit on the inventory of materials, then it is justifiable. It is the business of an industrial enterprise to produce goods, market them, and gain a profit on the output and not to make a profit on the raw material inputs. The enterprise has thus an economic function to carry out. But, in carrying out that function how much of self-interest should it serve? It is not easy to answer this question because there is a thin line between what is 'to hoard' and what is 'to ensure future supplies to production operations'. The difficulty is compounded in a scarcity-prone economy. The best thing would, perhaps, be to stick to the type of inventory 'norms' as suggested by the Tandon Committee (see Chapter 30). Also, if there is monitoring by an external agency such as a bank (which supplies funds), it would standardise and regulate the ethicality problem. With economic liberalisation and, therefore, competition with the multinational corporations, prices and, therefore, costs have to be kept low. Hence, there is an increasing emphasis, even in Indian organisations, on lean production that is, with minimal possible inventories of materials. This business imperative should put a damper on the speculative inventory, if any.

MAKE OR BUY

The purchase function would be incomplete if we do not make a mention of make/buy analysis. To put it briefly, a company should buy a component instead of making it:

(a) If it costs less to buy rather than to manufacture the component internally.
(b) If the return on the necessary investment to be made to manufacture the component is not attractive enough.
(c) If the company does not have the requisite skilled manpower to make the component.
(d) If it feels that manufacturing internally will mean additional labour problem.
(e) If adequate managerial manpower is not available to take charge of this extra work of manufacture.
(f) If the component to be manufactured shows much seasonal demand or upswings and downswings of demand resulting in a considerable risk of maintaining inventories of it; also if the raw material for the component faces much seasonal fluctuations, which makes the manufacture of the product more risky for the buying company.

(g) If there is no difficulty in transporting the component from the supplier to the buying company.

(h) If the process of making the product is confidential or is patented.

(i) If the same component is not needed year-in and year-out and there is much risk of technological obsolescence discouraging investment in capital equipment to manufacture the component internally.

Make or buy is a strategic decision, and therefore, much short-term as well as long-term thinking about various cost and other aspects needs to be done.

Thus, the role of the purchasing executive is as challenging as it is demanding because it requires an understanding of various functions within the company, a sensitivity to feel the market, the rigour to do a detailed analysis of the market forces now and later, the capacity to be a tough yet humane bargainer and negotiator, and excellent interpersonal skills to integrate conflicting viewpoints of a number of people with different objectives.

SOLVED PROBLEMS

1. For the manufacture of a precision engineered item, 95 per cent learning is said to apply. If the labour time required for the 10th item is 55 minutes, what is time taken for the 30th and 90th units?

Answer

Computations of the time needed for producing the 1st unit:

Refer to the Learning Curves table (Appendix to this chapter).

Corresponding to the 95 per cent learning and 10 units, the unit value is 0.8433. This means, if the 1st unit takes 1 hour, then the average time taken per unit when 10 units are produced is 0.8433 hour.

But, in order to find the time taken for making the 10th unit, we need to know the time taken for producing the first 9 items. This we find in a manner similar to the above.

Referring to the Learning Curves table, for 9 units and 95 per cent learning, we have 0.8499 hour per unit of the nine units.

Which means, the total time taken for making 9 units = $0.8499 \times 9 = 7.6491$ hours.

But, time taken for 10 units = $0.8433 \times 10 = 8.4330$ hours.

Hence time taken to make the 10th unit

= (Time taken to produce 10 units) – (time taken to produce 9 units)

= (8.4330) – (7.6491) = 0.7939 hour.

We remember that this 0.7939 hour is the time needed for the 10th unit, provided the 1st unit takes exactly 1 hour.

Now our 10th unit, in actuality, takes 55 minutes = 55/60 = 0.9167 hour.

Hence the time, in actuality, taken by the 1st item would be: 0.9167/0.7939 = 1.1546 hour = 69.28 minutes.

Computations for the time needed to produce the 30th unit:

While we can know the unit value (average value) for 30 units, in order to find the value for the 30th unit, we must find the value for 29 units. But, the value for 29 units is not

given in the table of unit values. In order to find the exact value, the procedure may be as follows.

We know the Learning curve relationship given below.

$$\log_{10} C_n = \log_{10} C_1 - b.\log_{10} n$$

where $b = (\log_{10} L)/(\log_{10} 2)$ where L is the learning rate expressed as a fraction, n is the number of units produced and C_1 and C_n represent the costs of the 1st unit and the average cost when n units are produced.

Rearranging the above equation, we have:

$$\log_{10}(C_n/C_1) = (\log_{10} n)(\log_{10} L)/(\log_{10} 2)$$

Now, plugging in our values i.e. $n = 29$ and $L = 0.95$, and since $\log_{10} 2 = 0.3010$, we have:

$$\log_{10}(C_{29}/C_1) = (\log_{10} 29)(\log_{10} 0.95)/(0.3010)$$

$$= (1.4624)(-0.02228)/(0.3010)$$

$$= -0.1083 = (-1) + 0.8917$$

Hence, on reading the antilog, we have: $C_{29}/C_1 = 0.7795$

So, $C_{29} = 0.7795$ for $C_1 = 1$.

This C_{29} is the unit value or average value per unit, after 29 units are produced.

Therefore, for 29 units, the total time = $(29) \times (0.7795) = 22.6055$

From the table of unit values, for 30 units, the unit (average) value = 0.7775.

For 30 units, the time taken would be = $(30) \times (0.7775) = 23.3250$

Hence, the time taken for the 30th unit

= (time taken for producing 30 units) – (time taken for producing 29 units)

= (23.3250) – (22.6055) = 0.7195.

Now the above figure is to be converted into actual hours. As per the calculations made earlier, the time needed to produce the 1st unit was 1.1546 hour.

Hence, the time for the 30th unit = (0.7195) (1.1546) = 0.8307 hour = 49.84 minutes.

Computations for the time needed to produce the 90th unit:

$$\log_{10}(C_{89}/C_1) = (\log_{10} 89)(\log_{10} 0.95)/(0.3010)$$

$$= (1.9494)(-0.02228)/(0.3010)$$

$$= -0.1443 = (-1) + 0.8557$$

Hence, on reading the antilog, we have: $C_{89}/C_1 = 0.7173$

So, $C_{89} = 0.7173$ for $C_1 = 1$.

This is the unit value or average value per unit for a production of 89 units.

Therefore, for all the 89 units, the total time is = $(89) \times (0.7173) = 63.8397$

From the table of unit values, for 90 units, the unit (average) value = 0.7168.

For 90 units the time taken would be = (90) × (0.7168) = 64.5120

Hence, the time taken for the 90th unit

= (time taken for producing 90 units) – (time taken for producing 89 units)

= (64.5120) – (63.8397) = 0.6723.

Now the above figure is to be converted it into actual hours. As per the calculations made earlier, the time needed to produce the 1st unit was 1.1546 hour.

Hence, the time for the 90th unit = (0.6723) (1.1546) = 0.7762 hour = 46.57 minutes.

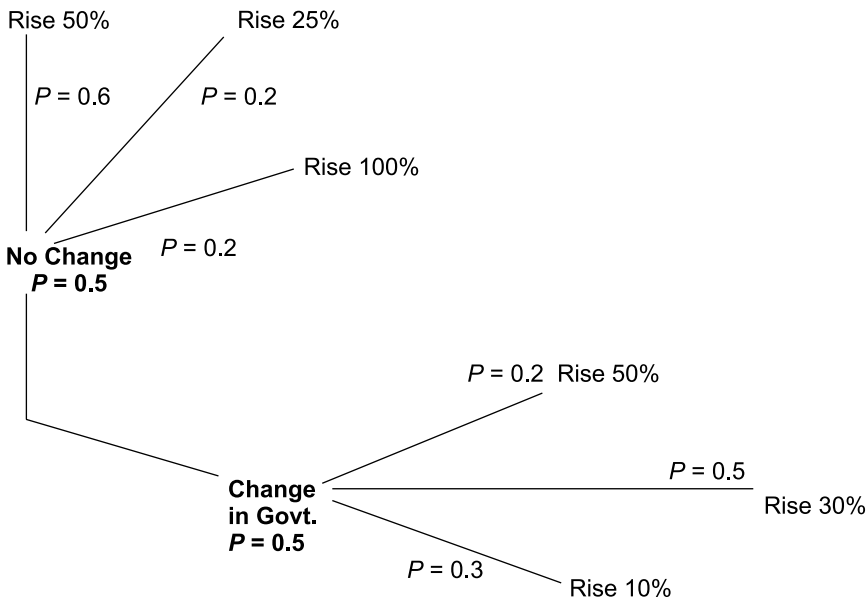
2. Thacker Aluminum Inc., an Indian-owned firm in USA, buys bauxite from Jamaica. All the aluminum companies in USA are almost totally dependent on the Jamaican bauxite which is the main export of Jamaica. The relationship between Jamaica and USA has gone sour during the recent past because the former is unhappy over the prices obtained for its export. The prices of Jamaican bauxite are therefore, expected to rise in the near future. There is, however, a possibility of a change in the Jamaican government (perhaps engineered by a foreign hand?) which may be somewhat more favourable to USA. The chances of such a change taking place are estimated to be 50 per cent.

Meanwhile, Thacker Aluminum's Purchasing Director Pat (Pratap) Thacker is closely watching the price scenario, because the volume of bauxite purchases from Jamaica is high (to the tune of $100 million). If there is no change in Jamaican government, the prices of bauxite may rise by 50 per cent with a probability of 60 per cent, by 100 per cent with a probability of 20 per cent, and by 25 per cent with a probability of 20 per cent. However, if the government changes, the price rise may be 50 per cent with a smaller probability of 20 per cent, 30 per cent (rise) with a probability of 50 per cent and 10 per cent rise with a probability of 30 per cent.

Jimmy (Jayant) Thacker, the President of Thacker Aluminum, has allowed an additional annual budget of $20 million for the import of bauxite. Would this be sufficient? Explain.

Answer

Perform Bayesian analysis. The probability tree (as per the given information) is shown in the figure below. The (3 + 3 =) 6 probabilities at the end of the tree are conditional probabilities. For instance, 0.6 is the probability of a price rise of 50% conditional to "No Change" in the government.



The probabilities for different price rises can be calculated as follows.

$P(50\%) =$	$(0.6 \times 0.5) + (0.2 \times 0.5) =$	0.4
$P(100\%) =$	$(0.2 \times 0.5) =$	0.1
$P(25\%) =$	$(0.2 \times 0.5) =$	0.1
$P(30\%) =$	$(0.5 \times 0.5) =$	0.25
$P(10\%) =$	$(0.3 \times 0.5) =$	0.15
Total:		1.00

The expected value of the bauxite purchases by Thacker Aluminum can be calculated as given below.

$150 \times 0.4 =$	60
$200 \times 0.1 =$	20
$125 \times 0.1 =$	12.5
$130 \times 0.25 =$	32.5
$110 \times 0.15 =$	16.5
Total:	141.5 million dollars

Thus, the additional budget of \$20 million allowed by Jimmy Thacker is not sufficient. It should have been \$41.5 million.

3. Sri Balaji Works is ranking vendors for future selection. Factors important for selection have been identified and rated in terms of their importance. Four suppliers A, B, C and D have been judged against each of these factors. Rank these suppliers, given the rating data as furnished in the following table.

Factor	*Importance Rating for the Factor (0 to 10)*	*Supplier Rating for Each Factor (0 to 10)*			
		Supplier A	*B*	*C*	*D*
Delivery	9	5	7	7	6
Quality	8	9	5	7	8
Price	9	8	6	9	4
Technical capability	7	9	4	7	9
Production capability	8	6	8	8	7

(Note: Rating of 10 is Excellent and 0 is Poor)

Answer

Given the above information, the vendor (supplier) rating for each of the vendors is multiplied by the "importance rating" (equivalent to weight) for the factors. The total points obtained by the vendors are compared to arrive at a ranking between themselves.

Factor	*Importance Rating for the factor (0 to 10)*	*Points Obtained by Supplier for Each Factor*			
		Supplier A	*B*	*C*	*D*
Delivery	9	$5 \times 9 = 45$	$7 \times 9 = 63$	$7 \times 9 = 63$	$6 \times 9 = 54$
Quality	8	$9 \times 8 = 72$	$5 \times 8 = 40$	$7 \times 8 = 56$	$8 \times 8 = 64$
Price	9	$8 \times 9 = 72$	$6 \times 9 = 54$	$9 \times 9 = 81$	$4 \times 9 = 36$
Technical capability	7	$9 \times 7 = 63$	$4 \times 7 = 28$	$7 \times 7 = 49$	$9 \times 7 = 63$
Production capability	8	$6 \times 8 = 48$	$8 \times 8 = 64$	$8 \times 8 = 64$	$7 \times 8 = 56$
	Total Points Obtained:	300	249	313	273

Looking at the above table, the relative ranking of the four suppliers is:
Rank 1: Supplier C
Rank 2: Supplier A
Rank 3: Supplier D
Rank 4: Supplier B

QUESTIONS FOR DISCUSSION

1. What is the scope of purchasing activities? Where would you fit purchasing in the materials management function? In the organisational structure, where should purchasing be fitted:
(i) in a single plant situation?
(ii) in a multiple plant situation?

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2. Elaborate on the concept of 'materials management as a profit centre'. How would you go about operationalising it? What advantages would you expect from making it into a profit centre?
3. 'The role of purchasing is now one of Supply Management'. Comment on this statement.
4. What commonalities do you see between Value Analysis, Quality Circles and Zero Defects programmes?
5. Take a carton or an electric plug or some such household item and value analyse it. Indicate the procedure in detail.
6. What are the merits and demerits of centralised and decentralised buying? For what type of situations and what kind of materials would you prefer centralisation or decentralisation of buying?
7. What is 'negotiation' in the purchasing function?
8. Discuss the importance of good vendor relations. What are the plus and minus points of a multiple-source buying policy?
9. Does the learning curve affect 'make or buy' decisions? Explain.
10. In what type of production situations is the make or buy decision very crucial?
11. What is meant by purchasing at the 'right time'? Discuss.
12. In an unstable market for raw materials, what type of a buying policy should be followed?
13. What are the typical difficulties in supply sourcing in countries like India?
14. What is 'quality' in the purchasing perspective?
15. What are the intangibles which vendor ratings do not usually take into account?
16. Would purchasing for non-profit organizations differ from purchasing for profit-making firms? How? Would purchasing in service industry differ from purchasing in manufacturing industry ? Discuss.
17. If a buyer is interested in minimizing the risk resulting from fluctuating market prices, what techniques should he apply?
18. A supplier's latest financial statement reveals the following information:

(a)	Total sales:	Rs 1.60 crore
(b)	Per cent of production capacity utilised:	80%
(c)	Rent, interest, depreciation, taxes, etc. add to:	Rs 40 lakh
(d)	Total costs:	Rs 1.40 crore

What is the break-even point for the supplying firm?

19. A specialised assembly unit is supposed to be experiencing a 90% learning curve. If the 50th assembled unit required a total of 3 hours of labour, what would be the time required for the 5th, 25th, 100th, 200th and 500th unit?
20. A first assembled unit costs Rs. 1000, of which Rs. 400 is labour and Rs. 600 is materials and other costs. You have agreed to a 15% mark-up on costs. What should be the agreed price for 700 units?

ASSIGNMENT QUESTION

1. Study the purchasing function in a manufacturing or service industry. Present a report on enhancing the competitiveness of that industry through changes/improvements in its purchasing operations.

APPENDIX

LEARNING CURVES: TABLE OF UNIT VALUES

	Learning Rate							
Unit	*60%*	*65%*	*70%*	*75%*	*80%*	*85%*	*90%*	*95%*
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.6000	0.6500	0.7000	0.7500	0.8000	0.8500	0.9000	0.9500
3	0.4450	0.5052	0.5682	0.6338	0.7021	0.7729	0.8462	0.9219
4	0.3600	0.4225	0.4900	0.5625	0.6400	0.7225	0.8100	0.9025
5	0.3054	0.3678	0.4368	0.5127	0.5956	0.6857	0.7830	0.8877
6	0.2670	0.3284	0.3977	0.4754	0.5617	0.6570	0.7616	0.8758
7	0.2383	0.2984	0.3674	0.4459	0.5345	0.6337	0.7439	0.8659
8	0.2160	0.2746	0.3430	0.4219	0.5120	0.6141	0.7290	0.8574
9	0.1980	0.2552	0.3228	0.4017	0.4930	0.5974	0.7161	0.8499
10	0.1832	0.2391	0.3058	0.3846	0.4765	0.5828	0.7047	0.8433
12	0.1602	0.2135	0.2784	0.3565	0.4493	0.5584	0.6854	0.8320
14	0.1430	0.1940	0.2572	0.3344	0.4276	0.5386	0.6696	0.8226
16	0.1296	0.1785	0.2401	0.3164	0.4096	0.5220	0.6561	0.8145
18	0.1188	0.1659	0.2260	0.3013	0.3944	0.5078	0.6445	0.8074
20	0.1099	0.1554	0.2141	0.2884	0.3812	0.4954	0.6342	0.8012
22	0.1025	0.1465	0.2038	0.2772	0.3697	0.4844	0.6251	0.7955
24	0.0961	0.1387	0.1949	0.2674	0.3595	0.4747	0.6169	0.7904
25	0.0933	0.1353	0.1908	0.2629	0.3548	0.4701	0.6131	0.7880
30	0.0815	0.1208	0.1737	0.2437	0.3346	0.4505	0.5963	0.7775
35	0.0728	0.1097	0.1605	0.2286	0.3184	0.4345	0.5825	0.7687
40	0.0660	0.1010	0.1498	0.2163	0.3050	0.4211	0.5708	0.7611
45	0.0605	0.0939	0.1410	0.2060	0.2936	0.4096	0.5607	0.7545
50	0.0560	0.0879	0.1336	0.1972	0.2838	0.3996	0.5518	0.7486
60	0.0489	0.0785	0.1216	0.1828	0.2676	0.3829	0.5367	0.7386
70	0.0437	0.0713	0.1123	0.1715	0.2547	0.3693	0.5243	0.7302
80	0.0396	0.0657	0.1049	0.1622	0.2440	0.3579	0.5137	0.7231
90	0.0363	0.0610	0.0987	0.1545	0.2349	0.3482	0.5046	0.7168
100	0.0336	0.0572	0.0935	0.1479	0.2271	0.3397	0.4966	0.7112
120	0.0294	0.0510	0.0851	0.1371	0.2141	0.3255	0.4830	0.7017
140	0.0262	0.0464	0.0786	0.1287	0.2038	0.3139	0.4718	0.6937
160	0.0237	0.0427	0.0734	0.1217	0.1952	0.3042	0.4623	0.6869

(*Contd.*)

	Learning Rate							
Unit	*60%*	*65%*	*70%*	*75%*	*80%*	*85%*	*90%*	*95%*
180	0.0218	0.0397	0.0691	0.1159	0.1879	0.2959	0.4541	0.6809
200	0.0201	0.0371	0.0655	0.1109	0.1816	0.2887	0.4469	0.6757
250	0.0171	0.0323	0.0584	0.1011	0.1691	0.2740	0.4320	0.6646
300	0.0149	0.0289	0.0531	0.0937	0.1594	0.2625	0.4202	0.6557
350	0.0133	0.0262	0.0491	0.0879	0.1517	0.2532	0.4105	0.6482
400	0.0121	0.0241	0.0458	0.0832	0.1453	0.2454	0.4022	0.6419
450	0.0111	0.0224	0.0431	0.0792	0.1399	0.2387	0.3951	0.6363
500	0.0103	0.0210	0.0408	0.0758	0.1352	0.2329	0.3888	0.6314
600	0.0090	0.0188	0.0372	0.0703	0.1275	0.2232	0.3782	0.6229
700	0.0080	0.0171	0.0344	0.0659	0.1214	0.2152	0.3694	0.6158
800	0.0073	0.0157	0.0321	0.0624	0.1163	0.2086	0.3620	0.6098
900	.0.0067	0.0146	0.0302	0.0594	0.1119	0.2029	0.3556	0.6045
1,000	0.0062	0.0137	0.0286	0.0569	0.1082	0.1980	0.3499	0.5998
1,200	0.0054	0.0122	0.0260	0.0527	0.1020	0.1897	0.3404	0.5918
1,400	0.0048	0.0111	0.0240	0.0495	0.0971	0.1830	0.3325	0.5850
1,600	0.0044	0.0102	0.0225	0.0468	0.0930	0.1773	0.3258	0.5793
1,800	0.0040	0.0095	0.0211	0.0446	0.0895	0.1725	0.3200	0.5743
2,000	0.0037	0.0089	0.0200	0.0427	0.0866	0.1683	0.3149	0.5698
2,500	0.0031	0.0077	0.0178	0.0389	0.0806	0.1597	0.3044	0.5605
3,000	0.0027	0.0069	0.0162	0.0360	0.0760	0.1530	0.2961	0.5530

Source: Albert N. Schrieber, Richard A. Johnson, Robert C. Meier, William T. Newell, Henry C. Fischer, *Cases in Manufacturing Management*, New York, McGraw-Hill Book Company, 1965, p. 464.

21 Inventory Models and Safety Stocks

WHAT IS INVENTORY MANAGEMENT?

Inventory is working capital and therefore the control of inventories is an important aspect of operations management. The basic questions in the management of inventory are:

1. How much inventory to keep; and
2. When?

Before getting to a mathematical treatment of the above questions, let us understand the functions of inventory.

(i) There are inventories for normal consumption requirements. Therefore, depending upon the average consumption rates and average lead times for procurement/manufacture of the material, inventories are kept at the appropriate times.

(ii) A production process, however continuous it may be, is bound to have some interruptions; it may also have imbalances in the consumption and production rates of the materials at different stages. These interruptions and imbalances make it necessary to keep stocks of inventory between the different stages of the operations.

BASIC FUNCTION

Inventory is needed for the definite consumption demand of materials, and to take care of the uncertainty involved in the usage or availability of the materials. The latter aspect is sometimes described by other authors as the 'decoupling function' of the inventory. It means that the various dependent operational stages in any production/operations process can act independent of each other, to some extent, if an inventory of materials is maintained at the different stages of production. The inventory ensures that one stage of production does not suffer because of the non-functioning or malfunctioning of the previous stage of production over which the former is dependent. The inventory taking care of the first aspect of normal consumption is called the normal inventory and the inventory taking care of the second aspect of uncertainty is called the safety stock or buffer stock of inventory.

There are various other categories of inventories mentioned in the literature such as the 'anticipation inventory', 'transit inventory' or the 'pipeline inventory'. But these are basically modified versions of the two concepts described above.

RELEVANT COSTS

To answer the 'how much' and 'when' questions of inventory, let us first concentrate on the normal inventory. As this inventory corresponds to the normal consumption rates of the material, we should procure the inventory as and when it is required for production. Let us examine whether 'procuring a material as and when it is required' requires the incorporation of other cost economies. Therefore, we shall consider the relevant costs associated with the normal inventory keeping.

The relevant costs for the 'how much' and 'when' decisions of normal inventory keeping are:

Cost of Capital Since inventory is equivalent to locked-up working capital, the cost of capital is an important relevant cost. This is the opportunity cost of investing in inventory. Of course, as mentioned in Chapter 6, a firm cannot always take the spot opportunity cost as the cost of capital. Similarly it cannot take the interest paid on the borrowed working capital as the cost of capital. The cost of capital has to be arrived at by giving suitable weightages to the different considerations about the use and procurement of the funds.

Space Cost Inventory keeping needs space and therefore, the 'how much' and 'when' questions of inventory keeping are related to the space requirements. This cost may be the rent paid for the space.

Material Handling Costs The inventory needs to be moved within the warehouse and the factory, and costs associated with the internal movement of the inventory are included in this category.

Obsolescence, Spoilage or Deterioration Costs If inventory is procured in a large quantity, there is always a risk of the item becoming obsolete due to a change in product design, or the item getting spoilt because of the natural ageing process. The latter is particularly true of many sensitive chemicals and drugs which have limited shelf-life. Such costs have, definitely, a relation to basic questions of 'how much' and 'when'.

Insurance Costs There is always a risk of fire, theft or pilferage of materials. These costs should, therefore, be estimated. Or a firm might have taken insurance against such mishaps and the insurance premiums paid are relevant costs for our decision.

Costs of General Administration Inventory keeping will involve the use of various staff. With large inventories, the costs of general administration might go up.

Inventory Procurement Costs In addition to the general administration, whenever an order for procurement is to be placed to an external agency supplying the materials, there is a cost associated with activities such as tendering, evaluation of bids, ordering, follow-up of the purchase order, receipt and inspection of materials, etc. Every time a purchase order is placed, these costs are incurred as against general administration costs which are incurred for the entire materials procurement activity.

BEHAVIOUR OF COSTS IN RELATION TO LEVEL OF INVENTORY

In regard to relevant costs the 'when' question is automatically answered if the former question of 'how much' is answered; this is so, particularly for normal inventories. Let us now consider the question 'how much' for the different cost components enumerated above.

The total cost of capital will be higher for higher levels of inventory. The cost of space may be higher for higher levels of inventory provided there is no idle space already existing. It may be noted here that we are considering only the out-of-pocket or situational or relevant cost. Therefore, in some cases we may have the cost of space, and in some cases it may not exist. The material handling may increase with increased volumes of inventory, though not necessarily be proportional. If the material has limited shelf-life or it is of a kind that might become obsolete over time, then with larger inventories there are greater risks and therefore larger costs of spoilage/obsolescence. These costs also need not vary proportionately to the amount of inventory, because what may not be spoilt over four months may be spoilt in the fifth month. The risk of spoilage might increase non-linearly with the age of the material and consequently with the volume of inventory. The cost of insurance will also be higher for higher levels of inventory, but this may also not be a continuous function but a step function. One thing is common to all the above categories of costs that is, all these cost components increase with the increase in the level of inventory; the increment may not be a continuous linear function of the level of inventory, but all the same the costs do increase. Whereas the costs of procurement of the inventory decrease with the increase in the level of inventory.

Example *Carrying Costs and Order Costs* A firm needs 12,000 numbers of an item every year. If the firm was to procure the material once every year, the average level of inventory of the material would be 6000 items. Instead if the firm procured the material twice annually, The average level of inventory would be only 3,000 (because the procurement is 6,000 items each time). What we notice here is that, if the 'how much' question is answered by a large number, then the number of procurements are correspondingly smaller. If the 'how much' question is answered by a small quantity, the number of procurements are larger correspondingly. Since the procurement cost depends on the number of times orders are placed, this cost component behaves in inverse proportion to the level of inventory. This is the only component of the relevant cost which behaves opposite to the rest. There is a trade-off between the procurement cost and the other relevant costs of inventory. Let us call the other costs (that is, those costs which increase with the increase in the level of inventory) as the carrying costs or holding costs. If the 'how much' question is answered by a large amount, the carrying costs increase, whereas the procurement costs decrease. If the 'how much' question is answered by a smaller number, the carrying costs decrease, but the procurement costs will increase. This opposite behaviour of these two distinct cost categories is shown in Fig. 21.1.

OPTIMAL ORDER QUANTITY

Figure 21.1 assumes a linear behaviour of the carrying cost and an inverse linear behaviour of the procurement or order cost. Although the assumption of linearity can be questioned, it is good enough for practical purposes. It will not affect the solution to the problem significantly. We notice that the total relevant costs would show a minimum at a certain value of the order quantity. The latter is the desired optimal order quantity. Based on the trade-off between the carrying and order costs, the optimal order quantity is determined.

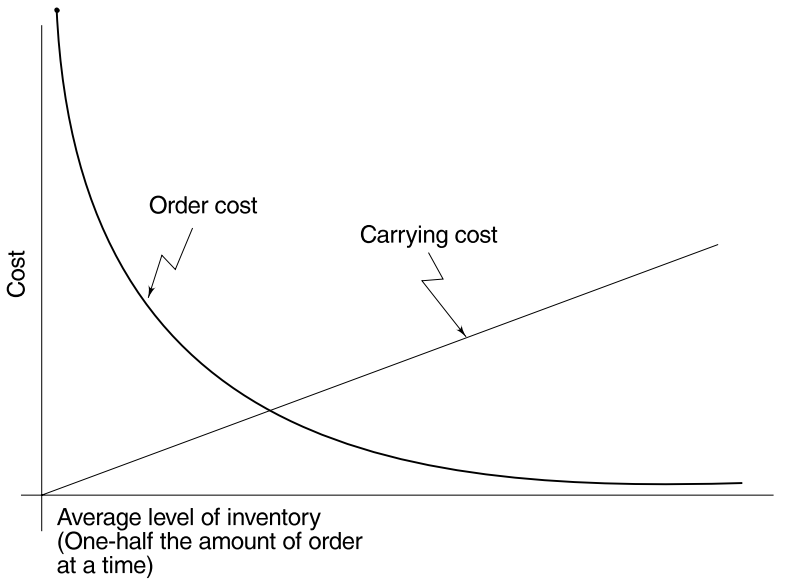


Figure 21.1 Behaviour of Two Distinct Cost Categories

Let us compute the optimal or Economic Order Quantity (EOQ) for a simple situation. Let us assume that a material is continuously used up at a constant rate, the annual consumption being A units. We place orders for the supply of the material periodically in such a way that by the time the inventory of the material is over the ordered consignment of quantity Q arrives. The lead time for the supply, L time units, is constant. Since the lead time for supply and the consumption rate are constant, the reorder to the supplier is placed whenever the inventory level comes down to a level hereafter called as the Reorder Point (ROP). This situation is depicted in Fig. 21.2.

For the model depicted in Fig. 21.2 the average level of inventory is = $\frac{Q}{2}$

If C_c is the cost of carrying an inventory of one unit per year, the cost of carrying the inventory over the year is

$$= C_c \times \frac{Q}{2}$$

The number of procurement orders placed during the year = $\frac{A}{Q}$

If C_p is the cost of procurement ordering per order, the cost of ordering during the year is

$$= C_p \times \frac{A}{Q}$$

Therefore, Total Cost (TC) = Carrying Cost + Ordering Cost

$$= C_c \times \frac{Q}{2} + C_p \times \frac{A}{Q}$$

This Total Cost is to be minimized.

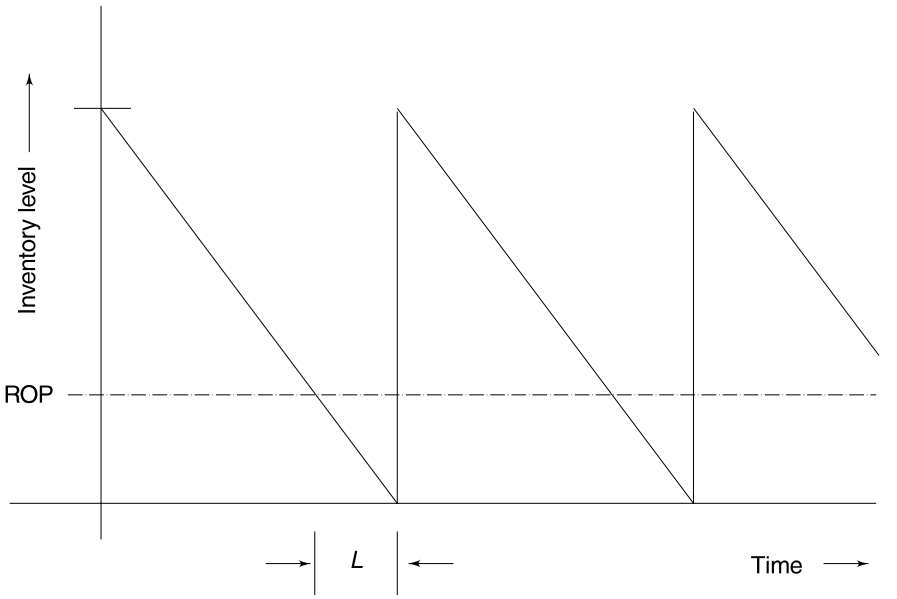


Figure 21.2 Basic Model for Fixed Reorder Quantity Inventory System

Therefore, taking derivative with respect to Q (which is the quantity to be determined) and equating it to zero, we get

$$\frac{d(TC)}{dQ} = \frac{C_c}{2} - \frac{C_p A}{Q^2} = 0$$

Therefore, $$Q^2_{\text{optimal}} = \frac{2C_p A}{C_c}$$

Hence, $$Q_{\text{optimal}} = \sqrt{\frac{2C_p A}{C_c}}a$$

This is the optimal or the EOQ. This is a very simple formula, yet one of the most widely used and important formula, in spite of some of its underlying assumptions.

ASSUMPTIONS OF THE ECONOMIC ORDER QUANTITY (EOQ) FORMULA

One important assumption in deriving the EOQ formula is the constant rate of usage of the material. In practice, very few materials are used continuously at a constant rate. It is assumed that even with some fluctuations in the rate of consumption of the material, the assumption of a uniform rate of consumption will more or less hold good. This is shown in Fig. 21.3.

Another assumption is that the material is supplied without fail at the end of one lead time after the re-order. Lead time is assumed to be constant.

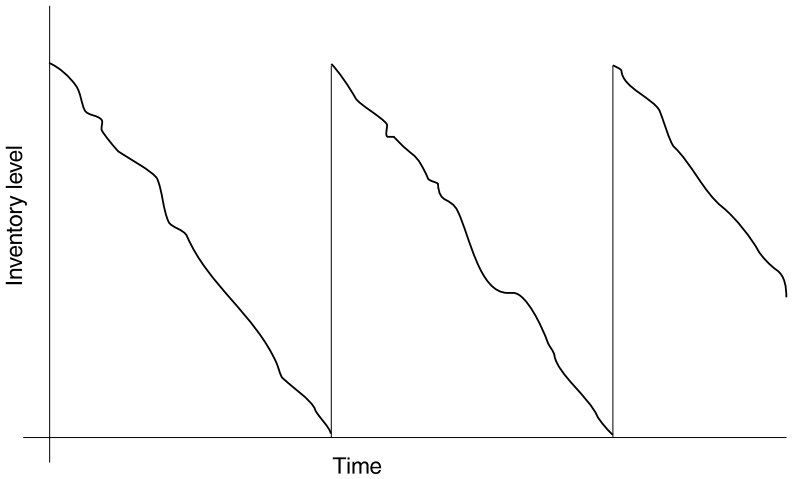


Figure 21.3 Basic Assumption of EOQ Formula

These are the two basic assumptions of this model, which amount to assuming non-variability of demand and supply of the material. If variation is present, and the EOQ model is still used, it amounts to averaging the demand and supply rates/times. The variability part can then be taken care of by providing adequate (calculated) buffer (or safety) stocks of the material.

In some situations, the assumptions given above assume importance to the point when the model is no longer valid; in such cases, the model is replaced by an entirely different procedure for inventory keeping (see Chapter 23).

In spite of the drawbacks of the basic EOQ model, it must be mentioned that it is conceptually sound with regard to its consideration of the various relevant costs. The trade-off expressed between the cost of carrying and the cost of ordering is present in any situation, despite the drawbacks of the basic EOQ model. Balancing the carrying cost and the ordering cost is the foundation of this model and this fundamental concept can be very well utilised in many other situations where the other assumptions of the model may not be quite valid.

Example A hospital procures its supplies of a material once a year. The total number procured is 2400 packages (in a year). This policy of procuring material once a year is being questioned. The accountants calculate the cost of inventory holding at Rs. 36 per package per year. It is also figured out that the costs of procurement add up to Rs. 1,200 per order. What inventory policy would you advise to this hospital?

Solution

$$\text{EOQ} = \sqrt{\frac{2 \times 1200 \times 2400}{36}}$$

$$= 400 \text{ units}$$

Therefore, it is best to place $\frac{2400}{400} = 6$ orders in a year.

ECONOMIC MANUFACTURING BATCH SIZE

The EOQ concept can be extended to the determination of optimal manufacturing batch size for semi-finished and finished goods. The trade-off of costs in this case is as follows. If the batch size is large, the average level of inventory of the product is also large and therefore the inventory carrying charges are high. But, in such a case, a few of such large batches would suffice for the annual requirements, the number of set-ups would be small and the corresponding set-up costs would be low. On the other hand, when the batch size is smaller, the number of set-ups required in a year to manufacture the same total quantity is higher, the order cost or the set-up cost is higher; but at the same time, the average inventory level is smaller thus making the carrying cost lower.

Cost of Set-up

The set-up cost will consist of the following elements:

1. Cost of the time spent in setting up the equipments and organising the labour for a manufacturing batch. This is the cost of the idle time of the labour and the machinery (due to set-up) which would have otherwise produced goods. This is the opportunity cost of the time lost due to a set-up.
2. Cost due to rejects, scrap, rework generated during a set-up.
3. Variable cost of administrative paper work for a set-up.

The model for the manufacture of a product is given in Fig. 21.4.

The production cycle is repeated after a time interval t. The consumption is constant at a rate r throughout the year. The product is produced during a small period of time t^* at the rate of p units. A cycle, therefore, consists of (a) time t^* in which manufacture takes place, and (b) time $t - t^*$ when only consumption of the product takes place. Note that the product is being consumed not only during the non-production cycle, but also during t^* (the time when production is on). For this reason, Fig. 21.4 gets its shape somewhat different from the basic inventory model presented in Fig. 21.2.

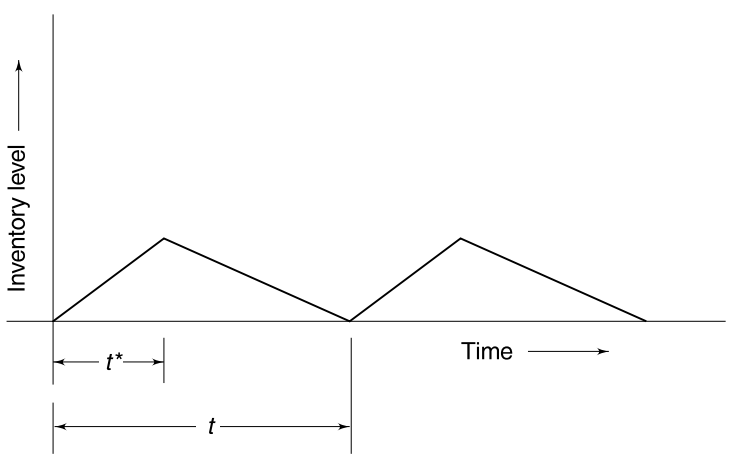


Figure 21.4 Model for Determining Manufacturing Batch Quantity

In this case we have:

$$\text{Peak inventory during any cycle} = t^* \times (p - r)$$

$$\text{Therefore, average inventory during the year} = \frac{t^* \times (p-r)}{2}$$

$$\text{The carrying cost of inventory} = \frac{t^* \times (p-r)}{2} \times C_C$$

If Q is the manufacturing batch quantity, then the number of set-ups during a year $= \frac{A}{Q}$

Therefore, the setting-up cost during the year $= C_p \times \frac{A}{Q}$

$$\text{Now, } Q = t^* \times p; \text{ therefore } t^* = \frac{Q}{p}$$

Using the above relation in the expression for carrying cost, we get

$$\text{Annual carrying cost} = C_c \times \frac{(p-r)}{2} \times \frac{Q}{p}$$

$$\text{Total Cost will be} = \text{Carrying cost + Set-up cost}$$

$$= \frac{C_c \times Q \times (p-r)}{2p} + C_p \frac{A}{Q}$$

In order to compute the optimal Q, the total cost needs to be differentiated with respect to Q and equated to zero.

ECONOMIC BATCH QUANTITY

The Economic Batch Quantity (EBQ) Formula for a single product is:

$$\frac{d(TC)}{dQ} = \frac{C_C(p-r)}{2p} - \frac{C_p A}{Q^2} = 0$$

$$\text{Therefore, } Q_{\text{optimal}}\ (EBQ) = \sqrt{\frac{2C_p A}{C_c \times \left(\frac{p-r}{p}\right)}}$$

This expression is similar to that derived for the classical inventory model except for the fact that it takes into consideration production and consumption rates of the product.

Example Compute the *EBQ* for manufacture given the following data:

Monthly demand = 500 units

Daily production rate = 25 units

Days in a month = 25 days

Cost of set-up = Rs. 1,500

Cost of holding inventory = Rs. 10 per unit per year

Solution

$$\text{Annual Demand, } A = 500 \times 12 = 6{,}000 \text{ units per year}$$

$$\text{The daily consumption rate, } r = \frac{\text{Monthly consumption}}{\text{No. of days in a month}} = \frac{500}{25}$$

$$= 20 \text{ units per day}$$

$$\text{Therefore,} \qquad EBQ = \sqrt{\frac{2 \times 1500 \times 6000}{10 \times \left(\frac{25-20}{25}\right)}}$$

$$= 3000 \text{ units}$$

$$\left(\text{No. of production batches taken in a year} = \frac{6000}{3000} = 2\right)$$

The above problem of optimal manufacturing batch size was confined to a case where only one product was being manufactured. In practice, a number of different products may be manufactured on the same plant facility. One might argue that the formula for the single product can be used to determine individually the optimal batch quantities for different products. Although this individual determination of the manufacturing batch sizes would produce most economical results as far as individual products are concerned, it might present some difficulties in a few cases.

Example VIBGYOR Company manufactures adhesive tapes in seven colours—violet, indigo, blue, green, yellow, orange and red. The annual requirements, the cost of holding, set-up cost and the daily production rates are indicated in Table 21.1.

Table 21.1

Product	*Annual Requirements (in units)*	*Cost of Holding (Rs. per unit per year)*	*Set-up Cost Rates (Rs. per set-up)*	*Daily Production Rates (units per day)*
V	24,000	5	2,000	480
I	12,000	5	1,200	360
B	36,000	5	2,400	480
G	6,000	5	1,000	240
Y	24,000	5	3,000	480
O	3,600	5	2,400	360
R	7,200	5	3,000	240

There are 300 working days in a year.

Based on the above given information, Table 21.2 gives the rates of consumption of the products, the economic batch quantities for each colour (calculated independently), the days for which a manufactured batch will last at the given consumption rate and the individual production times for each batch of product (along with the total time for production for a-batch-each of the entire range of products).

Table 21.2

I *Product*	*II* *Annual requirement (in units)*	*III* *Daily production-rate (units/day)*	*IV* *Daily consumption rate (units/day)*	*V* *Economic batch quantity*	*VI* *No. of days required to manufacture annual requirements*	*VII* *No. of days required to produce a batch quantity*	*VIII* *No. of days taken to consume a batch quantity*
V	24,000	480	80	4,800	50	10	60.00
I	12,000	360	40	2,548	33.3	7.07	63.60
B	36,000	480	120	6,770	75	14.12	56.50
G	6,000	240	20	1,621	25	6.75	81.05
Y	24,000	480	80	5,880	50	12.27	73.50
O	3,600	360	12	1,890	10	5.45	157.50
R	7,200	240	24	2,978	30	12.41	124.10
Total					**273.3**	**68.07**	

Table 21.2 gives the total production days required to manufacture the entire annual requirement of all seven coloured products as 273.3, whereas the total number of production days available are 300. Therefore, the aggregate capacity seems to be sufficient for the manufacture of the annual requirement of all the products. But, the total number of production days required, if an economic batch quantity of each of the products was produced, is 68.07 days. In other words, 68.07 days of the production cycle are required if each of the products is produced once in the amount as required by the economic batch quantity formula (independent EBQ determination). We observe in Table 21.2 that, for products V, I and B, the number of days to consume such as batch (EBQ) are less than 68.07. This means, in a situation when a batch (EBQ) each of the entire range of colours is to be manufactured (which takes 68.07 days totally) the colour V, I and B will experience shortage because each of them (V, I and B) will have been consumed fully much before the completion of the 68.07 days.

The above example shows the possible interference, and therefore, stock-outs, when the same plant facility is shared by multiple products. Such interference between different products is experienced sometimes, when the products share the same equipment but the batch quantities are calculated independently. To avoid this kind of problem, it is suggested that the economic batch size of the products using the same plant facility be determined jointly. Therefore, there will be joint cycles of manufacture and in each joint cycle all the products will be manufactured in appropriate quantities. The determination of the economic batch sizes of the different products then amounts to the determination of the optimal number of joint cycles in a year; annual demand for a product divided by the optimal number of joint cycles gives the economic batch quantity for the product.

Since all the products, using the same plant facility, are manufactured, one after another in each optimal joint cycle, there is no question of shortage of any product at any time.

JOINT CYCLE FOR MULTIPLE PRODUCTS

The principles to be followed in joint cycle determination are similar to that for the determination of the optimal batch quantity for individual products, as we shall see below. Let us denote C_{ci} for

the carrying cost of the product i and the corresponding set-up cost as C_{pi}. If A_i are the annual requirements of each of the products and n is the number of joint cycles to be conducted in a year, then we have

The average annual inventory carrying cost

$$= \frac{1}{2n}\sum_{i=1}^{s} A_i\left(1-\frac{r_i}{p_i}\right)C_{ci}$$

where, s is the number of products using the same plant facility, and r_i and p_i are the individual consumption and production rates for the products.

Please note that $Q_i = \dfrac{A_i}{n}$

The total set-up cost per annum is given by

$$n\sum_{i=1}^{s} C_{pi}$$

The total relevant cost for this model is the summation of the carrying and set-up costs.

That is, $\text{Total Cost} = n\cdot\sum_{i=1}^{s} C_{pi} + \dfrac{1}{2n}\sum_{i=1}^{s} C_{ci}\cdot A_i\cdot\left(1-\dfrac{r_i}{p_i}\right)$

The above total cost function needs to be differentiated with respect to n and equated to zero to find the optimal number of joint runs corresponding to minimum Total Cost. The expression for the optimal number of joint cycles for the products is given, therefore, as

$$n_{\text{optimal}} = \sqrt{\frac{\sum_{i=1}^{s} C_{ci}\cdot A_i\left(1-\dfrac{r_i}{p_i}\right)}{2\cdot\sum_{i=1}^{s} C_{pi}}}$$

Example Determine the optimal number of joint runs per year for VIBGYOR products (see previous example).

Solution

The relevant quantities for the joint cycle formula are determined in Table 21.3.

Therefore, $n_{\text{optimal}} = \sqrt{\dfrac{465{,}133}{2\times 15{,}000}} = \sqrt{15.52}$

$= 4$ cycles (approximately)

The optimal batch quantity for each of the products is now computed from the approximated optimal number of joint cycles during a year:

$$Q_v = \frac{24{,}000}{4} = 6{,}000 \text{ units}$$

$$Q_I = \frac{12{,}000}{4} = 3{,}000 \text{ units}$$

Table 21.3

Product Name	C_{ci} *(Rs. per unit/ year)*	A_i *(Units/ year)*	r_i *Usage*	p_i *Daily Production Rate*	$C_{ci} A_i \left(1 - \frac{r_i}{p_i}\right)$	C_{pi}
V	5	24,000	80	480	100,000	2000
I	5	12,000	40	360	53,333	1200
B	5	36,000	120	480	13 5,000	2400
G	5	6,000	20	240	27,000	1000
Y	5	24,000	80	480	100,000	3000
O	5	3,600	12	360	17,400	2400
R	5	7,200	24	240	32,400	3000
					465,133	15,000

$$Q_B = \frac{36,000}{4} = 9,000 \text{ units}$$

$$Q_G = \frac{6,000}{4} = 1,500 \text{ units}$$

$$Q_Y = \frac{24,000}{4} = 6,000 \text{ units}$$

$$Q_O = \frac{3,600}{4} = 900 \text{ units}$$

$$Q_R = \frac{7,200}{4} = 1,800 \text{ units}$$

Let us turn our attention to other inventory models.

INVENTORY MODEL WITH PURCHASE DISCOUNTS

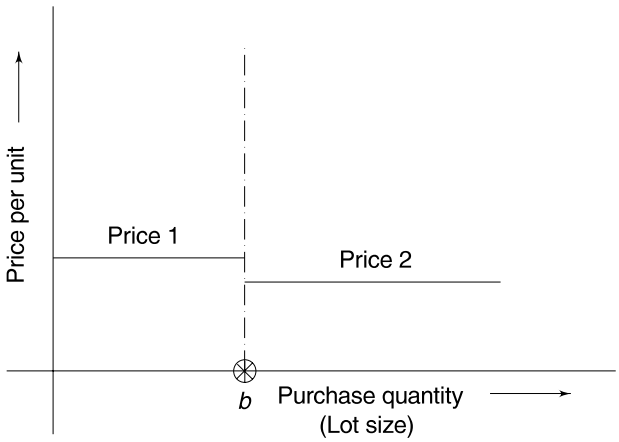
The classical model for inventory does not take into account, amongst other things, the quantity discounts given by the supplier if material is purchased in bulk. As the discount might be relevant in the inventory analysis, this could be included in the total relevant cost and therefore in this case, the total cost function becomes:

$$\text{Total Cost (relevant)} = C_p \cdot \frac{A}{Q} + \frac{Q}{2} \cdot s \cdot f + s \cdot A$$

where s is the supply price per unit of the inventory item, and f is the carrying cost of the inventory expressed as a fraction of the inventory value. (Other nomenclature remains the same.)

Differentiating the total costs with respect to Q and equating the result to zero, we get the optimal procurement quantity.

$$Q_{\text{optimal}} = \sqrt{\frac{2 C_p A}{s \cdot f}}$$



NOTE: b is the purchase lot size at which price 2 becomes applicable.

Figure 21.5 Purchase Lot Size and Corresponding Price Per Unit

and Total Costs (at optimality) = $\sqrt{2\,C_p \cdot s \cdot f \cdot A} + s \cdot A$

The quantity discount obtained is shown in Fig. 21.5.

At the two different prices (1 and 2) the Q_{optimal} values are different. Which one shall we choose Q_{optimal} for price 1 or Q_{optimal} for price 2? The answer is not straightforward. We shall have to plot the total cost (relevant) with respect to the procurement lot size. For lot sizes less than b, price 1 is operative and we get a total cost curve corresponding to it. For lot sizes equal to or greater than b we get another total cost curve. These curves need not exhibit minima within their zone. Price 1 total cost curve can have a minimum in the zone where price 2 is operating. Conversely. Price 2 total cost curve can have a minimum in the zone where price 1 is operating. The various possibilities are shown in Fig. 21.5.

It should be noted that due to the earlier given equations, the total cost curve for the second price will always be lower than the total cost curve for the first price, the minimum total cost for the second price will be lower than the minimum total cost for price 1, and the Q_{optimal} for price 2 will always be higher than Q_{optimal} for price 1. In spite of this, the three possibilities, as given in Fig. 21.6, arise.

Look at Fig. 21.6(i). Here it is obvious that we choose $Q_{2\text{ optimal}}$ for our economic order quantity.

Look at Fig. 21.6(iii). Here again, it is obvious that we choose $Q_{2\text{ optimal}}$. In fact, $Q_{1\text{ optimal}}$ does not exist. The lowest of the total cost at price 1 is at lot size 'b' and this total cost will have to be higher than the total cost for $Q_{2\text{ optimal}}$.

Now look at Fig. 21.6(ii). Here price 2 curve shows a minimum in the price 1 zone and the minimum is therefore imaginary. Hence, the only choice is between $Q_{1\text{ optimal}}$ and the price break quantity (at which the real part of the price 2 curve begins). This can be decided by comparing the total costs corresponding to the two choices.

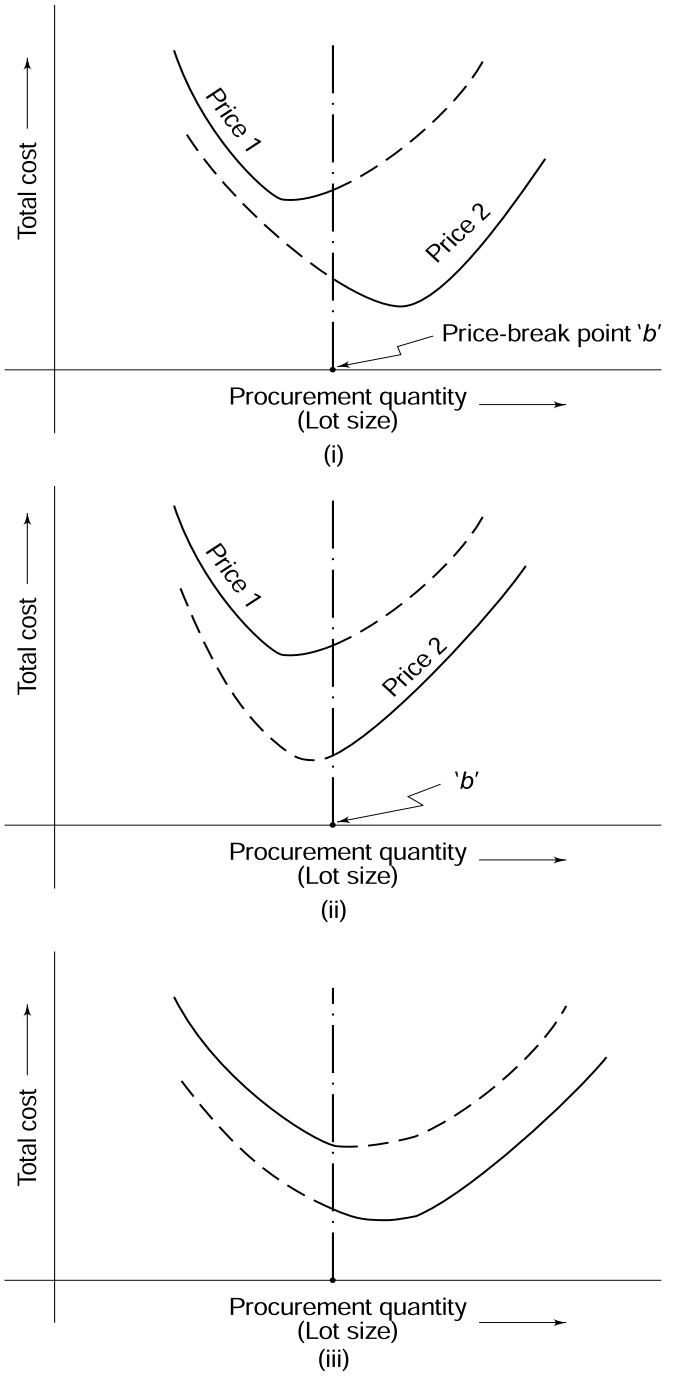


Figure 21.6 Complexities in Using Basic EOQ Model for Quantity Discounts

NOTE: Broken line shows the imaginary part of the curve.

The determination of the optimal quantity in the case of purchase discounts, therefore, follows the procedure given below:

1. Calculate $Q_{2\ optimal}$, the optimal lost size corresponding to price 2.
2. Find out if the $Q_{2\ optimal}$ falls in its own range. If so, our desired optimal order quantity is $Q_{2\ optimal}$. If not, carry out the following procedure.
3. Compare the total cost at $Q_{1\ optimal}$ with the total cost corresponding to the lot size 'b' (price break quantity) at the second price. If the former is less than the latter, choose $Q_{1\ optimal}$. Otherwise, the optimal order quantity is equal to the price-break point.

Example The supply of a special component has the following price schedule.

0 to 99 items: Rs. 1000 per unit

100 items and above: Rs. 950 per unit

The inventory holding costs are estimated to be 25% of the value of the inventory. The procurement ordering costs are estimated to be Rs. 2,000 per order. If the annual requirement of the special component is 300, compute the economic order quantity for the procurement of these items:

Solution

Step 1: $$Q_{2\ optimal} = \sqrt{\frac{2 \times 2000 \times 300}{0.25 \times 950}} \approx 71$$

Which is less than the price-break point.

Steps 2 and 3:

Therefore, we have to determine the optimal total cost for the first price and the total cost at the price-break point corresponding to the second price, and compare the two.

The Total Cost (optimal for the first price)

$$= \sqrt{2 \times 2000 \times 1000 \times 0.25 \times 300} + 1000 \times 300$$

$$= 17{,}320 + 300{,}000 = \text{Rs. } 3{,}17{,}320$$

The total cost for the price-break point (corresponding to the second price):

$$TC_b = 200 \times \frac{300}{100} + \frac{100}{2} \times 950 \times 0.25 + 950 \times 300$$

$$= 6{,}000 + 11{,}875 + 285{,}000$$

$$= \text{Rs. } 3{,}02{,}875$$

This is lower than the total cost corresponding to $Q_{1optimal}$.

Therefore, the economic quantity for a procurement lot is 100 units (price-break point).

CONSIDERATION OF UNCERTAINTIES

In the above given models for the determination of 'normal' inventory, consumption rates were assumed to be constant. In actual practice, there are always uncertainties stemming from two basic reasons:

1. Variability in sales, hence variability in the demand for the materials or the consumption of the materials.
2. Delay in the supplies of raw materials.

Let us first restrict ourselves to the non-constant or uncertain consumption of materials. There may occur shortages of materials because of uncertainties. For instance, let us take the basic inventory model and consider the effect of a sudden increase in the demand rate of the material during an order cycle. This sudden increase in consumption is illustrated by the broken lines in Fig. 21.7.

It may be noted that in this model, which is technically termed the 'fixed order quantity type' or a 'Q-system', the uncertainty in the consumption rates affects the material availability only so far as the lead time is concerned. The increased demand which leads to a stock-out of the material before the replenishment can arrive is felt during the lead time only. As Fig. 21.7 shows the amount of extra stock (Buffer Stock) to be kept depends upon the 'more than average' demand to be expected. In a probabilistic situation, various values of demand rate are possible with corresponding probability values.

APPROACHES TO DETERMINE BUFFER STOCK

There are two approaches to determine the buffer stock to be kept in order to cover demand rate variations:

(1) Explicit consideration of shortage costs; and (2) implicit consideration of shortage costs.

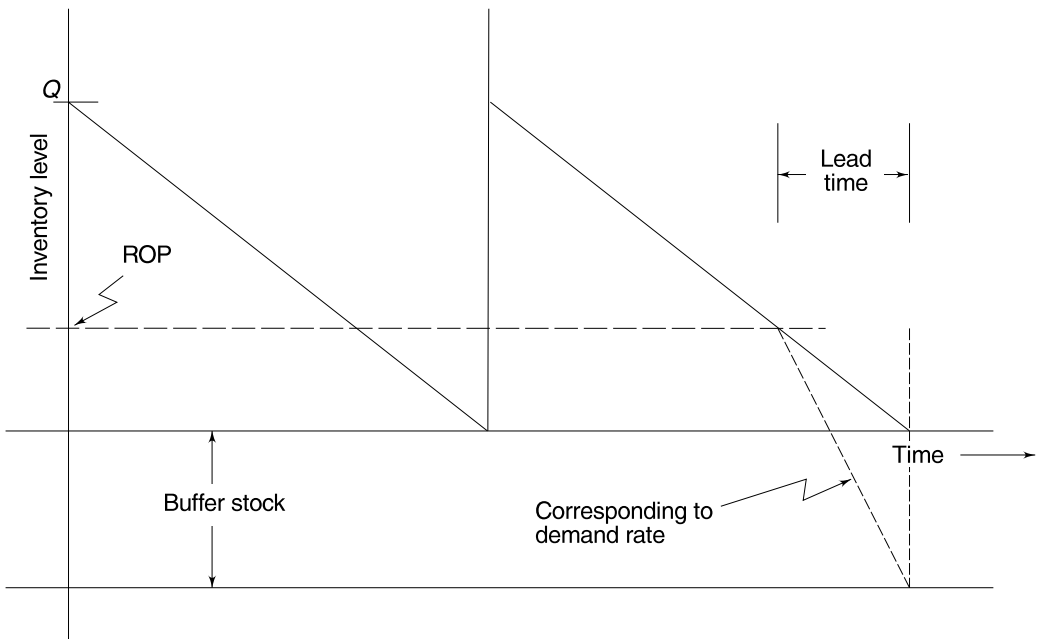


Figure 21.7 Basic Inventory Model Showing Requirement of Buffer Stock

NOTE: (Requirement of Buffer Stock is related to the maximum demand rate for which the protection is provided.)

1. Since inventory control basically involves the trade-offs between different costs, we may consider (a) the costs of not having the materials in the quantity that may be required and (b) the cost of keeping excess material in stock for fear of demand rate variations. The former cost per unit of the material is called as the 'understocking cost' or the 'shortage cost'; the latter cost per unit of the material is called as the 'overstocking cost'. These two categories of cost are the opportunity costs and a mathematical analysis can be carried out to find the optimal trade-off between these two opposing costs, to find the stock level at which the total of these two costs is minimum for a case where demand rates are probabilistic.

2. Instead of speaking in terms of explicit values of the understocking and overstocking costs, of which the former is not very easy to obtain, one may gauge the uncertain demand rates in terms of a 'risk' factor or 'risk-level'. The buffer stock is then computed based on the 'risk' which the organisation is willing to undertake.

For either of the above two approaches, the basic or key computation is to determine the maximum demand rate for which we would like to cover (prepare) overselves with the buffer stock. With reference to Fig. 21.7, once this maximum demand rate is fixed, the calculation of buffer stock is extremely easy. Since the buffer stock is required for the lead time only, the amount of buffer stock will be

$$(D_{\text{maximum}} - D_{\text{average}}) \text{ over the lead time}$$

Computations using Explicit Shortage Costs

For the determination of the maximum demand rate, let us consider the first approach, where the cost of under-stock and over-stock are considered explicitly:

If K_o = Opportunity cost of an over-stock of one unit*, and K_u = Opportunity cost of under-stock of one unit, x = the amount stocked $f(y)$ is the probability density function of demand:

Then the total cost (which is the addition of the over-stocking cost and the understocking cost), for the stock level of x units, is given by

$$\text{Total Costs} = K_o \int_o^x (x - y)\, f(y)\, \mathrm{d}y + K_u \int_x^\infty (y - x)\, f(y)\, \mathrm{d}y$$

Differentiating** this expression and equating the result to zero (for minimum), one gets

$$\frac{\mathrm{d}(TC)}{\mathrm{d}x} = K_o F(x) + K_u[F(x) - 1] = 0$$

---

* K_o is generally the Total Cost of one unit of item, s; and Ku is: (Cost of understocking a unit of item, C_s) – (Total Cost of one unit of the item), that is $(C_s - s)$. The salvage value of the item is assumed to be zero in this case.

**The mathematical procedure employs *Leibniz's Rule*:

If $$Q(x) = \int_{r(x)}^{s(x)} q(x, y)\, \mathrm{d}y$$

Then, $$\frac{\mathrm{d}Q(x)}{\mathrm{d}x} = \int_{r(x)}^{s(x)} \frac{\partial q(x, y)}{dx}\, \mathrm{d}y + q[s(x), x]\, \frac{\mathrm{d}s(x)}{\mathrm{d}x} - q[r(x), x]\, \frac{\mathrm{d}r(x)}{\mathrm{d}x}$$

Therefore, $$F(x) = \frac{K_u}{K_o + K_u} \approx \frac{C_s - s}{C_s}$$

This means the optimal level of x is given by the above expression.

Example A raw material item costs Rs. 200 per item. The shortage costs are estimated to be Rs. 1000 per item. Using the above derived expression,

$$F(x) = \frac{1000 - 200}{1000} = 0.8$$

Thus, this organisation should stock this material to the extent where the cumulative probability of demand is 0.80. Assuming that the probability distribution of the demand for this material follows a Normal distribution with a mean of 100 units per unit time, referring to the normal distribution tables (Appendix-II of this chapter), we see that

$$Z = \frac{x - m}{s.d.} = 0.84$$

Given that the standard deviation (s.d.) of the observed normal distribution is 20 units, we have:

s.d. for the lead time of 10 time units,

$$(s.d.)_{LT} = \sqrt{\sum_{i=0}^{10} (s.d.)_i^2} = \sqrt{10\,(20)^2} = 20\sqrt{10}$$

Since $z = 0.84$, the required buffer stock for the lead time of 10 time units is given by

$$(0.84) \times \left(20\sqrt{10}\right) = 53 \text{ units}$$

The above given example made use of the explicit computations of understocking and overstocking costs. Firstly, there were many mathematical assumptions or approximations made in the derivation itself of the given simple formula for the calculation of $F(x)$. These assumptions *per se* do not pose too many difficulties in this approach to calculate the buffer stocks. But, the real difficulty is the estimation of the understocking or stock-out costs.

Difficulties in Estimating the Shortage Cost Explicitly

What does the shortage cost comprise? It is the cost of not being able to fill the order. But if we closely look at the operations of any business, we will notice that not filling the order is not the only option open to the organisation. Alternatively, one can:

(a) Buy from another organisation or dealer and resell. The sale will not give the organisation any profit, but it will maintain the goodwill with its customer; possibly it may buy the goods from other organisations at a premium and this becomes the cost of this alternative.

(b) Postpone the order. The organisation can tell the customer to wait for some time and thus not lose the order. Here, one does not lose the profit, but one may lose the goodwill of the customer. How can one estimate the cost of goodwill? This is yet another problem.

(c) Rearrange the deliveries to various customers in such a way that one neither loses the goodwill nor the profit. But one may have to do rescheduling of production and other activities in its organisation, which would entail some cost to the organisation.

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As seen above, there are a number of ways in which a shortage situation can be met. Therefore, what is the shortage cost? It is the weighted average of all the above mentioned costs of the different alternatives, provided one knows how many times to follow the alternative (a), how many times alternative (b), (c), etc. This is not only difficult, but also naive. Therefore, there is much difficulty in estimating the shortage cost explicitly in terms of money. To alleviate this difficulty, one may resort to expressing the uncertainty in terms other than that of money. One may simply measure the uncertainty in terms of the risk level (the second approach suggested earlier).

Implicit Consideration of Shortage Costs by Management 'Risk-Level'

In the earlier given illustrative problem, instead of giving the understocking costs explicitly, we can state that the risk level tolerated by the management is 20%. In fact, what we are saying is that $F(x) = 0.80$. But this we do, without resorting to the estimation of the understocking cost and the subsequent calculation of the value of $F(x)$. The 20% risk level is an intuitive figure given by the management. This intuitive figure, in fact is an imputation of the understocking and the overstocking costs. So, when one says that the risk level tolerated by the management is 20%, this imputes an opportunity cost of under-stocking at Rs. 800 per item when the opportunity costs of overstocking are Rs. 200. For the reasons which were given in the preceding paragraph, it is better in most of the practical cases to arrive at an intuitive judgement of the risk tolerance and calculate the buffer stocks therefrom.

Example The demand for round-shafts required as raw material in a company is observed to be 180 units per day, on an average. The demand distribution follows the normal curve with a standard deviation of 30. If a 10% probability of stock-out is tolerated by the management and if the lead time for the procurement of the shafts is 20 days, compute the level of buffer stocks.

Solution $F(x) = 0.9$

Therefore, from the Normal tables: $Z = 1.28$

Now, standard deviation for the lead time of 20 days is $30\sqrt{20}$

Therefore, a buffer stock of $(1.28)\ 30\ \sqrt{20} = 172$ units is necessary to be kept.

Although we have assumed simple probability distributions in the earlier given examples, it is not necessary to make such assumptions for the calculations of the buffer stock. One can consider discrete values of the demand observed in the past and based on a histogram of the relative frequency of the discrete values of demand, calculate the value of the demand rate corresponding to a given management risk level.

Example A municipal hospital uses a raw material which it obtains from a local source. A fixed order quantity inventory system is used. The cost of ordering and carrying are estimated at Rs. 50 per order and Rs. 10 per unit per year respectively. The lead time for orders is constant at 30 days. The figures of the variable usage per day, observed in the past, are given in Table 21.4. Calculate the order quantity and the required buffer stock for a maximum of 5% risk of stock-out.

Table 21.4

Usage Per Day	*No. of Times such a Usage was Observed in the Past*
7	5
8	11
9	20
10	25
11	12
12	4
13	3

Solution

The information supplied regarding the usage variation is plotted in the histogram presented in Fig. 21.8.

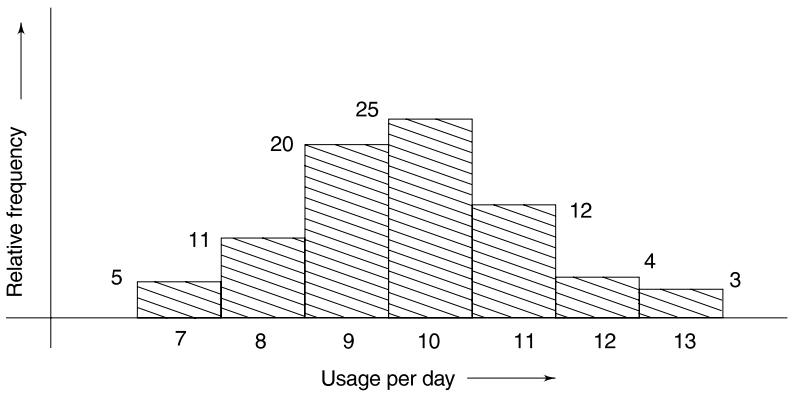


Figure 21.8 Histogram Depicting Usage Variation

This histogram is now converted into another histogram (or a graph) where the vertical axis gives 'the number of times a particular demand level was exceeded'. It is necessary to do this, since the risk to the management comes from the actual demand exceeding the assumed value of demand. In order to plot this histogram, Table 21.4 needs to be converted into Table 21.5 which is then plotted as presented in Fig. 21.9.

For convenience, the vertical axis in Fig. 21.9 has been converted into a 0 to 100 scale because management risk levels are expressed usually in percentages.

For the above given data, corresponding to the 5% risk level, we read off the corresponding demand level which is 11.80. Therefore, if we keep a buffer stock corresponding to the usage rate of 11.80 units a day, then we would have covered ourselves of exposure to risk of stock-out 5 times out of 100 (that is, if 100 order cycles are encountered, we may expect to come across stock-out situations for 5 order cycles).

Table 21.5

Usage Per Day	*No. of Times such a Usage was Observed in the Past*	*No. of Times the Usage Exceeded the given Level*
7	5	75
8	11	64
9	20	44
10	25	19
11	12	7
12	4	3
13	3	0

The average usage has not been supplied in the description of the problem, but it can be calculated from the data given in the table. The average usage,

$$D_{av} = \frac{7\times5+8\times12+9\times20+10\times25+11\times12+12\times4+13\times3}{5+11+20+25+12+4+3}$$

$$= 9.65 \text{ units per day.}$$

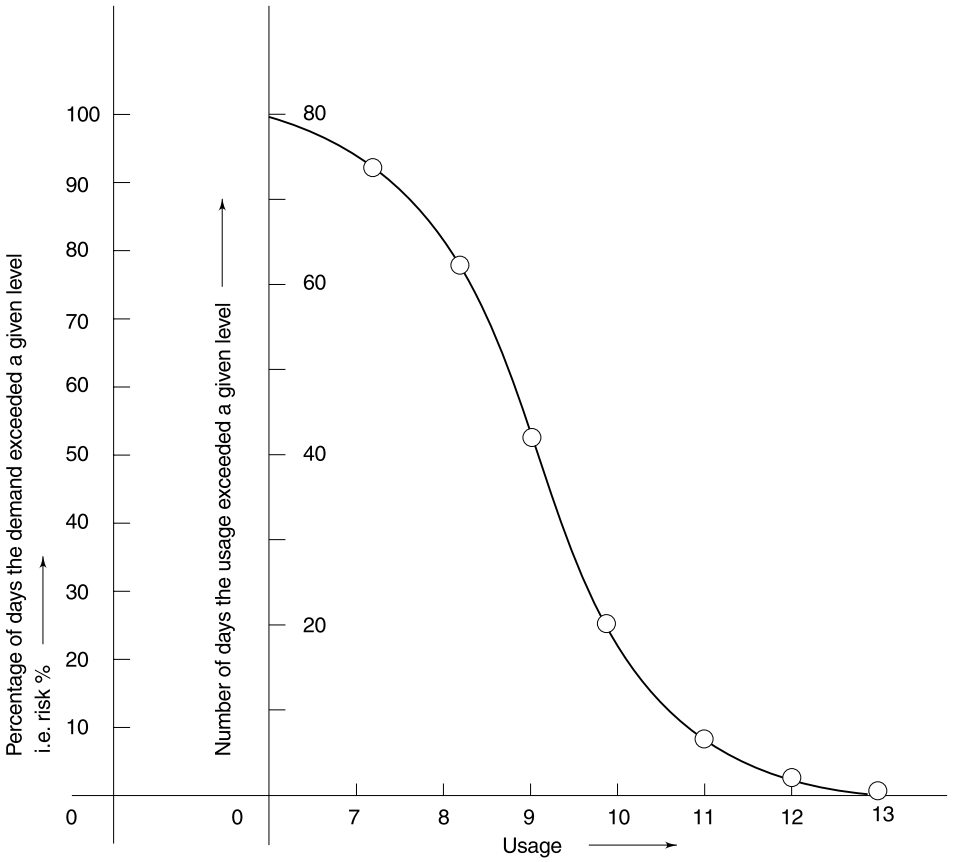


Figure 21.9 Usage Variation Diagram Converted in Order to Express Management Risk Levels

Therefore, Buffer Stock = $(D_{max} - D_{av}) \times$ lead time

$= (11.80 - 9.65) \times 30 = 64.5 = 65$ units, (approximately)

The EOQ can be easily calculated

$$\text{EOQ} = \sqrt{\frac{2 \times (9.65 \times 365) \times 50}{10}}$$

$= 187.7$

$= 188$ (approximately)

The above example considered only the variation in the consumption rates internally. The uncertainty could also be in terms of the variations in the lead times for supply of the material. In practice, we meet with both these uncertainties.

PROTECTION METHODS AGAINST USAGE RATE VARIATIONS AND SUPPLY LEAD TIME VARIATIONS

Common Sense Method

One common sense way of taking care of such uncertainties would be to gather the past data regarding the demand rates during a lead time. Remember, that this 'lead time' would have been a variable figure, and the data of demand rates we gather are regarding the consumption rates during these varying lead times. For instance, the lead times in the past could have been one month, two months, and three months and the data of demand rate has to be gathered for a lead time irrespective of whether the lead time is one month, two months or three months. Then, the analysis can proceed along very much the same lines as given before. Corresponding to risk level, the maximum demand is read off and from it the average demand during a 'lead time' is subtracted. This difference may be taken to be requirement of the buffer stock.

Calculation of Joint Probabilities Method

A mathematical method would be to find the probability distributions for the consumption rate as well as for the lead time. Then a joint probability distribution of the usage during 'a lead time' may be found. This distribution can then be converted into a cumulative frequency curve similar to that in Fig. 21.9. Now, corresponding to a risk level, the maximum demand rate can be read off from the cumulative frequency curve. The buffer stock is given by the difference between the maximum demand and the average demand.

Example The usage rate and the corresponding probabilities for a material are given below:

Usage Rate (units/week)	Probability
1	0.3
2	0.5
3	0.2

The lead time of supply of the material and corresponding probabilities are as follows:

Lead Time (weeks)	Probability
1	0.3
2	0.4
3	0.3

What is the required buffer stock, if the management risk level is 5%?

Solution

First, let us find out the joint probabilities of usage during a lead time. The minimum and maximum usage during a lead time are 1 unit and 9 units, respectively.

(i) *Calculation of probability of usage of 1 unit during a lead time:*

This usage can occur only when lead time is 1 week and usage rate is 1 unit/week.

Therefore, probability of this usage

= (Probability of lead time being 1 week) × (Probability of usage being 1 unit/week)

$= 0.3 \times 0.3 =$ **0.09**

(ii) *Calculation of probability of usage of 2 units during a lead time:*

This usage can occur in two ways:

(a) Lead time = 1 and usage = 2
Therefore joint probability $= 0.3 \times 0.5 = 0.15$

(b) Lead time = 2 and usage of 1 unit/week during first week and usage of 1 unit/week during second week
Therefore, joint probability =

(Probability of lead time of 2 weeks) × (Probability of usage rate of 1 unit/week) × (Probability of usage rate of 1 unit/week)

$= 0.4 \times 0.3 \times 0.3 = 0.036$

Therefore the probability of usage of 2 units during a lead time is the addition of the joint probabilities derived for the two ways:

$= 0.150 + 0.036 =$ **0.186**

Similarly, we can calculate for usages up to 9 units. The calculations in abbreviated notations are given below:

LT = Lead Time; U = Usage rate

(iii) *Lead time usage of 3 units*			*Probability*
LT = 1	U = 3	0.3×0.2	= 0.06
LT = 2	U = 1 & 2 or 2 & 1	$0.4 \times 0.3 \times 0.5 \times 2$	= 0.12
LT = 3	U = 1, 1 & 1	$0.3 \times 0.3 \times 0.3 \times 0.3$	= 0.0081
			Total = 0.1881

(iv) *Lead time usage of 4 units*			*Probability*
LT = 2	U = 1 & 3	$0.4 \times 0.3 \times 0.2$	= 0.024

	or		
	3 & 1	$0.4 \times 0.2 \times 0.3$	$= 0.024$
	or		
	2 & 2	$0.4 \times 0.5 \times 0.5$	$= 0.100$
LT = 3	U = 1, 1 & 2		
	or		
	2, 1 & 1	$0.3 \times 0.3 \times 0.3 \times 0.5 \times 3$	$= 0.0405$
	or		
	1, 2 & 1		
			Total = 0.1885

(v) *Lead time usage of 5 units*

			Probability
LT = 2	U = 2 or 3 & 3 & 2	$0.4 \times 0.5 \times 0.2 \times 2$	$= 0.080$
LT = 3	U = 1, 3 & 1 & 1	$0.3 \times 0.3 \times 0.3 \times 0.2 \times 3$	$= 0.0162$
	or 1, 1 & 3		
	or		
	1, 2 & 2 & 1	$0.3 \times 0.5 \times 0.5 \times 0.3 \times 3$	$= 0.0675$
	or 2, 1 & 2		
			Total = 0.1637

(vi) *Lead time usage of 6 units*

			Probability
LT = 2	U = 3 & 3	$0.4 \times 0.2 \times 0.2$	$= 0.0160$
LT = 3	U = 2, 2 & 2	$0.3 \times 0.5 \times 0.5 \times 0.5$	$= 0.0375$

or 3, 1 & 2 or 1, 3 & 2 or 1, 2 & 3 or 2, 1 & 3 or 3, 2 & 1 or 2, 3 & 1	$0.3 \times 0.3 \times 0.5 \times 0.2 \times 6$	$= 0.0540$
		Total = 0.1075

(vii) *Lead time usage of 7 units* — *Probability*

LT = 3 U = 3, 3 & 1 or 1, 3 & 3 or 3, 1 & 3	$0.3 \times 0.2 \times 0.2 \times 0.3 \times 3$	$= 0.0108$
or 3, 2 & 2 or 2, 3 & 2 or 2, 2 & 3	$0.3 \times 0.2 \times 0.5 \times 0.5 \times 3$	$= 0.0450$
		Total = 0.0558

(viii) *Lead time usage of 8 units* — *Probability*

LT = 3 U = 3, 3, 2 or 3, 2, 3 or 2, 3, 3	$0.3 \times 0.2 \times 0.2 \times 0.5 \times 3$	$= 0.018$

(ix) *Lead time usage of 9 units* — *Probability*

LT = 3 U = 3, 3, 3	$0.3 \times 0.2 \times 0.2 \times 0.2$	$= 0.0024$

The results of the above calculations, are shown in Table 21.6.

(NOTE: Instead of such tedious calculations, one can use a Monte Carlo Simulation to find out the joint probabilities.)

Table 21.6 Probabilities of Lead Time Usage Found by Joint Probability Calculations

Lead Time Usage (units)	*Probability*	*Probability that the Demand will Exceed a given Level*
1	0.0900	0.9100
2	0.1860	0.7240
3	0.1881	0.5359
4	0.1885	0.3474
5	0.1637	0.1837
6	0.1075	0.0762
7	0.0558	0.0204
8	0.0180	0.0024
9	0.0024	0.0000
Total = 1.0000		

Referring to Table 21.6 corresponding to the management's risk level of 5% (i.e. probability that the demand will exceed 0.0500), the lead time usage is 7 units (without resorting to interpolation).

The average demand $D_{av} = 1 \times 0.0900 + 2 \times 0.1860 + 3 \times 0.1881 + 4 \times 0.1885 + 5 \times 0.1637 + 6 \times 0.1075 + 7 \times 0.0558 + 8 \times 0.0180 + 9 \times 0.0024 =$ **3.800**

$$\text{Buffer Stock} = D_{max} - D_{av}$$
$$= 7 - 3.800$$
$$= \textbf{3.200 units}$$

A Simple Practical Formula

The above calculation is somewhat combersome. A formula for use in practice can be as follows:*

The standard deviation of total demand during the lead time σ_D is given by

$$\sigma_D^2 = \bar{t}\,\sigma_x^2 + \bar{x}^2 \cdot \sigma_t^2$$

where $\bar{x}$ = the average demand per month, $\bar{t}$ = the average lead time in months, σ_x = the standard deviation of demand, and σ_t = standard deviation of lead time in months. (We may use month or any other suitable time unit.)

This expression assumes that the two distributions—lead time and demand rate—are independent. This is one of the drawbacks of this formula. For instance, if the demand rates are more, the demands on the supplier for raw materials are more and this is bound to increase the lead time of supply. Inspite of some amount of dependency of the two distributions, the above formula gives satisfactory results for use in practice.

Example The average demand rate for a particular raw material for a company is estimated to be 1000 items per month. The distribution of demand rates is found to approximate a normal distribution with a standard deviation of 200. The average lead time for the procurement of the raw material is observed in the past to be approximately 3 months and the normally approximated lead times have a standard deviation of 1 month. If the risk level tolerated by the management is only 5%, what is the buffer stock required for this raw material?

Solution

Applying the given formula:

The standard deviation of total demand during a lead time

$$\sigma_D = \sqrt{3 \times (200)^2 + (1000)^2\,(1)^2}$$

---

* (i) The *component* of the standard deviation of the demand during a lead time, *due to lead time variation*, is (s.d. of lead time, σ_t) *x* (mean demand rate, $\bar{x}$)

The variance due to this component is: $(\sigma_t \times \bar{x})2$

(ii) The variance of demand during a lead time, *due to demand rate variation*, is

$$\sum_{0}^{\bar{t}} \text{(s.d. of demand, } \sigma_x)^2 = \bar{t} \cdot \sigma_x^2\text{, whether } \bar{t} \text{ is the average lead time.}$$

The variance of the total demand during a lead time is the summation of the above two variances.

$$= \sqrt{1.12 \times 10^6} = 1060 \text{ units}$$

Therefore, corresponding to 5% risk level, we have, under Normal distribution, 1.645 standard deviations from the mean.

Hence, Buffer Stock = 1.645×1060

= 1,744 units

FIXED ORDER PERIOD MODELS

So far we have considered situations where the order quantity was fixed. The entire range of models given earlier are called as the 'fixed order quantity' models and the inventory control system is called a *Q*-system. Here, the economic order quantity for the normal inventory is determined, and this fixed quantity of order is placed on the supplier every time the inventory level reaches the reorder point. In addition to the normal inventory given by the EOQ, a buffer stock, as calculated earlier, is also maintained, to take care of the uncertainties. Therefore, in the fixed order quantity models, the economic order quantity plus the buffer stock will give us the maximum inventory to be maintained. One thing to be noted in these models is that the orders are placed without any definite periodicity. Periodicity of placing the orders is not the concern of fixed order quantity models.

But in many organisations, the purchasing policy is to place an order for materials at definite periodic intervals, such as monthly, quarterly, etc. In such cases, different type of inventory models will have to be used. These are termed as 'fixed order period' models or *P*-system of inventory control. In the *P*-system, as illustrated in Fig. 21.10, the ordering period is fixed but the order size (quantity) may be varying. The procedure for *P*-system consists of:

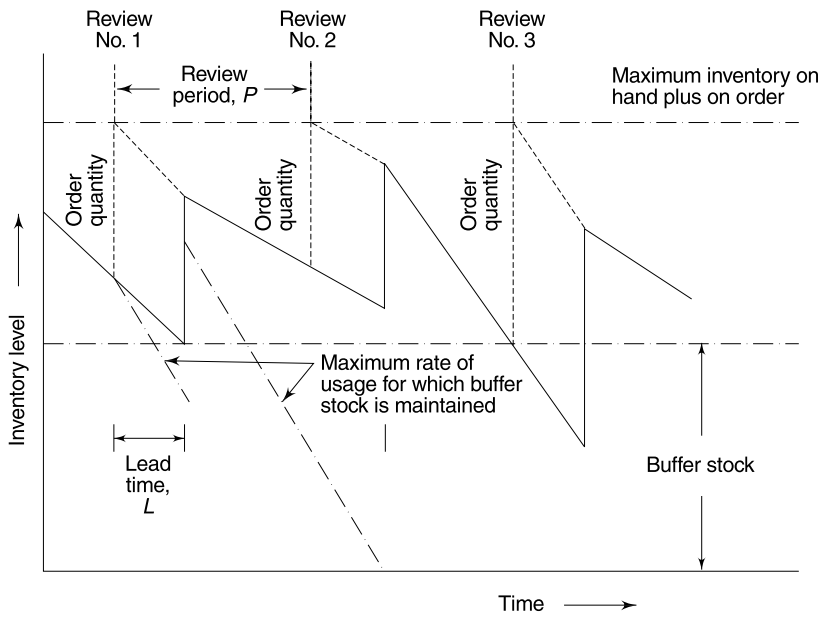


Figure 21.10 Illustration of the Fixed Order Period System (*P*-System)

1. determining the optimal order cycle analytically, including some practical considerations;
2. determining the maximum level of inventory on hand and on order analytically; and
3. determining the amount to order, at each period, by subtracting the actual amount on hand from the earlier determined level of maximum inventory on hand plus on order.

The two quantities which need to be determined in a *P*-system are, therefore

(a) the order cycle, and
(b) the maximum inventory on hand plus on order.

Review Period for P-System

The optimal review period is approximately given by

$$P = \frac{1}{N_{opt}}$$

where N_{opt} is calculated by the basic EOQ formula for a Q-system.

(N_{opt} = optimal number of orders = annual requirement of the material divided by the economic order quantity)

Although this approximation is good, there are still some practical difficulties associated with it. The basic idea of using the *P*-system is to club together the orders for various raw materials and place these jointly at every period. If one calculates the review period for each inventory item independently, the very purpose of a *P*-system is defeated. Therefore, in practice, while fixing the review period it may be advisable to also consider other aspects such as the time required to accumulate orders for different raw materials so that an order of sufficiently large quantity can be placed with the supplier, or the financial or budgetary cycle of the organisation, etc.

Maximum Inventory on Hand Plus on Order

Next is the determination of the maximum level of inventory on hand and on order. This is deter mined by the addition of two quantities:

1. The average requirement of material for usage during a review period plus lead time.
2. The buffer stock specially determined for the *P*-system. The basic difference between the *P*-system and the *Q*-system is that, in the latter, the buffer stock needs to be carried only for the lead time, whereas in the former the buffer stock requirements are for both the lead time as well as the review period. In the *P*-system, one has to maintain the buffer stock to protect against demand fluctuations during the order (review) period also because there is no flexibility in the order period as in the case with the fixed order quantity system. The latter system absorbs the demand fluctuations during the order period by varying the order period itself and therefore does not require buffer stock for this additional consideration. Remember that in the P-system, the buffer stock will be required not only for the order period but also for the lead time.

Example Consider a case where the average demand during the past is observed to be 100 units per month. The review cycle is one month. A safety stock of 20 units is kept to protect against consumption rate variation during the review period. The lead time is half a month. The maximum

inventory we have on hand is 120 units (100 for normal consumption and 20 for safety). Suppose the consumption rate suddenly increases to 120 units per month starting from a time of review period denoted as Review Period No.1. The inventory levels at different points of time will be as follows:

At Review No. 1	:	70 units (120 – 50 units)
At the end of Lead Time No. 1	:	70 – 60 = 10; plus 100 units received due to order placed at Review Period 1 = 110 units.
At Review No. 2	:	110 – 60 = 50 units; now an order for 120 units is placed.
At the end of Lead Time No. 2	:	50 – 60 = – 10 units.

We notice, therefore, that we face a stock-out during lead time No. 2. This situation has arisen because we did not provide for safety stock for the lead time; our provision of the safety stock was only for the review period.

Let us provide, safety stock for review period plus lead time (i.e., for $1\frac{1}{2}$ months). The safety stock will be 30 units and maximum inventory on hand will be 130 units. Now, the stock levels at different points of time are:

At Review Period No. 1	:	130 – 50 = 80 units.
At the end of Lead No. Time No. 1	:	80 – 60 = 20 units; plus 100 units received due to order placed at Review Period 1 = 120 units
At Review Period No. 2	:	120 – 60 = 60 units. An order for 120 units is placed.
At the end of Lead Time No. 2	:	60 – 60 = 0 units; plus 120 units received due to order placed at Review Period 2.

Note that there is no stock-out situation now. In short, in a *P*-system, buffer stock should be kept for consumption variations for amounts of time equal to review period plus lead time.

The same statement is valid even when the review period is equal to or smaller than lead time. Readers can check the validity by similar calculations.

Summary

1. Buffer stock is kept for review period + lead time.
2. Maximum Inventory on hand plus on order, I_{H+O} } = (Normal Consumption + Buffer Stock) both for review period plus lead time.

Example The Public Works Department has to place orders for supply of raw materials every three months. A number of different raw materials are procured from a supplier at periodic intervals. The annual requirements of all these products amounts to Rs. 12 lakh. The cost of ordering is estimated at Rs. 5,000 per order and the cost of holding inventory is estimated at 25% of the value

of inventory. Average lead time for procurement of these materials from the supplier is observed to be two months. The demand for the raw materials can be roughly approximated to a normal distribution with a standard deviation of Rs. 1 lakh per period.

Suggest an inventory system for these materials.

Solution

The economic order quantity is given by

$$\sqrt{\frac{2 \times 12,00,000 \times 5,000}{0.25}} = \text{Rs. } 2,20,000$$

Therefore, the model suggests that the number of orders during a year should have been 5 to 6, whereas the number of orders due to the organisational constraints are 4. If the organisational policy of ordering every quarter is to be followed, then the stock policy can be calculated as follows:

$$I_{H+O} = \text{Quantity required for the Review Period plus Lead Time + Buffer Stock}$$

$$= \text{Rs. } \frac{12,00,000 \times 5}{12} + \text{Buffer Stock (for 3 + 2 = 5 months)}$$

Providing a service level of approximately 97% (our assumption):

$D_{\max}$ will be = D_{av} + 2 standard deviations

where standard deviation = 1,00,000 for 3 months

$$= \text{Rs. } 1,00,000 \times \sqrt{\frac{5}{3}} \text{ for 5 months}$$

$$= \text{Rs. } 1,29,200 \text{ (approx.)}$$

Therefore, $I_{H+O} = (5) + (2 \times 1.292) = \text{Rs. } 7.584 \text{ lakh}$

This is the maximum inventory on hand plus on order which along with the review periodicity of a quarter (3 months) determine the *P*-System.

The buffer stock is 2.584 lakh.

In addition to the buffer stock requirements for the usage rate uncertainties considered in the preceding discussion on *P*-system, one has also to provide buffer stock protection for lead time fluctuations. This can be done very much along the same lines as was done for the *Q*-system. It may not be difficult for the reader to apply the same concepts in a *P*-system.

In the entire chapter so far it was implicitly assumed that lead time consisted only that of the supplier. Since the calculations of the buffer stock are meant for taking care of uncertainties, it is necessary in many cases to consider internal uncertainties in the processing of the procurement orders themselves. Therefore, lead time need not be restricted only to things external to the organisation.

Although, EOQ and buffer stock calculations may not totally reflect the practical situation, still the concepts behind these two are good enough to serve the practical requirements of organisations. They may not be, in many cases, exact estimates, but conjectures. The merit is more in the underlying conceptual base than in the precision of the figures estimated.

While the EOQ and safety stock approach has been in vogue for the past several decades, the recent wave of world-class management has been bringing in a paradigm shift shaking the fundamental basis of the conventional inventory management techniques. It is true that the function of the Inventory Control is to minimise the costs related to inventory. But, are they really doing it? The premise that deliveries must precede with a lead time, that uncertainties are unavoidable natural phenomena, and that safety stocks are required to take care of the changes in customer demand or other factors, is now being seriously questioned. This will be discussed in the later chapters of this book.

SOLVED PROBLEM

1. Bishambhar Rai & Company at Raipur makes transformers and uses copper conductors as an important input into their product. The company's annual requirement for the copper conductor is 83,500 kg. Copper is expensive and the carrying cost of Rs. 150 per kg per year includes the cost of capital on the conductor as a major component and several others like the cost of storage space, the cost of additional personnel, and even the cost of pilferage. Understandably, the company plans to purchase the conductors in a number of orders placed during the year. However, the cost of placing the order involves employing purchasing executives, cost of stationery, and fax and telephone charges among other expenses. All this totals to an estimated Rs. 16,800 per order. The supplier of conductors generally takes only one week to deliver the material.

(a) What should be the reorder point for copper conductor for Rai & Company?

(b) What should be the amount of copper conductor ordered every time?

(c) For the above reorder policy, what is the annual cost of carrying the inventory of these copper conductors?

(d) If only four orders are placed per year, what will be the effect on the average inventory holding cost for Rai & Company on account of these conductors?

(e) If the average cost of placing an order was Rs. 4,200 per order, what will be the amount of the inventory of copper conductors on an average?

Answer

(a) & (b)

Economic Order Quantity (EOQ) = $\sqrt{2(16,800)(83,500)/(150)}$

= 4,324.81 or 4,325 kg approximately.

Number of such orders placed per year = 83,500/4,324.81

= 19.31 or 20 approximately.

Therefore, every time an order is placed, the company may order (83500/20) = 4175 kg of copper conductor.

The consumption of copper conductor per week = 83,500/52 = 1,605.77 or 1,606 kg.

The consumption during the lead time of 1 week = 1,605.77 or 1,606 kg.

When the stock of the conductor reaches (i.e. falls down to) this level i.e. 1,606 kg, it is time to reorder. This 1,606 kg is the 'Reorder point' or also known as 'Reorder level'.

(c) Under this stocking policy, the average level of inventory is = ½ (Order Quantity)

$$= 1/2\ (4{,}175\ \text{kg}) = 2{,}087.5\ \text{kg}.$$

The holding cost for this stock is = (Rs. 150 per kg) × (2,087.5 kg) = Rs. 3,13,125.

This, Rs. 3,13,125 is the total annual cost of carrying the copper conductors.

(d) If only 4 orders are placed every year, the ordering quantity would have to be

$$= (\text{Annual requirement})/4 = 83{,}500/4 = 20{,}875\ \text{kg per order}.$$

The average level of inventory would then be = 1/2 (20,875) = 10,437.5 kg.

The holding cost for this stock is = (Rs. 150 per kg) × (10,437.5 kg.)

$$= \text{Rs. } 15{,}65{,}625.$$

Thus, Rs. 15,65,625 would now be the annual cost of carrying the copper conductors. This is 5 times the total carrying cost under previous ordering policy.

(e) If the average cost of placing an order is Rs. 4,200 per order, we need to compute the EOQ once again.

$$\text{EOQ} = \sqrt{2(4{,}200)(83{,}500)/(150)} = 2{,}163.41\ \text{kg}.$$

The average level of inventory of the copper conductors would then be

$$= 1/2\ (2{,}163.41) = 1{,}081.75\ \text{kg}.$$

2. If the above company used a fixed review period system instead of the fixed reorder quantity system, but the figures for the annual requirement (83,500 kg per year), order cost (Rs. 16,800 per order) and holding cost (Rs. 150 per kg) were the same as earlier, what is the periodicity of orders under this new inventory control system?

Answer

The optimal review period is given by $P = 1/N$

where, N ≡ optimal number of orders as per the EOQ formula of fixed order quantity system.

$$P = 1/(19.31)\ \text{years}$$

$$= 52\ /(19.31)\ \text{weeks} = 2.69\ \text{weeks}.$$

Rounding off, $P = 3$ weeks.

3. Continue with the earlier solved problem No. 1. If the total annual demand is the same, but there is a variation in weekly demand of the conductors with a standard deviation of 150 kg, assuming a Normal distribution of demand:

(a) What should be the buffer stock of this item for Bishambhar Rai & Company? The company can tolerate a risk of stock-out of only 2 per cent.

(b) What would be the annual cost of holding the inventory of these conductors?

(c) If the lead time was 2 weeks, what would be the annual cost of holding the inventory of these conductors? Use the risk of stock-out of 2 per cent.

(d) What would be the buffer stock of these conductors, if the company used the fixed review period system (P-system)? Take lead time as 2 weeks, standard deviation of weekly demand as 150 kg and the risk of stock-out of 2 per cent. What would be the defining characteristics of this system?

(e) Continuing with the above mentioned fixed review period system, if the company had 5,000 kg of these conductors in stock at a particular review period, what should be the amount that should be ordered?

Answer

(a) Risk of stock-out of 2 per cent ≡ Service level of 98 per cent.
Buffer stock = Maximum demand during the lead time corresponding to a 'service level' of 98 per cent *minus* Average demand during the lead time.
Referring to the Normal distribution table, corresponding to 98 per cent service level we have $Z = 2.054$.

Thus, $Z = (x - \mu)/\sigma = 2.054$

Since μ = mean weekly demand = 83,500/52 = 1605.77 kg and σ = 150 kg, we have: $(x - 1605.77)/150 = 2.054$.
That means, $x = 150\ (2.054) + 1605.77 = 1913.87$ kg. This is the maximum demand which the current inventory stocking policy is prepared to meet.
Buffer stock = $(Z) \times (\sigma) = 308.1$ kg.

(b) Average stock level of conductors = Buffer stock + 1/2 (Ordering Quantity)

= 308.1 + 1/2 (4324.8) = 2470.5 kg.

Annual holding cost = 2470.5 × Holding cost per kg

= 2470.5 × Rs. 150 = Rs. 3,70,575

(c) If the lead time was 2 weeks, then the standard deviation of the demand during the lead time of 2 weeks would be: (std. devn. during 1 week) × $(\sqrt{2})$

= (307.5) × (1.4142) = 434.87 = 434.9 kg.

Average stock level of conductors = Buffer stock + 1/2 (Ordering Quantity)

= 434.9 + 1/2 (4324.8) = 2597.3 kg.

Annual holding cost = 2597.3 × Holding cost per kg

= 2597.3 × Rs. 150 = Rs. 3,89,595.

(d) If the company used a fixed review period system of inventory control (P-system) with a periodicity of ordering every 3 weeks as calculated in Solved Problem (2) earlier, we have the following:
Under the P-system, the buffer stock has to provide cover for (lead time + review period), i.e. for (2 + 3) = 5 weeks.
Now, standard deviation of demand during 5 weeks

= Std. deviation of demand for 1 week × $(\sqrt{5})$ = 150 × $(\sqrt{5})$ = 335.41 kg.

Therefore, buffer stock required = $Z \times 335.41 = 2.054 \times 335.41 = 688.9$ kg.
An important and defining characteristic of the P-system is "Maximum Inventory on Hand *plus* on Order", I_{H+O}.

I_{H+O} = Stock needed for the average demand during (review period + lead time) + Buffer stock
= Stock needed for (3 + 2 = 5) weeks + Buffer stock
= (1605.77 × 5) + (688.9) = 8717.75 kg. or 8718 approximately.

Thus, the P-system is described by:
Review period = 3 weeks and

I_{H+O} = 8718 kg.

(e) The amount to order at that period =
{Maximum Inventory on Hand *plus* on Order", I_{H+O}} – (Inventory on Hand)
= (8718) – (5000) = 3718 kg.

4. Manjari Menon is a Senior Purchasing Executive at a large multinational high-end hotel chain. She buys single-use designer napkins from a local textile firm at Rs. 10 per piece. Her hotel chain needs 80,000 such napkins annually. The ordering cost is estimated to be Rs. 1,250 per order and the carrying cost of inventory is at 30 per cent of the unit cost per annum. Manjari Menon has been approached by another textile firm that has made an offer of a price of Rs. 9.80 per piece provided the shipment is of at least 20,000 pieces. Purely from an economic point of view, should Manjari Menon go for the second supplier? Show the computations for your answer.

Answer

*Relevant costs if the **first supplier** is to be chosen:*

EOQ with the first supplier = $\sqrt{2(1,250)(80,000)/(0.30)(10)}$ = 8,165

Therefore, the number of orders per year
= 80,000/8,165 = 9.798

Therefore, the Order Quantity = 80,000/9.798 = 8,165
The order cost per year = 9.798 × 1250 = Rs. 12,247.50
The average inventory = 1/2 (8,165) = 4082.5 units
Cost of carrying per annum = 4,082.5 × (0.30 × Rs. 10) = Rs. 12,247.50
Total relevant cost for the decision = $(C_p\, A/Q) + (Q/2) \cdot s \cdot f + (A \cdot s)$
= (1,250)(80,000)/8,165 + (8,165/2)(10)(0.30) + (80,000)(10)
= 12,247.50 + 12,247.50 + 8,00,000
= Rs. 8,24,495

*Relevant costs if the **second supplier** is to be chosen:*
EOQ with the second supplier = $\sqrt{2(1,250)(80,000)/(0.30)(9.80)}$ = 8,247.9

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EOQ is lower than the price beak point of 20,000 pieces. This EOQ is, therefore, irrelevant for the decision as the price of Rs. 9.80 does not exist at that level. Hence, the relevant cost comparison can only be done at the price-break point (Q = 20,000).

Total relevant cost for the decision = $(C_p\ A/Q) + (Q/2) \cdot s \cdot f + (A \cdot s)$

$= (1{,}250)(80{,}000)/20{,}000 + (20{,}000/2)(9.80)(0.30) + (80{,}000)(9.80)$

$= 5{,}000 + 29{,}400 + 7{,}84{,}000 =$ Rs. 8,18,400

Hence, the second supplier is to be preferred.

5. Meethalal Mithaiwala needs 2800 special boxes per day on an average for packing sweets. The demand for the boxes can be taken to be following a normal distribution with a standard deviation of 400. The average lead time for procurement has been found in the past to be 6 days and the normally distributed lead times have a standard deviation of 1 day. The risk of stock-out is to be not more than 2 per cent of the time.

(a) What should be the amount of safety stock that Mithaiwala maintains only on account of the variations in demand? That is, if lead time remains constant at 6 days.

(b) What is the safety stock on account of the variations in lead time only? That is, if the demand rate remains constant at 2800 boxes per day.

(c) What should be the safety stock if both demand and lead time vary as given above?

Answer

(a) Given: Average demand, $D_{average} = 2800$ per day;

Standard deviation of demand, $\sigma_{demand} = 400$;

Lead time = 6 days, assumed to be constant for this case.

2 per cent stock-out means 98 per cent service level.

The 98 per cent service level, under Normal distribution, corresponds to 2.054 standard deviations.

Therefore, safety stock required = $2.054 \times (400 \times \sqrt{6}) = 2012.5$ or 2013 boxes.

This is only on account of the variations in demand; lead time is assumed to be constant at 6 days.

(b) Given: Mean lead time, LT = 6 days.

Standard deviation of lead times, $\sigma_{LT} = 1$ day.

Demand per day, $D_{average} = 2800$. This is now assumed to be constant.

The demand during the lead time is normally distributed with expected value of $\mu = 2800 \times (6) = 16800$ with a standard deviation of (2800×1).

Safety stock for 98 per cent service level = $2.054 \times (2800 \times 1) = 5751$.

(c) When both demand rate and lead time vary:

Assume that the lead time variation process and the demand rate variation process are non-interacting and, therefore, the variances of both these processes are additive. Then, we get:

Variance of the combined processes = $6(400)^2 + (2800 \times 1)^2 = 960000 + 7840000 = 8800000$.

Hence, standard deviation of the combined processes = $\sqrt{8800000}$ = 2966.5
Safety stock, for 98 per cent service level, with both the demand rate and lead time varying would be

$$= 2.054 \times (2966.5) = 6093.2 \text{ rounded off to } 6093.$$

This is a little more than 2 days' requirement of the boxes.

6. Daily usage of a perishable item utilised in a product varies. The past observations of its usage are as given in the table below.

Usage in a day (No. of units)	*No. of days on which this usage occurred*
54	0
55	1
56	4
57	6
58	9
59	11
60	10
61	5
62	2
63	2
64	0
	Total = 50

The item is procured at Rs. 50 per unit. But, if it is not used during the day, it gets deteriorated and can be sold at a salvage price of only Rs.15 the next day. However, if the item is not available in the required quantity on any day, it has to be procured from elsewhere at a premium of Rs. 25 per unit.
What would be the optimal stocking policy for this item?

Answer

The under-stocking cost K_u is the premium paid for it when not available to meet the demand. This is Rs. 25 per unit.
The over-stocking cost K_o is the loss incurred when sold with a salvage value of Rs. 15. The loss is Rs. (50 – 15) = 35 per unit.
The optimal stocking policy is given by:

$$K_u/(K_u + K_o) = 25/(25 + 35) = 0.4167$$

= Cumulative probability at optimum i.e. $F(x)$.

The probability distribution for the demand of this item is given below:

***x* No. of units**	54	55	56	57	58	59	60	61	62	63
***p* probability**	0	0.02	0.08	0.12	0.18	0.22	0.20	0.10	0.04	0.04
cum. prob.	0	0.02	0.10	0.22	0.40	0.62	0.82	0.92	0.96	1.00

The desired cumulative probability $F(x) = 0.4167$ is attained (surpassed) at the 'x' value of 59. Hence, one should stock 59 units of this perishable item.

7. Trilok Hosieries produces five different types of underwears which are marketed under the names of Akash, Patal, Bhoolok, Trishanku and Swarga. All the five items are made on the same production facility. The annual demands for these underwears, the rates of production on the facility, the set-up costs and the inventory carrying costs are furnished as:

Product	*Annual Demand (Units)*	*Production per Day (Units/day)*	*Cost of Set-up Rs per set-up*	*Cost of Carrying Rs per Unit per Year*
Akash	180,000	3,000	2,000	10
Patal	70,000	2,000	5,000	7
Bhoolok	150,000	4,000	4,000	6
Trishanku	90,000	3,000	3,000	4
Swarga	270,000	4,000	9,000	5

The set-up between any two products takes an average of half a day. There are 300 working days in a year. Suggest optimal batch quantities for these products.

Answer

Here, multiple products are to be produced on the same production facility. Therefore, while determining the economic batch quantities for each of the products, we need to ensure that there are no interactions (interferences) between these products. Since these interferences are to be identified, it will be advisable, to first check as to whether the total production capacity itself is adequate; otherwise, the 'apparent' interferences may be due to an insufficiency in the production capacity. This is verified as shown in the calculations:

Product	*Annual Requirement, 'A' ('000) Units*	*Production Rate 'p' ('000) Units*	*No. of Days Required to Produce the Annual Requirement*
Akash	180	3	60
Patal	70	2	35
Bhoolok	150	4	37.5
Trishanku	90	3	30
Swarga	270	4	67.5
			Total = 230 days

Since the total number of 'working' days are 300, the total capacity of the production facility is adequate to produce all the five products.

The question which needs to be asked next is: Can we decide independently on the economic batch quantities of each of these five products? In order to answer this question, the EBQ of each of the products is at first, calculated as though the other products did not exist or did not matter. The calculations of these economic batch quantities are shown in the next few paragraphs.

In order to compute these EBQ's, it is necessary to compute daily usage '*r*' values as below. For this purpose, the annual requirement is equally divided in 300 days, which we shall assume as constituting a year.

Product	*Annual Requirement, A ('000) units*	*Daily Usage, r ('000) units*
Akash	180	0.600
Patal	70	0.233
Bhoolok	150	0.500
Trishanku	90	0.300
Swarga	270	0.900

Sample Calculation:
Daily Usage of Akash = $\frac{180,000}{300}$ = 600 units, i.e. 0.600 thousand units

Now the EBQ's can be computed by using the formula:

$$\text{EBQ} = \sqrt{\frac{2 \times C_0 \times A}{C_c \times \frac{(p-r)}{p}}}$$

Product	*A* *Annual Requirement ('000) Units*	C_O *Set-up Cost Rs ('000) per Set-up*	C_C *Carrying Cost Rs per Unit per Year*	*p* *Production Rate ('000) Units per Day*	*r* *Usage Rate ('000) Units per Day*	$\frac{(p-r)}{p}$	*EBQ Units*
Akash	180	2	10	3	0.600	0.800	9,487
Patal	70	5	7	2	0.233	0.883	10,642
Bhoolok	150	4	6	4	0.500	0.875	15,119
Trishanku	90	3	4	3	0.300	0.900	12,247
Swarga	270	9	5	4	0.900	0.775	35,415

Sample Calculation: $\text{EBQ}_{\text{Akash}} = \sqrt{\frac{2 \times 2,000 \times 180,000}{10 \times (0.800)}} = 9,487$

What are the implications of these 'independently' computed EBQ's?

- Allowing for the set-up times each time a batch quantity is to be run, is the production capacity adequate?

Product	*EBQ (units)*	*A (units)*	*No. of Times an EBQ is Run, (A/EBQ) = N*	*Total Set-up Time in a Year = (N × 1/2) Days*
Akash	9,487	180,000	18.97	9.49
Patal	10,642	70,000	6.58	3.29
Bhoolok	15,119	150,000	9.92	4.96
Trishanku	12,247	90,000	7.35	3.68
Swarga	35,415	270,000	7.62	3.86
				Σ = 25.28

Adding production time (230 days) and set-up time, we get:

230 + 25.28 = 255.28, which is under 300 (number of working days available in a year) Thus, there is adequate production capacity (in terms of time) if we were to have *independent* EBQ's for the products.

- Is there a possibility of one of the products getting fully used up (i.e., a stock-out situation) before a batch of them can be run on the production line? This can be examined by looking at the total time ('cycle time') to produce all the products in their respective economic batch quantities. If a product's EBQ can last during this length of time, then there is no interference between the products; if not, there is interference and the products have to be produced in *EBQ*'s that are jointly calculated. All the products are produced in a *definite sequence* in an optimal number of joint runs. The following table of computations checks the possibility of the interference.

Product	*EBQ (independent)*	*Production Rate, p*	*Time to Produce an EBQ,* $\frac{EBQ}{p}$	*Usage Rate, r*	*Time to Use up an EBQ,* $\frac{EBQ}{r}$	*Whether* $\frac{EBQ}{r} \le \sum \frac{EBQ}{p}$
	(units)	*(units per day)*	*(days)*	*(units per day)*	*(days)*	*(Yes/No)*
Akash	9,487	3,000	3.16	600	15.82	Yes
Patal	10,642	2,000	5.32	233	45.67	No
Bhoolok	15,119	4,000	3.78	500	30.24	No
Trishanku	12,247	3,000	4.08	300	40.82	No
Swarga	35,415	4,000	8.85	900	39.35	No
			$\Sigma = 25.19$			

We notice that product 'Akash' has a problem; if produced in its 'independently' computed EBQ, it may face a stock-out situation. Therefore we decide to run all the five products in a sequence, the number of such runs being computed jointly.

$$\text{Optimal number of joint runs} = \eta_{\text{optimal}} = \sqrt{\frac{\sum^{i} C_{ci}\, A_i \times \frac{(p_i - r_i)}{p_i}}{2 \cdot \sum^{i} C_{oi}}}$$

These calculations are as follows:

Product	*A (units)*	C_0 *Rs per set-up*	$\frac{p-r}{p}$	C_c *Rs per unit per year*	$C_c \times A \times \frac{p-r}{p}$ *('000)*
Akash	180,000	2,000	0.800	10	1440
Patal	70,000	5,000	0.883	7	432.7
Bhoolok	150,000	4,000	0.875	6	787.5
Trishanku	90,000	3,000	0.900	4	324
Swarga	270,000	9,000	0.775	5	1046.3
		Total = 23,000			Total = 4030.5

$$\eta_{\text{optimal}} = \sqrt{\frac{4030.5 \times 1000}{2 \times 23000}} = 9.36$$

Assuming that the planning is done on a yearly basis, we approximate the number of cycles to nine. The batch quantities of the products in any joint run will be as follows:

Product	*Annual Reqt. A (units)*	*Production Batch Quantity = (A/9) (units)*
Akash	180,000	20,000
Patal	70,000	7,777
Bhoolok	150,000	16,666
Trishanku	90,000	10,000
Swarga	270,000	30,000

The above are the optimal batch quantities of the given products. It is seen that, now, a significant trade-off has occurred between Akash and Patal.

QUESTIONS FOR DISCUSSION

1. Can the cost of the material delivery be a relevant cost for the control of the inventory of the material? Explain.
2. What are the basic assumptions underlying the classical EOQ model? Mention a few situations where these assumptions may not be valid and therefore the EOQ model cannot be used straightaway. In such situations, check the validity of the basic concepts behind the EOQ model. How could these concepts, if they are valid, be used in such situations?
3. What is the set-up cost in manufacture? If a number of products are produced on the same plant facility, would the set-up cost for the individual products depend upon the sequence in which the products are manufactured?
4. If the set-up cost does depend upon the sequencing as mentioned above, will that make a difference in the calculation of the optimal batch quantities for the joint run of these products?
5. If the individual batch quantities of multiple products run on the same plant facility are to be calculated individually, how will the individual set-up costs for each of the products be determined? Will it depend upon sequencing?
6. In a sequence *A*-*B*-*C*, how should the opportunity cost of set-up time be allocated to the products *A*, *B* and *C*? Is there any conceptual difficulty in allocating these costs? How will you take care of these difficulties and arrive at a proper set-up cost for each of the products?
7. Compare the order cost in a purchasing situation with the set-up cost in a manufacturing situation. Mention the similarities and dissimilarities between the two.
8. What are the difficulties in expressing the carrying cost of inventory as a fraction of the value of the inventory? In what situations might such an expression for the carrying cost be more useful than expressing it as cost per unit per unit time?
9. When a company procures a number of raw materials, what could be the problems in calculating the EOQ of individual items?

10. In the case where multiple number of items are procured, how would you apply the EOQ concepts to aggregate inventory control as opposed to individual items inventory control?

11. What is the shortage cost? Is it difficult to estimate? If so why?

12. In what different ways can the risk of stock-out be expressed and measured? In what way has the risk of stock-out been expressed in this chapter?

13. What is the function of a safety stock or buffer stock? What are all the different uncertainties against which you would like to protect the inventory?

14. If two raw materials *R* and *M* are required to make a product and the service level is to be 95% for the production of the product, what are the service level requirements for items *R* and *M* individually?

15. In a fixed order quantity model, the desired protection for the fluctuations in the consumption rates is required only for the lead time of supply of materials. Explain why this is so? How is it different for a fixed order cycle model (*P*-system) and why is it so?

16. When is the fixed order cycle model preferred? And when is the fixed order quantity model preferred? Explain.

17. What is lead time? What are the factors you will take into consideration while computing the lead time?

18. The inventory control procedure as suggested in this chapter is being followed in a company. What reactions would you expect from the Purchase Manager and from the Manager, Physical Distribution?

19. 'Inventory is a part of manufacturing strategy.' Do you agree with this statement? If so, explain why it should be only a part of the total manufacturing strategy?

20. How would you fit in inventory control as a part of the wider organisational strategy? Are the inventory models real optimising models?

21. If you have answered the above questions, explain how you would relate inventory control with purchasing, manufacturing, sales and physical distribution?

22. Srinivasa Iyengar's Bakery in Bangalore makes 'aloogedde buns', one of its fast selling products. From the past history, Srinivasa Iyengar estimates the demand pattern to be as follows:

Demand	*Probability of Demand*
400	0.05
500	0.10
600	0.20
700	0.30
800	0.20
900	0.10
1000	0.05

The selling price of each bun is Rs. 4.00. The buns that are not sold on the day they are made, are sold the next day as old buns at a reduced price of Rs. 2.50 each. If the cost of each bun is Rs.3.10, what is the optimum number of buns Iyengar should make?

23. Sainath Electrical Works buys electrical switches locally, for use in its assembly of a variety

of electrical products. Sainath observes that the usage pattern of these bought out switches follows a normal distribution with a mean of 1000 switches per week and a standard deviation of 200. The buying process takes one week. The inventory holding cost is Rs. 5 per unit per year and the cost of ordering is Rs. 200/-per order. Sainath desires to allow for only 2 stock-out situations in a year. Compute the safety-stock required.

24. Bharati Fibre Products Limited produces a special fibre in its plant at the rate of 5000 metres per hour. The fibre is used in the other products made by Bharati, at the rate of 20,000 metres per day in an 8-hour day. The cost of fibre is Rs. 5 per metre. The inventory carrying charges are 25% and the set-up costs are Rs. 450 per run. Compute the optimal number of cycles required in a year for the manufacture of this special fibre.

25. Compute the EOQ, given the following:

No. of units bought at a time	*Price per unit, (Rs.)*
less than 1000	10.00
1000 to 2999	9.85
3000 and more	9.70

The order cost is Rs. 60 per order and the carrying cost is 20% of the price. Annual requirement of the item is 10,000 units.

26. Velayudhan & Company (VACO) buys the following items for use in production:

	Price per unit (Rs.)	*Weekly Usage (units)*
Bushings	160	20
Spl. gaskets	50	30
Rings	20	180
Seals	250	20
Pins	10	75

Each of these item is bought from a different supplier. The purchase office can place only 10 orders per week. How should VACO order the different items if the total average stock value (in Rs.) is to be kept as low as possible?

ASSIGNMENT QUESTION

1. Visit an operations facility of any manufacturing or service organisation. Study its inventory management function. Present a report on your observations and discuss possible improvements.

APPENDIX I

CONSIDERATIONS OF INFLATION IN THE ECONOMIC ORDER QUANTITY CALCULATIONS

If an item is going to cost more in the future, one would tend to procure more of the item 'now' than 'in the future'. Putting it the other way, one would order large quantities whenever the order is to be placed. The simple EOQ formula (square root formula) should reflect the same. It is obvious that the cost of carrying C_c is not the same under inflationary conditions, and it needs to be reduced in some way to take care of the inflation rate, i.

The total relevant (annual) cost, TC, under the inflationary condition is

$$TC = \text{Carrying Cost} + \text{Order Cost} + \text{Purchase Cost}$$

Let us analyze the purchase cost. Maintaining the same notation as was used in this chapter, we have

No. of Orders Per Year	*Average Purchase Cost Per Unit*
1.	s (note = 's' is the purchase price at the beginning of the year)
2.	$\dfrac{\left[s+s\left(1+\dfrac{i}{2}\right)\right]}{2}=s\left(1+\dfrac{i}{4}\right)$
3.	$\dfrac{\left[s+s\left(1+\dfrac{i}{3}\right)+s\left(1+\dfrac{2i}{3}\right)\right]}{3}=s\left(1+\dfrac{i}{3}\right)$
4.	$\dfrac{\left\{\begin{array}{l}S+s\left(1+\dfrac{i}{4}\right)\\ +S\left(1+\dfrac{i}{2}\right)+s\left(1+\dfrac{3i}{4}\right)\end{array}\right\}}{4}=s\left(1+\dfrac{3}{8}i\right)$
5.	$\dfrac{\left\{\begin{array}{l}s+s\left(1+\dfrac{i}{5}\right)+s\left(1+\dfrac{2i}{5}\right)\\ +s\left(1+\dfrac{3i}{5}\right)+s\left(1+\dfrac{4i}{5}\right)\end{array}\right\}}{5}=s\left(1+\dfrac{2}{5}i\right)$

Therefore, generalising:

For n orders per year $\quad s\cdot\left[1+\dfrac{i\left(1-\dfrac{Q}{A}\right)}{2}\right]$

where Q is the order quantity and A is the annual requirement.

Therefore, the annual purchase cost is

$$A.s.\left[1+\frac{i\left(1-\frac{Q}{A}\right)}{2}\right]$$

On similar lines, the order cost for n orders per year would be

$$C_p\cdot\left[1+\frac{i\left(1-\frac{Q}{A}\right)}{2}\right]\cdot\frac{A}{Q}$$

where C_p is the cost for ordering at the beginning of the year.

Similarly, the annual inventory carrying costs would be

$$s.\left[1+\frac{i\left(1-\frac{Q}{A}\right)}{2}\right]\cdot\left(\frac{Q}{2}\right)\cdot(f)$$

where f is the inventory carrying cost expressed as a fraction of the inventory value

Thus, returning once again to the total relevant annual cost, it is

$$TC=\left[1+\frac{i\left(1-\frac{Q}{A}\right)}{2}\right]\left[s\cdot f\cdot\frac{Q}{2}+C_p\cdot\frac{A}{Q}+A\cdot s\right]$$

In order to minimize TC, taking derivative with respect to Q and equating to zero, we have

$$\frac{s\cdot f}{2}-\frac{s\cdot i\cdot f\cdot Q}{2A}-\frac{C_p\cdot A}{Q^2}-\frac{i\cdot C_p\cdot A}{2Q^2}-\frac{i\cdot s}{2}=0$$

If, i and f are both reasonably small, their product $i\times f$ can be approximated to zero. We can then write the above equation as

$$\frac{s}{2}(f-i)=\frac{C_pA}{Q^2}\left(1+\frac{i}{2}\right)$$

Therefore,

$$Q_{\text{opt}}=\sqrt{\frac{2C_p\cdot A\cdot\left(1+\frac{i}{2}\right)}{s(f-i)}} \tag{1}$$

One would have intuitively arrived at using $(f-i)$ for the inventory carrying cost under inflationary conditions. Therefore, one might modify the simple EOQ formula to give (under inflation rate 'i'):

$$Q_{\text{opt}} = \sqrt{\frac{2 \cdot C_p \cdot A}{s \cdot (f - i)}} \tag{2}$$

Now, Eqs. (1) and (2) differ only with respect to the term $\sqrt{\left(1 + \frac{i}{2}\right)}$ in the numerator. With inflation being 10% or 20%, the term works out to 1.024 and 1.048 respectively. Hence, by using Eq. (2), one might have been off by 2.5% and 4.8% respectively for 10% and 20% inflation rate. This is not a substantial departure, considering that in many cases the total cost is not very sensitive to the order quantities around (near) EOQ.

Kanet and Miles* have in addition to the annual cost model used a discounted cost model. For a wide range of values of a number of parameters, the simple annual cost model was found to compare quite well with the discounted cost model.

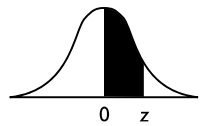
Thus, it appears that under inflationary conditions, either Eq. (1) or Eq. (2) would suffice.

* J.J. Kanet and J.A. Miles, 'Economic Order Quantities and Inflation', *International Journal of Production Research*, 1985, Vol. 23, No. 3, pp. 597–608.

APPENDIX II

AREAS UNDER THE STANDARD NORMAL PROBABILITY DISTRIBUTION

Values in the table represent the proportion of area under the normal curve between the mean ($\mu = 0$) and positive value of z.



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2703	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3780	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990

Source: R.G. Schroeder, *Operations Management—Decision Making in the Operations Function,* McGraw-Hill, International Student Edn, 1985.

22 ABC and Other Classification of Materials

In any medium to large industry there are thousands of items in the inventory. The items may range from a spare generating set to cans of paint or small nuts and bolts. It is neither logical nor possible to exercise tight management control over these different items varying in their value, complexity, size or necessity. It will be too much of effort for little benefit.

SELECTIVE MANAGEMENT CONTROL

The principle of Management by Exception is better suited here. Items of inventory are classified into A, B, C, or other classes for selective management control. Controls exercised selectively contribute to better management, in most cases avoiding wastage of precious management time and, more importantly avoiding the confusion resulting from excessive controls. The degree and the character of the controls to be exercised by the management should depend upon (a) the necessity of the control, (b) the relative importance of the material to be placed under control, and (c) the particular characteristics of the material.

Materials may be divided into three categories or classes—for selective management control. More than three gradations in materials will not be fruitful. The division of materials into three grades, for selective management control purposes, is known in general as the ABC classification. The alphabets A, B and C stand for the three different classes.

ABC analysis is based on the relative importance of the materials. Therefore, there are various bases for ABC classification: A material's price, its criticality, its non-availability, its size vs. weight, etc. For various situations, various characteristics are more or less important. That is why there are a number of ways of classifying the materials on the ABC scale.

Conventionally, however, ABC analysis refers to the *annual consumption value* of the items. It has been found in many industries, that a small number of items account for a large proportion of the annual turnover (in money terms) of the inventory. These items should attract the Materials Manager's attention immediately. We call such items as Class 'A' items. It is also observed, in most industries, that a very large number of items in the inventory account for a small fraction of the annual turnover (annual consumption value of the materials). These are many items contributing very little to the ultimate problem of managing the working capital investment. Naturally, the Materials Manager should turn his attention to these items only after he has taken care of the high

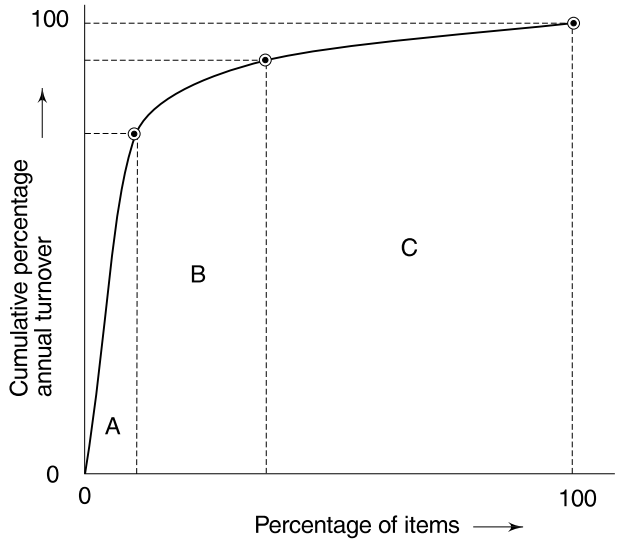


Figure 22.1 ABC Classification

annual turnover items (A class items). Such items are called Class 'C' items. Class 'B' items belong to the inbetween categories; neither is their total annual consumption value high nor are their total numbers high.

The phenomenon as described above occurs in almost all industries, and therefore, the conventional ABC classification can be applied in most of the industries.

Figure 22.1 shows that about 10% of the items contribute to about 75% of the total annual consumption value of all materials in the inventory; about 70% of the items contribute to about 10% of the total annual consumption value of all the materials; and 20% of the materials account for about 15% of the total annual consumption value of the materials. The items are classified as A, C and B respectively.

One must understand that there is nothing sacrosanct about the percentages mentioned above; they are only illustrative. But, the fact remains that a few items in inventory are more important than some others in terms of the managerial attention they deserve.

Example Consider a company which stocks 20 items. Table 22.1 gives the number of units and the consumption value of each item. The items are listed in decreasing order of their consumption value.

Check the Col. Nos 2 and 6 which give respectively the cumulative percentage of the items and cumulative percentage of the total annual consumption value. As seen in Table 22.1 the first 2 items account for 70% of the annual turnover. Therefore, we may classify the first 2 items as class 'A' items. Item Nos. 8 to 20 which constitute 65% of the items account for only about 6% of the annual consumption value. Therefore, items 8 to 20 will be classified as class 'C' items. The remaining items, that is, from Nos. 3 to 7 may be classified as class 'B' items. Figure 22.2 gives a graphical depiction of ABC analysis for this example.

Table 22. 1 Computations for ABC Analysis

Item No.	*Cumulative Percentage of Items*	*Annual Consumption*	*Value Per Unit*	*Annual Consumption Value*	*Cumulative Percentage*
	(%)	*(units)*	*(Rs.)*	*(Rs.)*	*(%)*
1	5	100	400	40,000	40
2	10	500	60	30,000	70
3	15	200	70	14,000	84
4	20	25	200	5,000	89
5	25	25	100	2,500	91.5
6	30	65	20	1,300	92.8
7	35	50	25	1,250	94.05
8	40	50	20	1,000	95.05
9	45	30	30	900	95.95
10	50	50	14	700	96.65
11	55	20	30	600	97.25
12	60	90	5	450	97.70
13	65	40	10	400	98.10
14	70	35	10	350	98.45
15	75	20	17.5	350	98.80
16	80	50	6	300	99.10
17	85	100	3	300	99.40
18	90	25	10	250	99.65
19	95	20	10	200	99.85
20	100	25	6	150	100.00
Total				1,00,000	

It is seen that by exercising control over only 2 items as much as 70% of the annual turnover value would be controlled. The management effort need not be spread thin over all the 20 different items. ABC analysis helps in focussing the management effort, and thereby increasing the efficiency of the effort.

PERIODIC REVISION OF CLASSIFICATION

One should note that the ABC classification depends not only on the value per unit, but also on the number of units consumed over the year. Because, in this classification, we are dealing with the annual consumption value. Therefore, if the value of an item were to increase or if the amount of annual consumption of the item were to increase, the 'annual consumption value' of the item would increase. Therefore, the classification of an item may change from say class B to class A, or from class C to class B. The point is that the ABC classification is not done once and for all time;

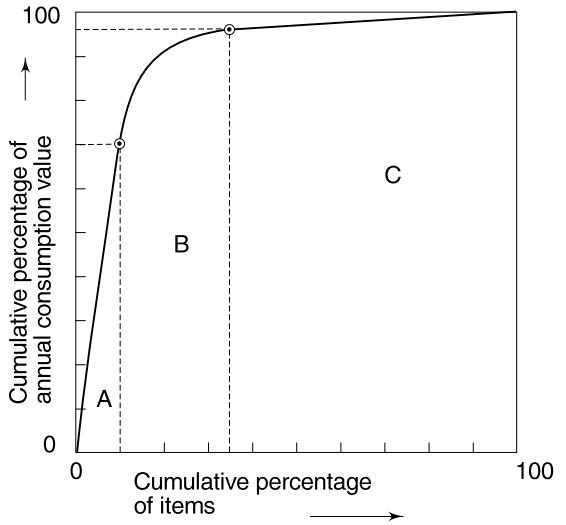


Figure 22.2 Example of ABC Analysis

the classification needs to be monitored periodically and any changes need to be incorporated accordingly. ABC classification of the previous year will not necessarily hold good for this year or the coming year.

A proper ABC analysis will lead to better control over materials and consequent reduction in costs associated with inventories.

VED ANALYSIS

In addition to the intrinsic or market value of materials which is invested in the materials, there is sometimes a 'nuisance' value to the materials. What we discussed in earlier paragraphs was the cost of materials due to their presence. Whereas the nuisance value is the cost associated with materials due to their absence. Certain materials are important by their absence and not necessarily by their presence. If they are not available, they hold up production and, therefore, there are high costs of shut-down or slow-down of production. By themselves these materials may not be priced high in the market. The investment in these materials may be small but for lack of any of them, the production process may come to a grinding halt. These are critical items which are required in adequate quantity.

This gives us a clue to another kind of classification of materials which has to deal with the critical nature of the items, i.e. whether they are 'vital' to the production process, or 'essential' or just 'desirable'. Vital (V) items have extreme criticality, desirable (D) items are not critical and essential (E) items are somewhere in between. In addition to the conventional ABC analysis, this VED Analysis is of great importance. Such VED ranking can be done on the basis of the shortage costs of materials which can be either quantified or qualitatively expressed.

COMBINATION OF ABC AND VED ANALYSIS

Since the conventional ABC analysis and VED analysis are both important, it is preferable to combine both these classifications and arrive at a joint classification of materials. Such a classification of materials is shown in Figure 22.3.

As shown in Fig. 22.3 we may classify materials into 9 categories for management control purposes. The classification, is for giving guidelines or helping management to have better control over the materials. It should tell us—What the inventory policy should be? How much of which class of materials should be held in inventory: What should be the service levels and consequent safety stocks for the different classes of inventory?

	V	E	D
A	AV	AE	AD
B	BV	BE	BD
C	CV	CE	CD

Figure 22.3 ABC-VED Matrix Classification

PURPOSE OF CLASSIFICATION

The V class of items by their extreme critical nature need to be held in a large quantity in the inventory. The stock-out costs associated with such materials are very high and therefore, the service levels will be very high for this class of materials. The service levels for the subsequent E and D class materials will be lower and lowest respectively. The D class items are easily available in the market. They do not hold up production and may be substituted as well. Therefore, we can manage with small inventories of these items without drastic consequences on the running of the production line. Coming to the conventional ABC: The A class items incorporate a large turnover value in them. Naturally, the management attention must be focused on these items. This is possible as they are very few in number. Therefore, A class items are always under the scrutiny of the management. They are always monitored and followed up with respect to their stock levels, their availability in the market, their substitutes if any, etc. Since these are directly and constantly under the vision of the management, they can be kept in smaller quantities in inventory. Class C items contribute very little to the total annual consumption value and, therefore, even if they are kept in a large quantity in the inventory, it really does not significantly add to the inventory related cost. It is better that they be purchased or procured in large quantities, say once in a year and thus cut down on the number of transactions and management follow-up. Therefore, the service levels of C class items will be high. B class items fall somewhere inbetween in terms of the service levels.

The service levels of inventory, therefore, increase from D to V and from A to C. This suggests that the maximum service level will be for the CV class items and the lowest service level will be for the A D class items. Others, fall inbetween. This has been illustrated in Fig. 22.4. The figures

	V	E	D
A	90%	80%	70%
B	95%	85%	75%
C	99%	90%	80%

Figure 22.4 Illustration of ABC-VED Matrix Classification (showing service levels)

of service levels given therein are only for the purpose of illustration and there is nothing rigid or sacrosanct about service levels indicated therein.

OTHER CLASSIFICATIONS

Besides (i) money value, and (ii) criticality of the items, at different times there may be other issues relating to materials which may be of importance to the management. For instance, the perishability or obsolescence. This is particularly important with respect to chemicals and drugs which have a low shelf-life. In such cases, the classification of materials has also to be done in terms of the perishability of the materials like low shelf-life, medium shelf-life, and long shelf-life. We can call this as PQR classification.

Sometimes the bulk versus weight of the materials is of importance in terms of providing space for the materials in the stores, and therefore, another 'XYZ' classification such as (i) bulky, (ii) medium bulky, and (iii) not bulky may also be of interest.

It has been found in some organisations that they have large inventories of materials sitting idle in the stores for years together. Sometimes, nobody is aware of their existence. There may be a variety of reasons for this, chiefly the obsolescence of the materials. The materials might have been bought in large quantities a few years ago and would have become obsolete over time and therefore forgotten. These materials, however, have some salvage value or at least a scrap value. It has been found advantageous in such situations to carry out an analysis on the basis of the rate of movement of the materials in the stores like fast-moving , slow-moving and non-moving items. The non-moving items can be in such cases listed and the list be sent to the different departments which might be interested in these materials to ascertain whether they still desire storing of these materials in the stores. The items which have become obsolete can be sold for whatever salvage value they obtain. Such studies have been done in some major organisations and have produced results amounting to many millions of rupees of salvage value.

The classification of materials could be for various such situational purposes. The idea behind these classifications is to draw the attention of the management selectively. The problem-materials are, thus, highlighted and precious management time can be devoted to these problem items in the inventory. Management by Exception for Better Control is the theme behind these classifications. Used in this perspective, the classification of materials will reap rich dividends to the organisation.

SOLVED PROBLEMS

1. Mahalakshmi Mali (called Maha) has a boutique where she stocks a variety of artificial flowers she imports from her sources abroad. Maha has maintained records of the annual demand and per unit cost for each variety of flowers. These are given in the table below. She feels that an ABC analysis will be useful to her in making decisions on stocking of these flowers. Please help Maha in making the ABC analysis.

Name	*Item No.*	*Cost per Unit*	*Annual Demand*
Anemone	1	28	550
Aster	2	7	1050
Bouvardia	3	32	100

Contd..

Carnations	4	10	3700
Standard Chrysanthemum	5	18	500
Cushion Chrysanthemum	6	33	200
Daisy	7	26	1100
Daffodil	8	21	1200
Gladiolus	9	16	100
Lilac	10	8	450
Oriental Lily	11	9	200
Dendrobium Orchid	12	45	4500
Oncidium Orchid	13	45	4250
Peony	14	30	100
Queen Anne's lace	15	25	1100
Roses Red	16	10	22500
Roses Yellow	17	7	1500
Statice	18	43	100
Stock	19	10	150
Tulips	20	15	4150

Answer

(1) Calculate the annual cost for each of the above items.
(2) Find the total cost for all these items put together.
(3) Arrange the items in descending order of their annual cost.
(4) Compute the percentage of the total cost for each item.
(5) Compute the cumulative percentage from the top of the list (maximum percentage) to the bottom of the list (minimum percentage cost).
(6) Find a small number of the top items that make up a very large cumulative percent cost; these are "A" class items.
(7) Find a very large number of items that make up only a small percentage of total cost; these are "C" class items.
(8) Remaining items are "B" class items.

As per the steps (1) to (5), following table has been developed.

Item No.	*Annual Cost*	*Cumulative Cost*	*Cumulative Percentage*
16	225000	225000	25.95
12	202500	427500	49.30
13	191250	618750	71.35
20	62250	681000	78.53
4	37000	718000	82.80
7	28600	746600	86.10
15	27500	774100	89.27

Contd..

8	25200	799300	92.18
1	15400	814700	93.95
17	10500	825200	95.16
5	9000	834200	96.20
2	7350	841550	97.05
6	6600	848150	97.81
18	4300	852450	98.30
10	3600	856050	98.72
3	3200	859250	99.09
14	3000	862250	99.43
11	1800	864050	99.64
9	1600	865650	99.83
19	1500	867150	100.00

From the above table, you may choose first three items comprising 71.35 per cent of annual cost as "A" class items. Thus, Maha will have 15 per cent of items comprising 71.35 per cent of the annual cost.

Also, you may choose for her the twelve items from the bottom, comprising 6.05 per cent of the total annual cost as the "C" class items. So, these 60 per cent of items in stock comprise only 6.05 per cent of yearly cost.

The remaining items (five of them, i.e. 25 per cent of total items) constitute the "B" class of items and account for 20.83 per cent of total annual cost.

2. You also ask Maha to mark the relative importance of the different items on a ten point scale (10 being highest importance and 1 being the lowest). For instance, the Roses (both Red and Yellow) are extremely important as without them a combination bunch of flowers cannot be made. Customers will not buy the bunch, if the roses are not there. Maha comes up with the following points for the items.

Item No.	*Points*	*Item No.*	*Points*
1	10	11	3
2	9	12	6
3	1	13	6
4	6	14	1
5	6	15	2
6	6	16	10
7	6	17	10
8	3	18	2
9	9	19	3
10	9	20	6

Help Maha to make a VED classification and come up with an ABC-VED matrix. Because, you feel that such a classification is very important from the viewpoint of purchasing and stocking decisions.

Answer

You may decide to treat those items that got 10 and 9 points from Maha as "Vital" or "V" class items. Those that received 4 or less points may be classified as "Desirable" or "D" class items. Those between 5 and 8 (both inclusive) may be classified as "Essential" or "E" class items.

You may combine both ABC and VED classifications to come up with an ABC-VED matrix classification.

All the above are shown in the table below.

Item No.	*Points*	*VED Class*	*ABC Class*	*ABC-VED Class*
1	10	V	C	CV
2	9	V	C	CV
3	1	D	C	CD
4	6	E	C	CE
5	6	E	C	CE
6	6	E	C	CE
7	6	E	B	BE
8	3	D	B	BD
9	9	V	C	CV
10	9	V	C	CV
11	3	D	C	CD
12	6	E	A	AE
13	6	E	A	AE
14	1	D	B	BD
15	2	D	B	BD
16	10	V	A	AV
17	10	V	C	CV
18	2	D	C	CD
19	3	D	C	CD
20	6	E	B	BE

The matrix classification with the item numbers in each matrix class is shown below.

	V	**E**	**D**
A	16	12, 13	–
B	–	7, 20	8, 14, 15
C	1, 2, 9, 10, 17	4, 5, 6	3, 11, 18, 19

QUESTIONS FOR DISCUSSION

1. What is the use of ABC, VED and other classifications to departments other than Inventory Control? What is the use for Purchasing, for Maintenance, for Quality Control?
2. How does classification of materials affect the inventory control for the same?
3. What is' Pareto's law'? What is the 'Lorenz Curve'? Research and find out.
4. Does ABC behaviour apply to situations other than materials? Does it apply to situations much outside of Production and Operations Management and to *non-business* situations? Give examples.
5. Is it necessary to update the ABC or VED classification of materials? Why or why not? If yes, how frequently?
6. 'VED analysis is situational and judgemental.' Do you agree with this statement? Explain.
7. How are the (a) classification of materials, and (b) EOQ concepts put together?
8. How is the concept behind ABC classification useful for managing a manager's time? Explain.
9. What difficulties would you visualise in installing the ABC classification system in an organisation?

23 Materials Requirement Planning

Materials Requirement Planning is a special technique to plan the requirements of materials for production. How is it different from techniques such as Economic Order Quantities and Safety Stock Computations? In order to understand the differences we need to take another look at our EOQ and Safety Stock Computational Methods.

It is not uncommon for the practicing production managers to come across a situation where out of 10 raw materials needed at a point of time to run a particular product-line, excepting for one raw material, all the rest (nine) are available. And for want of one, the production of the product-line cannot be undertaken.

DRAWBACKS OF SERVICE LEVELS AND SAFETY STOCK COMPUTATIONS

Let us say 10 different chemicals are needed to make a particular brand of shampoo. A cautious manager fixes 95% servive level for the stock of raw materials and, therefore, expects a stock-out to occur only 5% of the time. He is confident 95% of the time about the availability of the materials. In spite of such precaution, he observes that production stoppages due to the lack of raw materials are much more than 5% of the time. Where has he gone wrong?

Let us examine the basics of his computation. He needs 10 materials at a time. Each material is stored with 95% service level. The probability that each material is separately available over a long length of time is 0.95. But, the probability that all the ten materials are available simultaneously is

$$0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95 \times 0.95$$
$$= 0.5987 \approx 0.60$$

The result is that the actual availability is only 60% of the time. Four out of ten times he should expect inability to run the particular shampoo line. This is how limited statistical methods of computation are if not interpreted and understood properly. Safety stock calculations were made for individual item requirements and never for bunched requirements of materials. In many production situations the latter is the case. Probably, in such cases we need not adopt statistical safety calculations in the first place.

MATERIALS REQUIREMENT PLANNING (MRP)

When we are formulating chemical or pharmaceutical products, or when we are making assemblies out of various components (manufactured or bought-out), we are dealing with bunched requirement of materials. The requirement of raw materials then depends upon the requirement of production of the finished product (assembly, or a shampoo, or a medical formulation). It seems, it would be better if we know the production plan/schedule for the assembly of the finished product and accordingly arrange for all the raw materials that go into the finished products, rather than depending upon statistics and probabilities. This is precisely what MRP attempts to do. It is a simple system of calculating (arithmetically) the requirement of the input materials at different points of time based on the plan or schedule for production of the finished good.

There are no probabilities involved anywhere, only the derivation of the requirements of input materials based on the requirement or plan for production of the final products. Such a system will work well for materials that have no direct demand of their own, but have only a derived demand. These materials can be called *dependent demand items*. The finished assembly has a direct demand of its own and therefore it is an *independent demand item*.

Let us also review the EOQ model/s. All of them assume a uniform (or a more or less uniform) pattern of consumption of material. Based on averaged consumption, the EOQ model answers the 'how much' and 'when' questions for optimal cost considerations. Optimal cost or otherwise, the basic difficulty in some peculiar production situations arises because of the averaging of the consumption of materials.

When we are dealing with five different varieties of shampoos, five varieties of soaps, another five of cleaning powders or solutions, the requirement for many raw materials over time for these formulations does not fall in the smooth average consumption pattern. On the contrary, we may observe the requirement of a material over time as shown in Fig. 23.1.

It is interesting to note in Fig. 23.1 that if the material is stocked as per EOQ, we may have excess material in inventory during February, March, May and September months when we do not need the material at all. Also, in April and August we fall terribly short of the required material. In all

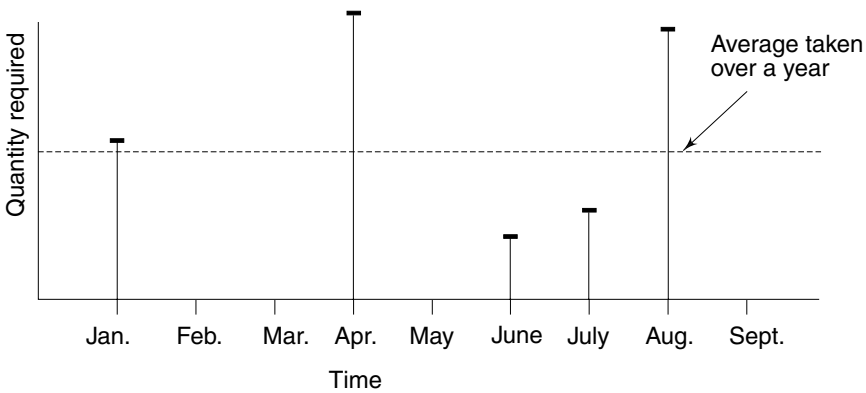


Figure 23.1 Requirement of a Raw Material for Different Months: An Illustration of the Drawback of EOQ Models

good faith, the EOQ model tries to answer the questions of 'how much?' and 'when to stock'? but fails miserably when encountered with an erratic (seemingly) requirement pattern for the material. But, in many industries particularly for dependent demand items such seemingly erratic requirement patterns are common.

Statistics is the science of averages. And precisely because of this characteristic, the statistical or averaging methods fail in situations such as the above.

MRP CALCULATIONS—AN ILLUSTRATION

It seems, therefore, that for assembling (or similar) situations it is better on our part to calculate the requirement of materials from the production schedule/plan of the final goods. Let us illustrate how we may do those calculations (Fig. 23.2).

Master Schedule, Table (desks)

Week No.							
1	2	3	4	5	6	7	8
50	0	30	20	0	0	70	20

Lead time = 3; Order quantity = 100

MRP—Desk-Tops

Requirements		50	0	30	20	0	0	70	20
Scheduled Receipts			100						
On hand	60	10	110	80	60	60	60	– 10	– 30
Planned Order Release					100				

Lead time = 5; Order quantity = 250

MRP-Plywood Sheets for Desk-Tops

Requirements			40*		100			90*	
Scheduled Receipts									
On hand	160	160	120	120	20	20	20	– 70	– 70
Planned Order Release			250						

*Requirements from other variety of furnitures.

Figure 23.2 MRP Calculations

In Fig. 23.2 note how the requirements of desks generates requirements of lower level components such as desk-tops and plywood sheets. Note how the on-hand balances, the scheduled receipts of materials have been taken into account. The scheduled receipt is due to some plan (MRP) generated earlier. This material is already on order and is scheduled to arrive. The desk-tops calculation gives us a negative figure in the 7th week. Therefore, 3 weeks prior to it (lead time is 3 weeks), i.e. in the 4th week, we must order for desk-tops. Although the requirement is only 10 units, we order for 100 units, because that is the economic lot size. We have combined the benefits

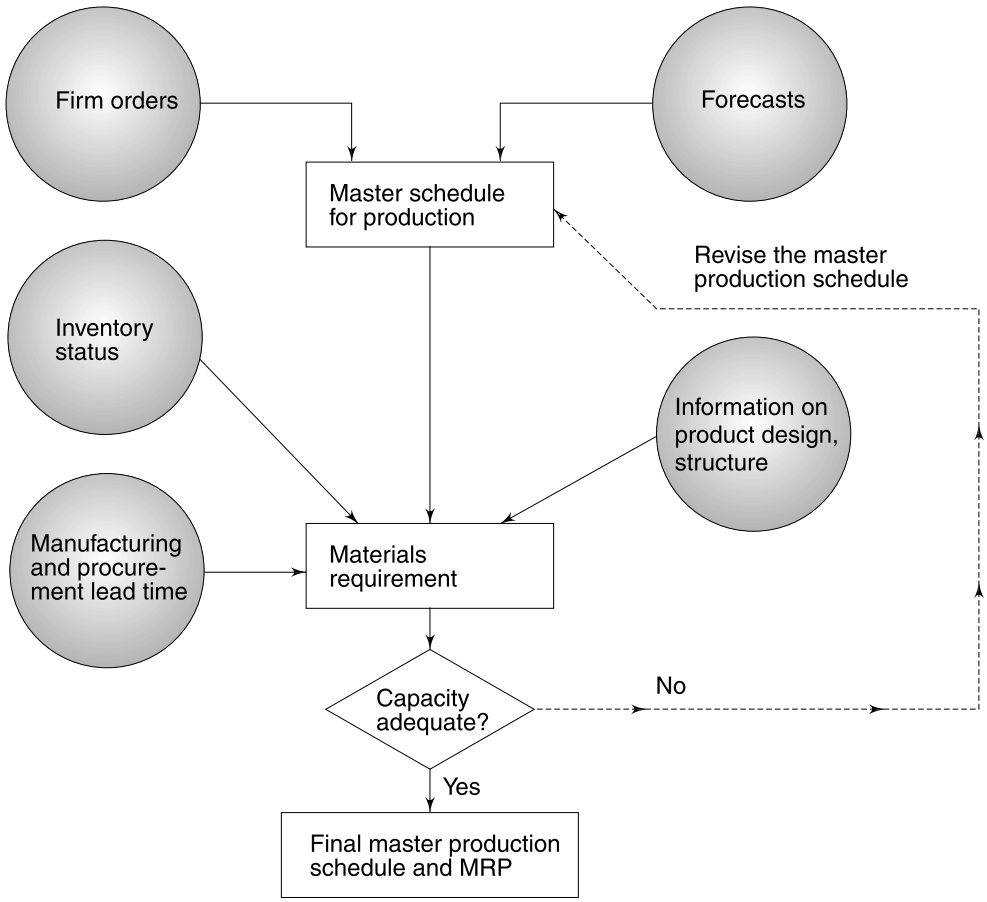


Figure 23.3 Materials Requirement Planning Process

of EOQ and MRP in this illustration. MRP is for generating correct calculated requirements for lower category materials at appropriate times as per the need of the Master Schedule. EOQ concept is also utilised for generating additional cost economies of larger lot sizes.

The process of MRP can be represented by Fig. 23.3.

GENESIS

People have been calculating requirements of materials prior to the advent of statistics. As industry became more complex, models such as EOQ and the science of statistics became available and offered relief from cumbersome and detailed calculations for planning. The trouble was that even in those situations where arithmetical computations would have done a better job, people used statistical and averaging methods.

But, with the advent and proliferation of computers things changed. The cumbersome arithmetical computations could be done in no time at all. Naturally, since the last two decades, the MRP system is being once again, seriously considered. Several decades ago this was the only planning system available and had no special name to it. Today it has come to be known as MRP.

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With the modern-day works using thousands of different materials, and manufacturing a variety of products, a computerised system for MRP becomes essential. In the Western countries and also in India many organisations have installed an MRP system.

How successful has the experiment of installing the MRP system, particularly in India been? The degree of success of any system depends upon the proper consideration of the prerequisites of the system. This is true with MRP system as well.

PREREQUISITES

We may mention the prerequisites or premises on which the MRP system is built:

(a) This system, in its pure form, is suitable for 'dependent demand' situations—as we saw earlier.

(b) The demand for the dependent items is derived from (i) the master-schedule for the finished goods, and (ii) the various manufacturing or procurement lead-times for these components of the final finished goods.
Therefore, proper figures for the respective lead-times must be available.

(c) And, a firm schedule for the delivery or assembly of the finished goods should be available. Firm schedules can be had if the customers commit orders with enough time to cover the various lead-times from the raw materials stage to the finished-good stage of the product. The firmer the schedule for finished goods, the more valid will be the MRP system to derive requirements of materials at different time.
MRP is not and should not be a rigid system; it takes into account variations in the materials inventory position and the committed final goods orders at various points of time as the production process continues.

(d) Therefore, MRP should have an immediately correcting mechanisms for the above mentioned deviations. A quick efficient information feedback system is an essential prerequisite of an MRP system. Without this, the inventory status figures will be incorrect, the bill of materials will be incorrect (if some design changes take place), the lead-time will be incorrect and, thus the whole detailed calculations which are supposed to indicate correct quantities of inventory (how much?) for correct points of time (when?) will turn out to be a futile effort. A good Management Information System and MRP go hand-in-hand.

HANDLING UNCERTAINTIES

Although firm data is desirable, it may not always be possible to have customer-orders committed quite ahead of time. Part of the orders may be so, but not all.

A certain amount of forecasting is inevitable in such cases. The forecasts, being forecasts, will go wrong to some extent and corrections become necessary for the MRP process. Constant (i.e. frequent periodic) updating is essential for the success of the MRP system. It means, a certain amount of uncertainties can be handled by revised planning carried out frequently. Of course, as the uncertainty component increases more and more, the safety stock and EOQ concepts become more and more relevant. When everything is planned by means of uncertain forecasts it is wise to take calculated risk and maintain calculated buffer stocks and conduct calculated size of production runs.

The more the component of uncertainty, the more one needs to plan based on safety stock and other concepts.

One cannot do away with the safety stock (or the related safety time) concept. It must be used along with the MRP to the required degree at requisite places. But, the more there is the component of safety stocks or safety times, the less is the validity of the MRP system. In short, a judicious combination of MRP concept and the statistical/probabilistic concepts have to be used for a good materials and production plan.

COMBINING GOOD POINTS OF EOQ WITH MRP

Similarly, one can also use the EOQ concept advantageously along with the MRP system. The EOQ model may rest on certain assumptions of the linearity of consumption, but the basic concept—of balancing the order/set-up costs with the carrying costs of inventory—is pretty good. This concept can be utilised in deriving a batch-size for a product in an MRP (Fig. 23.4).

Week	*Amount Required*	*Cumulative Batch Sizes*	*Cumulative Carrying cost Corresponding to the Batch Sizes*	*Order Cost (mentioned here for comparison)*
1	1000	1000	0	500
2	0			
3	2500	3500	300	500
4	0			
5	0			
6	500	4000	450	500
7	1000	5000	810	500
8	0			
9	0			
10	2000	7000	1890	500

Order Cost = Rs 500 per order or set-up.
Inventory Carrying Cost: Rs 0.006 per week per Rupee
Cost per unit: Rs 10

Figure 23.4 Utilising EOQ Cost-balancing Concept in MRP

It is beneficial to make material available only when required (MRP concept) but it may be additionally beneficial if this material is also procured/produced in batches ahead of time so that carrying costs are offset by the reduction in cost due to economies of scale.

What we saw in the earlier example is called 'part-period balancing'. There are many other economic lot sizing devices such as the 'Period Order Quantity'—the order quantity is not in quantity or numbers, but is in terms of the number of periods of supply. One must remember though, that the lot sizes deal with 'how much?' Which is a question which comes after 'when?'. Unless the 'when?' is solved first, there is little benefit to be gained by answering 'how much'?

To summarise, MRP is an old system, revisited once again and found to have immense benefits for planning materials whose requirements are generated by higher-level materials in which the former are incorporated. With computations being done on a computer the MRP system is dynamic, i.e. it can respond speedily to the changing situations such as customer demand

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changes, order priority changes, and even design changes. The same old system is made much more dynamic, and retains whatever is good in the EOQ, Safety Stock and similar techniques. MRP provides important and calculated information for materials and production planners.

EVOLUTION OF MRP INTO MRP II

While MRP that has grown out of traditional production and inventory management does an excellent job of planning for the materials, such a technique cannot be fully effective in achieving the business objectives unless it takes into account the other resources of a manufacturing organisation. Without such integration, the planning for materials may not be able to mesh properly with the production schedules, the production plans in the longer term, the planned production capacities and more importantly, the other resources required for the manufacturing function such as the human resources, the machines and the finance. Therefore, planning for the requirement of materials has to take into consideration the business plans, the financial plans, the available human resources at any point in time, the available capacities, the machines, and also the aspects of logistics such as shipping status. Because of these needs and considerations there evolved an integrated manufacturing management system called manufacturing resources planning (MRP II). MRP II has been defined by APICS (American Production and Inventory Control Society) as:

'A method for effective planning of all the resources of manufacturing company. Ideally it addresses operational planning in units, financial planning in dollars and has a simulation capability to answer 'what-if' questions. It is made up of a variety of functions each linked together: Business Planning, Production Planning, Master Production Scheduling, Material Requirements Planning, Capacity Requirements Planning and the execution system for capacity and priority. Outputs from these systems would be integrated with financial reports, such as the business plan, the purchase commitment report, shipping budget, inventory production, etc.'

Thus MRP II is a logical extension that goes beyond the computations for materials requirement. It aims at addressing the entire manufacturing function rather than just a single task within that function. This is very significant improvement in terms of integration that has been achieved by the use of information technology (IT). The developments in IT have made these improvements more and more possible.

However, MRP II suffers from a few drawbacks. For instance, it assumes a static nature of an enterprise and fits the systems to it. The various times to setup, move, and processing are taken to be deterministic. The batch sizing concept is another drawback. Over the years, other tools had evolved to automate the manufacturing management process like Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), computer integrated manufacturing, customer oriented manufacturing management system, etc. These developments indicated the scope available for introducing these product-design and customer requirement variables into the system for better integration.

From the basic concept of MRP which brought in integration in the materials management function, there has been an ongoing search for further integration of other areas of the firm. The intention behind these measures to integrate has been to help an organisation make holistic decisions rather than based upon compartmentalised information, fragmented understanding of the situation and, therefore, probably an insufficient and incorrect analysis. Organisations have always been looking for a total solution and MRP II has been a step in that direction.

FURTHER EVOLUTION TO ENTERPRISE RESOURCE PLANNING (ERP)

The last decade has seen the global competition becoming intense. Manufacturing and operations in general had to become not only flexible but agile. Just-in-Time systems which came into existence in the 1980s tried to fulfill the needs of the customer in a very short time, almost instantly. The focus was still about needs that did not change drastically. However, this situation rapidly changed to that where the product life cycles became short. More and more services and other values were necessary to be added to the products and services offered to the customer. Business process reengineering came into being in order provide a process orientation to the company. This meant integration of all activities done in a business firm in order to meet the customers' needs. The focus of improvement was with respect to the ultimate goal of satisfying the customers' needs.

The manufacturing function needed to be more alert to the market. Marketing and manufacturing needed to have a close coordination. Due to globalisation, it became clear that this was also not enough. Firms could arrange for finance in a scale not earlier experienced. In addition to manufacturing and selling, the firms had to have the accounting and finance also to be integrated. Globalisation also meant that multiple currencies had to be handled; multiple trade rules and regulations and accounting practices had to be taken care of. Therefore, there was a need to integrate manufacturing with all other functions within the firm. Marketing, order processing, accounting, finance, production, materials and logistics, quality management, product design, human resources and other functions had to be integrated. In short, all the functions of the enterprise had to be integrated. It was no longer just manufacturing resources but the resources of the entire enterprise that needed to be integrated from the product design to marketing in a closed loop. Thus, MRP II would only be a subset of this objective. Such an enterprise-wide system—that would meet the information and decision needs of the enterprise as a whole spanning all the functions of management—is the enterprise resource planning (ERP) system. ERP software is an integrated software programme that allows various functional departments to share information and to communicate with each other.

Take the case of an export-oriented-unit dealing in specialised silk fabric. When an enquiry for an order arrives from a foreign country, the delivery dates and the quantity etc. need to be confirmed very quickly. This has to be done by looking at the stock, if any, in the warehouse and/or the power-looms' capacity, the dyeing unit's present load and its capacity, availability of the particular grade of silk yarn, the delivery lead times and/or capacity of the shippers etc. In addition, the price has to be quoted in the foreign currency, making note of the prices of the raw material—which could be international price that could vary frequently, the internal costs of the company and the costs of dispatch and delivery. The price and the delivery time and quality all have to be internationally competitive in order to bag the order. In fact, that firm's order taking department should have comprehensive and up-to-date information that can allow them to make decisions and immediately convey their order acknowledgement or quotation and invoices to the international customer. ERP could make that possible. Once the customer order is accepted, the next job would be that of order fulfillment. The material procurement, the production scheduling in dyeing and power-loom units, the quality control, and the shipping and billing have to be done in a way that fulfills the customer requirements. So, from customer enquiry to the realisation of the revenue the entire process has to be handled in an interactive way.

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Generally, ERP has a central database and a cross-enterprise interfacing facility shared by all functions of the enterprise. It should always offer a total solution and therefore it should have seamless integration across functions and across different divisions of the enterprise. Being seamless is an important property. Order management, manufacturing/operations planning and implementation, resource management (materials, machines, men, and finance), logistics management, strategic business planning and strategic resources management, new product introductions and change management are some of the elements of an ERP system. ERP provides an almost instantaneous access to transactional information across the enterprise.

Benefits of ERP

ERP enables an organisation to look at itself inwards as well as outwards towards the market. Due to the holisticbt view provided by ERP, the organisation has a better insight into its own policies, systems and procedures. The organisation is also able to look at the inefficiencies, bottlenecks and deficiency in communication across functions/departments/divisions present in the enterprise. It can help identify any area where the different departments of the enterprise are working at cross purposes. The very word integration signifies that no part of the organisation is an island. All those that were islands earlier would be connected to each other effectively with the introduction of ERP.

ERP's strength lies in its ability to provide information that is comprehensive, instantaneous and up- to-date. It provides this to all segments of the enterprise. The information from the different segments of the enterprise also gets into the ERP system seamlessly. Thus, the two-way exchange is almost effortless. Sharing of information should make it easy for people to work together. Many of the wastes in corporations are due to the non-availability of information or due to constrained flow of information and hence the same not being available at the time when it is needed. These wastes could be eliminated with the use of ERP. ERP proves that information is indeed power in today's competitive market that needs an agile response from an organisation.

The benefits of having an ERP system installed are:

1. It provides information that is
   - **(i)** up to date
   - **(ii)** uniform
   - **(iii)** comprehensive, across the entire organisation
   - **(iv)** integrated, linking all the functional departments and divisions
2. The ERP software embeds the best practices followed by corporations across the world.
3. The instantaneously available comprehensive information, the linking of different departments, and the embedded business processes in the ERP software can help a manager to take appropriate decisions with speed and quality.
4. It integrates the work flow in the entire enterprise. The organisation could thus be made more agile responding quickly and appropriately to the market situation and in attending to the customer.
5. Every decision-maker, whether the decision is big or small, is put on the 'value chain'. There is, therefore, more focus imparted to the organisation.
6. It helps an organisation to look inwards and thus discover areas that could be improved upon.

Since establishing an ERP requires large investment, the CEOs of the enterprises are typically interested in the return on investment (ROI). While there is nothing wrong in watching the ROI, the top executives should be conscious of (and develop measures to monitor) customer satisfaction (the ultimate goal), cycle times, delivery performance, decision making time and intangibles like the quality of decisions, etc.

Implementation of ERP

However, just by installing an ERP system an organisation cannot expect the benefits to flow. Much of the results depend on the way ERP is implemented. First and foremost, the attitudes of people have to change. ERP expects people to change the way they do their jobs. People, in general, resist change. The software is less important than the changes in the way people do their jobs. In fact if people's attitudes are not changed, the software may even become an impediment to the smooth running of the operations. That is the downside, if the organisation is not well prepared for the changes.

Moreover, the results from ERP—like any transformation in the systems—are not instantaneous. At least not those that concern the revenues, profits and ROI. ERP, as a transformational process, can take two to three years. An organisation has to keep on improving its policies, systems, procedures and ways of transacting business with ERP as an enabler. The point is not to expect a revolution, but a gradual transformation. Much of the benefits due to ERP depend on the amount of introspection the organisation does about its own ways of doing business. It is a prerequisite to put one's house in order before one does business with other organisations.

It helps significantly if a certain amount of introspection has already been done prior to installing the software. ERP further improves on this introspection. This is one reason why organisations have a Business Process Reengineering preceding the installation of ERP.

There are several instances of companies in India that have installed ERP software at considerable expense, often running into several crores of rupees, but have failed in bringing about any tangible improvements in their business. If people in the organisation are not willing to change their ways, such a software may increase the complexity rather than making the matters simple. For instance, an old established company doing good business in the pre-liberalisation licenses-permits era had miserably low productivity levels unacceptable under the changed economic conditions where India was open to international competition. The company never attended to this basic problem; the standard times for items remained the same before and after the ERP installation. Lead times, internal and external, did not change. People were comfortable in their old ways and resisted change. The ERP installation, if any, only increased the problems of the management. The ERP was erected on a base of rigid and sometimes spurious activity times.

Some companies even customise the ERP software to suit their organisation's prevailing ways of doing things. While there is nothing wrong in customising the software to suit an organisation's certain special needs, such customisations should not hit at the very purpose of having the ERP.

Continuous improvement is the crux of change management. In ERP implementation, there is nothing like 'getting it right the first time'. The ways of doing things have to undergo these necessary modifications on a more or less continual basis.

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Costs of Installing ERP

In addition to the cost of the software, that of the consultants who help in its installation, and the costs of the required IT infrastructure, there are other costs to ERP.

For one, the organisation implementing ERP must train its employees. The training is not just about developing skills in operating the system and interfacing, but about the new methods of doing things. People in the organisation need to have a process-orientation. They should think about the process that leads to the customer and thus have a larger perspective. They should also be trained in the new methods and procedures. This training takes time to sink in the minds of people and then to start giving results.

Data of the old systems have to be moved to the new system. Some of the old data could be useless or obsolete in the new system. Some of it could be spurious. When data starts getting transferred, one discovers the extent of work required to modify the old data and generate the new.

As had been mentioned earlier, ERP is not a project that comes to an end at one point in time. It becomes a more or less continuous process of improvement. The costs, therefore, will continue.

Steps in ERP Implementation

1. Identify the need for having an ERP system on board. The management of the organisation should, in a broad sense, know as to what it wants in terms of the business and where do the lacunae lie.
2. Assess whether the organisation is ready for ERP. Much of it has to do with the top management commitment and the attitudes of the people in the organisation.
3. Assess the costs of installing ERP on a long-term basis and the readiness of the management to bear it.
4. Start organising for ERP implementation. Select the persons within the organisation who will interact with the consultants of the ERP software vendor. Assign specific roles and jobs.
5. Document and evaluate the old process and the new process that is desired. Process mapping and modeling can help in evaluating the probable results. Based upon it, the new process can be further revised.
6. Select the software and the vendor or its associate that would do the desired job. This would involve parameters such as:
   (a) The global and local presence of the software and its vendor (i.e. which other organisations have used it. Check these organisations' experiences.)
   (b) Type of industry that the software attempts to target (for instance, some software packages are specific to engineering industry while some others could be for a process industry).
   (c) Obsolescence of the software package.
   (d) Price of the package plus the cost of implementation. This could vary from one package to the other.
   (e) The calibre, expertise and attitude of the vendor or its local associate who would interface with the organisation during implementation.

(f) Ease of implementation (involving the nature of the package, its design, its modularity and the people who install it).
(g) After-sales service or support offered by the vendor or its associates.

7. Draw up a detailed plan of implementation that should include:
(a) Forming a team for implementation.
(b) Training of the team.
(c) Mapping of the business processes onto the package.
(d) Deciding upon customising where essential.
(e) Schedule for the test runs.
(f) User training.

Leading ERP Software Vendors

SAP SAP is a German company that operates all over the world having a large share of the ERP software market. Its flagship product SAP R/3 is its high-end software. The strength of SAP is in its research and development support, its process-orientation rather than being technology-oriented, partnership with consulting and IT firms and training. It meets the needs of modern day corporations that have global accounting standards and other modern business practices, multiple currencies and multiple languages. It controls SAP certification very stringently and thus has a name for quality. In India, SAP has had a lion's share of the market, and large business houses of repute such as Tata, Kirloskar and Mahindra have been their user licensees. P&G, LG and HP in India have implemented SAP.

BaaN The BaaN Company operates from The Netherlands as also from USA (Menlo Park, California). Its major differentiator from other ERP software package vendors is Orgware that enables it to use Dynamic Enterprise Modeling (DEM). With this capability, the package BAAN IV can take care of alignment with the changing business processes and organisation models. The BaaN Company has international service centres in The Netherlands, the USA and in India.

The other companies in ERP software package are PeopleSoft, Oracle, JD Edwards and Gartner.

What Next? ERP II?

After integration at the unit level, the corporations are now ready for a web-enabled ERP that can be run on the Internet. The concept of multi-organisation supply chains has picked up lately. Electronic commerce (e-commerce) is also getting to be the trend of the future. Since a supply chain involves several firms, integration only at a single enterprise level is not enough. It is not enough that an organisation is seamless. Seamlessness has to come into the entire chain of organisations. Therefore, further advanced software solutions are necessary. SAP R/3 and Oracle are two such applications that can be used for a business-to-business (B2B) e-commerce. DEM based systems may overcome the shortcomings of the plain ERP systems. Gartner has come out with ERP II (appropriately named so) to position an enterprise in the supply and value chain.

ELECTRONIC COMMERCE

Since the past ten years, the Internet has become a great source of information. It is also blooming into a place for transactions. Business transactions are now increasingly being conducted via the

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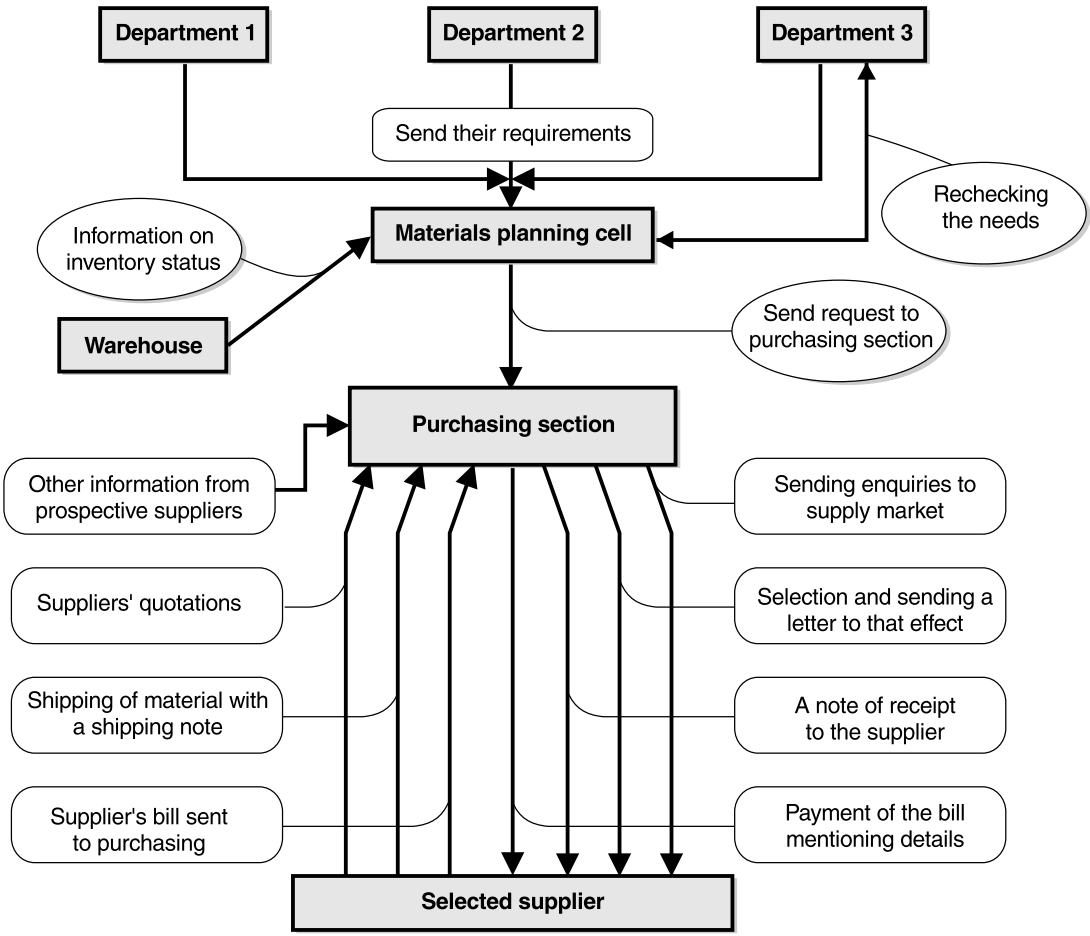


Figure 23.5 Information Flows in a Simple Purchase Transaction (Business has a Large Content of Information Transaction)

Internet or the 'web'. After all, a business transaction involves a lot more transaction or exchange of information than that of the physical goods. The various stages in a simple buying process for a company are shown in Fig. 23.5.

As is seen from Fig. 23.5, the physical transactions are far fewer than the transactions of information. Traditionally, this information flow has involved paperwork such as gathering requisitions from the manufacturing and/or materials and/or quality departments, sending letters of enquiry to the prospective suppliers, inviting tenders or quotations again in the form of letters, and after a purchase decision is made, transactions such as a purchase order mentioning the details of the quantity, quality and delivery specifications, the invoice or the bill from the supplier mentioning the amount payable, the confirmation of receipt of the goods from the buyer company, and finally the payment. All this paperwork is nothing but a flow of information back and forth from one business organisation to the other business organisation. With the advent of the 'web' or the Internet,

the entire information flow can be completed in a few seconds or minutes, sometimes literally with the click of the computer mouse.

Fast, Cheap and Convenient

The very property of being time-efficient imparts several other values to such a transaction:

(i) Buying companies now have more time to search and select appropriate vendors who would fit the bill. This may result in a wider choice and an efficient selection of vendors.

(ii) Time is not wasted on avoidable paperwork, courier or mail delays. Lead times for procurement would be substantially lower.

(iii) For the same reason as above, lead times to supply would be substantially lower, almost Just-in-Time.

(iv) Many of the benefits of a Just-in-Time system could be realised, such as lowered inventories, better flexibility and lowered cycle times.

(v) New product designs could also be done with more information and quicker flow of information about the quality, cost and availability of components, parts, supplies, equipment, apparatus, testing facilities, etc. In an enterprise, the data base could be accessible to any authorised person at any location.

(vi) Being time-efficient improves the 'connectivity'—there is a possibility of frequent and quick feedback between the two transacting organisations which can improve the performance of operations for both the transacting organisations.

Web and Relationships

The very words 'web' and 'Internet' signify the connectivity between different organisations. Relationship is the order of the day and Internet makes that possible. E-commerce or electronic commerce is about business or commercial transactions involving transfer of information on the Internet. There are various forms of interaction.

There are *retail sites* like Amazon.com where the website acts as an intermediary between the producers and the customers. This site posts various books, toys and other such items for sale where the price of the product is mentioned along with a brief description. The price is fixed by the website; the products on sale are also selected by the site. The customer places an order on the site and the site takes the responsibility to fill that order.

There are some *auction sites* which bring the seller and buyer together and provide for the negotiation of the price of the product/service being sold. eBay and Priceline.com are two such examples. Customers can also bid on airline tickets, among other things, on such sites.

A business web (or B-web for short) such as America Online facilitates *sharing of information* between online organisations.

Companies like Dell Computers and Cisco Systems have set up websites to transact business with both the customer and the supplier. Dell's products are mostly sold over the Internet and it *integrates the partnering companies* (suppliers) to meet the customer needs.

B2B and B2C e-Commerce

Electronic commerce between businesses is termed business-to-business or B2B, while that between a business and a consumer is termed as business-to-consumer or B2C e-commerce. World-

wide B2B e-commerce is projected to reach $7.3 trillion by 2004. The distinction, if any, between the conventional business and the modern electronic business is getting blurred by the day as more and more companies are conducting several aspects of their business on the Internet. The Internet has become something like a large universal virtual market square where anyone could conduct business. In many ways it is similar to the physical market place.

However, it is the phenomenal networking ability that the Internet provides which is of great significance. Therefore, really speaking it is neither the 'e' (that stands for 'electronic') which is very significant, nor the 'commerce' bit. The significance is of the two conjoined words—'Inter' and 'net'. The entire transformation that the traditional management is undergoing in the recent times is about networking within the organisation (between different departments and divisions and between different people that are working in the organisation) and outside the organisation (between the various currently transacting organisations, between the various other organisations that could potentially transact). Due to the universality of the web and the ease of access to customers/potential customers/suppliers/partners and also the ease of access to information about these players and their products or services, the character of business worldwide is changing.

Direct consumer transactions (B2C)—eliminating the middleman—are now possible, thanks to the Internet. A company can establish a web-based retail store, or it can set up a promotional office on the web or it can set up an office to provide customer support. The concept of a middleman is now changing radically. Such a person/organisation is no longer the one who *physically* stocks the products. Instead, either he stocks the information or he offers the convenience of exchange of information.

The emphasis is on information availability and exchange. Since information is transacted in seconds or minutes, the need for the traditional middleman who takes risks of the marketplace is diminishing. A high level of feedback, which is now possible, is reducing the conventional market risks. There are, however, other risks that need to be addressed to such as the financial security of a transaction.

Significance of e-Commerce to Operations Management

Production and operations management people have been talking about the importance of speed in decision-making while responding to the changes in the marketplace and also within one's own organisation. The 'e' or 'electronic' aspect of B2B or B2C does fill in this need for speed.

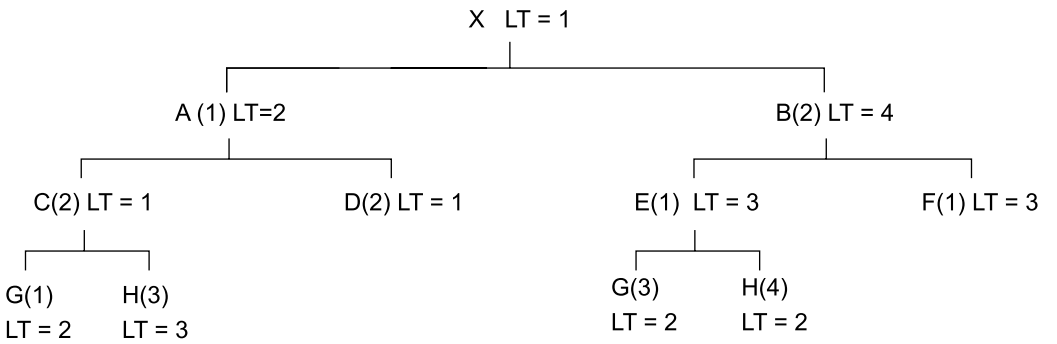
However, the major benefit of e-commerce to production/operations has been in supply chain management, which demands a high level of connectivity between the firms on the supply chain. The kind of transparent interfacing that is required in these supply chains is now possible because of the Internet and B2B transactions. The B2B transactions here would be between the companies on the supply chain. Operations managers are now better able to oversee their supply chain. The business transactions made at one link in the supply chain are known to the other links in the chain who need that information. The links are, therefore, made stronger. Also, B2B transactions allow a company to be in touch with the business world outside its supply chain and provide vital information regarding the market environment to the concerned members of the chain. E-commerce makes a supply chain stronger due to its members being better informed. It enhances the overall competitiveness of the organisations.

ERP connects all the functional departments, divisions and locations within an enterprise. B2B connects the suppliers and the buyers. These two concepts could possibly be combined for further

improved performance of the organisations. ERPII as mentioned earlier may be one such step. The future may hold a prospect of what may be termed supply-chain resource planning. The distant future may have individual business organisations and supply chains replaced by 'communities' that could possibly be connected, among other forms of connections, by extended resource planning network. Perhaps, it would be community resource planning. CRP? May be.

SOLVED PROBLEMS

1. The product structure and the lead times for a finished product '*X*' are given in the figure below.



If 100 units of *X* are to be produced, what are the requirements at various levels of the product? Write an indented Bill of Materials and calculate the requirements of materials at the various levels.

Answer

The requirements of various materials can be calculated as follows. First the indented Bill of Materials (BOM) is computed as given below.

Part Name	*No.*	*Level*
A	1	1
C	2	2
G	1	3
H	1	3
D	2	2
B	2	1
E	1	2
G	3	3
H	4	3
F	1	2

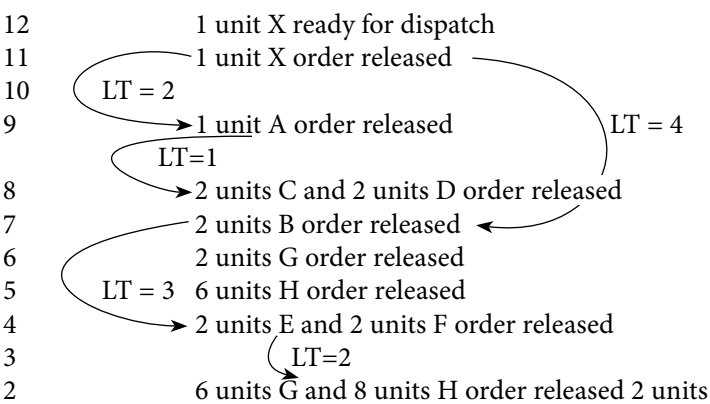
The requirement of parts is calculated as follows.

Part	*Requirement*
A	1
B	2
C	$2 \times 1 = 2$
D	$2 \times 1 = 2$
E	$1 \times 2 = 2$
F	$1 \times 2 = 2$
G	$1(2 \times 1) + 2(1 \times 3) = 8$
H	$1(2 \times 3) + 2(1 \times 4) = 14$

2. For the above case, if 100 units of product '*X*' are required in week 12 and if none of the components, sub-assemblies and the end product are either on hand or on order, compute the amounts and dates of the planned order releases for all the components and sub-assemblies. Assume that there is no particular order size and, therefore, all order quantities are 'lot for lot'.

Answer

The order releases can be planned by counting backwards on the lead times given.



The schedule of order releases with quantities of different materials (components , sub-assemblies and assembled product) are shown in the table below.

	Week									
12	11	10	9	8	7	6	5	4	3	2
Order	X(100)		A(100)	C(200) D(200)	B(200)	G(200)	H(600)	E(200) F(200)		G(600) H(800)

Note: Figures in parentheses indicate quantity of the order releases (material ordered).

3. Given the following information regarding a particular material, how many units would be on hand in (at the end of the) week 11? We are at the end of the week 0 (zero) and have 50 units of the material on hand and none on order. The scheduled receipt of the material (order quantity = 75) is by the start of week 3.

EOQ = 75 LT = 3 wk.	Week										
	1	2	3	4	5	6	7	8	9	10	11
Requirement	40	–	30	40	–	20	–	50	–	30	20
Scheduled Receipts			75								
On Hand at the end of the period 50											
Planned Order Release											

Answer

Carrying out the arithmetical calculations from week 1, we get for week 1: On hand = 50 – 40 = 10.

Next, during week 3: We have 75 units arriving plus 10 are on hand giving a stock of 85, out of which 30 would be used up. Hence, 55 units would remain on hand.

Next, during week 4: We have 55 units on hand out of which 40 would be used up. So, 15 units would remain in stock at the end of week 4.

Next, during week 6: We have 15 units on hand, but the demand is for 20 units. So, there would be a shortfall of 5 units (shown by a minus sign in the table below). Hence, we would need the material (always ordered in 75 units) by the start of the week 6. Since the lead time is 3 weeks, we need to order for it in week 3. Therefore, the following table shows a "planned order release" of 75 units in week 3. That means, the order has to be placed in week 3.

Rest of the computations can be done by the reader. The final table looks like below:

EOQ = 75 LT = 3 wk.	Week										
	1	2	3	4	5	6	7	8	9	10	11
Requirement	40	–	30	40	–	20	–	50	–	30	20
Scheduled Receipts			75			75				75	
On Hand at the end of the period : 50	10	10	55	15	15	$\frac{-5}{70}$	70	20	20	$\frac{-10}{65}$	45
Planned Order Release			75				75				

It is observed that at the end of week 11, there are 45 units on hand.

QUESTIONS FOR DISCUSSION

1. What are the drawbacks of 'service level' concepts in maintaining Buffer Stocks of inventory?
2. EOQ concept optimizes the relevant costs of inventory. Then, why is it often found to be lacking in validity in practice?
3. How does MRP propose to surmount the above two drawbacks?
4. 'Safety Stock and EOQ concepts are inimical to the MRP System'. Discuss.
5. 'Installing MRP system tends to bring in an integration of the Materials Management, Production Management and other functions in the organisation'. Discuss the preceding statement.
6. What are the 'independent demand' items? Give examples. Do spare parts belong to the 'independent demand' category?

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7. Is the 'when?' question more important than 'how much?' in Materials Management? If so, why?
8. What is the role of MIS in the successful implementation of MRP?
9. Stick-fast Adhesives Ltd. makes adhesive plasters, cellophane tapes, plastic-coated adhesive tapes, etc. all of which need the basic ingredients of special rubber (Code: RB 342) and a resin (Code: RS 108) in addition to various other ingredients. The requirements as per the formula are as follows:
   (a) Adhesive Hospital Tape (AHT)
   RB 342: 100 kg per 1000 m
   RS 108: 90 kg per 1000 m
   (b) Cellotape (CT)
   Transparent (CTT)
   RB 342: 50 kg per 1000 m
   RS 108: 60 kg per 1000 m
   Coloured (CTC)
   RB 342: 60 kg per 1000 m
   RS 108: 72 kg per 1000 m
   (c) Plastic-Coated Tape (PCT)
   RB 342: 40 kg per 1000 m
   RS 108; 40 kg per 1000 m
   (d) Water-Proof Sticking Tape (WPT)
   RB 342: 80 kg per 1000 m
   RS 108: 75 kg per 1000 m

   The RB 342 needs to be masticated and cured before it can be incorporated into the tapes. The mastication and curing time is roughly two weeks. RS 108 is procured from another plant of the same company located elsewhere and the usual notice needed by that plant is about 4 weeks. RB 342 (Raw) is supplied in batches of 4000 kg with a lead time of 4 weeks.

   The process of manufacture of these tapes consists of:
   (a) Firstly masticating and curing the rubber.
   (b) Mixing the masticated rubber, resin (RS 108) and other ingredients with n-Hexane in a mixer.
   (c) Coating the solution, thus prepared, onto the cello-paper or cloth (as the case may be) and simultaneously curing the coated sheet in heated chambers.
   (d) Slitting the tapes into standard sizes such as 1 inch, 1/2 inch, etc. and packing in containers.

   The manufacturing times for all the tapes (inclusive of packaging) are approximately two weeks before the product can be shipped out.
10. Does ERP implementation require organisational preparation? Discuss.
11. What is Internet connectivity? Whether and how is it important in today's business world?
12. What are the implications of B2B and B2C on Production and Operations Management?
13. List the socio-economic conditions necessary for B2B and B2C to flourish. Explain your response.

24 Other Aspects of Materials Management

So far we have discussed inventory control, classification of materials, purchasing, and spare parts management. In this chapter, we shall deal with aspects which we have not covered earlier, such as codification of materials, standardisation of materials, and a few points about materials handling and stores management.

CODIFICATION

Codification of materials can also be termed as the identification of materials. This deals with uniquely identifying each item in the inventory. It is useful in requisitioning items for the operational departments, in placing of orders by the purchase department, in receiving and expediting the items on receipt from the supplier, in having a unique record of each of the items in stores and in work-in-process or in warehouse so as to facilitate the control over the inventory levels, and also in having a good control over the loss, deterioration, obsolescence, non-movement, or pilferage of the items in the inventory. Unique identification of the materials—whether they are raw materials, work-in-process or finished goods—is the first step towards a good materials management system. Without it, the control over inventory by rigorous exercises such as inventory control techniques is not very effective. Without it, confusion might prevail in the operational departments. Moreover, for a good quality control system, a unique identification is a pre-requisite. There are many other advantages such as variety reduction and standardisation, etc. which we shall describe in the later sections of this chapter.

It is amazing to find that in many of our large public and private sector corporations, a considerable amount of inventory lies in the stores or elsewhere because of a confused nomenclature and a lack of proper identification system. Many items in inventory such as pipes, rods, angles, electrical switches, cables, valves, similar equipments, spare parts and even nuts, bolts and such items in inventory are available under different names and codes thereby reducing the actual availability of the item for operational needs. An item may be called a 'nut and bolt' by one section of the organisation, whereas another may call it a 'fastener', and because of this there are two separate requisitions made, two separate purchase orders sent out, and two separate inventory levels of the items built into the system. One section might call an item a 'pipe', whereas another might call it a

'conduit', in fact both sections using the same item. This increases the inventory level unnecessarily. Prevention of duplication is one of the important benefits of a good materials coding system.

Needless to say, for proper stock-taking a good identification is of immense help. Many cases have been observed in large corporations where the concerned people do not even know what materials have been lying in the inventory for a large duration of time. These materials could easily be eliminated from the list, salvage value recovered and the storage space freed. It is also not uncommon to observe that although a material is available with the stores in reality, due to duplication of the identity it is often quoted as 'not available' and thus, many production programmes suffer with consequent loss to the organisation as a whole. Proper identification of inventory items helps in simplification of all the processes such as storing, receiving, procuring, manufacturing, warehousing and this results in a multiplicity of benefits to the company. It is a simple concept. If followed, it might produce results of proportions equivalent to that of a rigorous application of the inventory control principles with, perhaps, much less effort.

Codification by Group Classification

What do we mean by coding? By this, we give a unique number to a particular item in the inventory. For instance, 010237 might mean a specific item in inventory such as a particular kind of gasket, of a certain material, of a certain shape, and of certain dimensions. Of course, each of these numbers or groups of numbers (within the total identification number) should convey some unique information. For instance, the following numbers might be used to describe the first classification of materials in an inventory:

01—Raw materials
02—Purchased components
03—Spare parts
04—Tools
05—Fixtures and Patterns
06—Other supplies
07—Work-in-process material
08—Finished goods
09—Capital Equipment

The next classification group may be based on, say, 'shape' of the items. For instance:

1 … Wire 4 … Bar
2 … Tubing 5 … Sheet
3 … Rod 6 … Strip

Further classification could be based on the material of construction. For instance:

01 … Mild Steel 07 … Brass
02 … Stainless Steel—304 08 … Bronze
03 … Stainless Steel—316 09 … Aluminium
04 … Stainless Steel—… 10 … Special alloy
05 … Stainless Steel—… 11 … PVC
06 … Copper 12 … Polypropylene

To this, one may add further classifications in terms of the composition, use, characteristics, etc. For instance, for metals we could have a group of classification as follows:

01 … Cold rolled, 04 … Annealed,
02 … Tempered, 05 … Hardened,
03 … Normalised, etc.

If the material is a wire, then the next group of classification could be in terms of the 'use' characteristics, such as:

01 … 5 amps
02 … 15 amps
03 … 25 amps

Thus, an item could be coded as:

08 1 06 03 01

This nine-digit code uniquely identifies the item as a 'Finished Product, Wire, made of copper, Normalised, for 5 amps performance.'

Codification, as done above is called Codification by Group classification where the identification is done by reserving a number of characters (spaces) for each 'group' of classification. In each group the relevant 'details' are sequentially numbered.

Mnemonic Coding Method

The other major codification method is by 'Mnemonic Code' which includes numerals and also alphabets. These numerals and alphabets are derived from the description of the materials itself. For example:

SH 015 60 would mean
'a shunt, 150 amps. , 60 mV.'

Similarly, SH 100 75 would mean
'a shunt, 1000 amps, 75 mV.'

One obvious demerit of a Mnemonic Coding System is that two different names or sizes, for instance, may suggest the same mnemonic code. When the number of items gets larger, then we encounter such a problem more often. This drawback makes this coding method somewhat restricted in its use, particularly where a very large number of items are processed on a computer.

Hybrid System of Coding

One could have a 'hybrid' system, using group classification and mnemonic codes. For instance:
PI 1 1015 would mean
'a Pipe, Vinyl hosepipe, 10 mm.ID × 15 mm ED.'
Whereas, PI 3 1134 would mean
'a Pipe, PVC flexible pipe, corrugated 3/4 inch.'

Basis for Codification

The basis for a codification system lies in the answer to the following fundamental questions:

(1) Who will be the users?
(2) To what use is the codification going to be put?
(3) What kind/degree of mechanisation will be needed to use the codification systems?

Every organisation can arrive at its own system based on its special needs. Identification or coding system generation should be more situational, guided by the necessities of that particular

organisation. In an 'assembly line' situation, the classification (for coding) could be by the 'level' of the part in the assembling process, i.e., component, group of components, module, subassembly, assembled final product, etc. In a Group Technology (GT) environment, the classification could be by 'sameness', in a group of parts, with respect to, most importantly, the required production operations. Then, of course, the material, size, shape, tolerance, finish would also matter for the 'grouping'.* Some other coding system may cater to emphasis on supplier and storage. For any coding system, the amount of detail, the 'decoding' facility of the code, will depend upon the degree of automation (or computerisation) prevalent in the organisation. Mnemonic codes are easier to decipher by humans, but not very suitable for a very large list of items which could expand in the future substantially. Hence, in this case the use of a computer loses some of its value.

CHARACTERISTICS OF A GOOD CODING SYSTEM

A few points to be taken into consideration while codifying the items in the inventory are given below:

Flexibility

A codification system should last a long time to derive proper benefits from it. It is not something which we change every quarter or every other year. Therefore, the long-term requirements of materials for the organisation should be kept in mind while providing the digits or alphabets for the items. Moreover, the codification system should not only have enough of vacant spaces but should be flexible enough to suit the requirements of the long-term future.

Precision

The codification system should ensure a unique code for each item.

A proper dictionary or vocabulary for the decoding should be made while installing a codification system.

The number of letters or digits should be the same for all items.

Brevity

The total number of letters or numbers should not be too large so as to lose its immediate meaning to the user of the material. (7–10 digits or spaces are adequate for many of the coding systems. However, with a high degree of computerisation one could have more digits.)

Comprehensiveness

While classifying and sub-classifying the items for coding purposes, the nature of the item, its specifications, its end-use and the suppliers, etc. should all be comprehensively taken into account; and therefore, for the codification system to work, prior consultations with the concerned departments such as the operations department, purchasing department, engineering department,

* Coding is the basis of the GT concept. For an interesting discussion on the same, read, Dilip T. Desai, 'How one firm put a GT parts classification system into operation'. *Industrial Engineering*. November 1981, pp 78—86.

and finance department, etc. should be absolutely necessary. The basis of classification and sub-classification should be understood and be approved by these user departments.

STANDARDISATION

A good system of codification helps in the standardisation of items in the inventory. Standardisation consists of reducing the variety of items stocked in the inventory to a workable minimum, by fixing sizes, shapes, dimensions and other quality characteristics of the item. For instance, paint may be bought from a number of suppliers in different sizes of containers and different shades of colour. All of these might blow up the inventory of paints considerably. The same could be reduced if the number of suppliers is cut down, if the variety in the sizes of the containers is reduced and if the number of shades of colour is also reduced. There may not be a good reason why the paint should be procured from so many different suppliers and in so many different sizes. With standardisation, the amount of inventory on paint can easily be cut down to almost a quarter or even much less. In one of the recent exercises done in an Indian electrical machinery manufacturing company (which mostly does jobshop type of work, i.e. manufactures items on order), it was found that by means of conscious thinking they could standardise their regular items and reduce the amount of inventory to almost 60%. Note, that this reduction is being done in a company dealing with *make-to-order* type of business; the potential for other kinds of business can only be inferred from this experience.

A standardisation programme consists of examining the items stocked critically for:

1. The use or uses to which the items are put in the organisation (i.e. the need of the organisation/plant).
2. The performance characteristics and the use characteristics (such as a certain socket could be used for 230 V). By a critical examination one can determine which items in the inventory can be totally eliminated. What specification ranges will satisfy the performance and use characteristics? Which items could be grouped together and a different specification be arrived at? It is necessary that during this examination, the Quality Control, Production Operations Department, Engineering Department, Purchase Department should all be consulted. Specification ranges, grouping of items, etc. is not possible unless all the concerned departments are consulted.

Many a time codification, because of its unique identification of the items, suggests a standardisation programme and helps the latter in the initial data gathering about the number of items, their composition/s, the end uses, the performance characteristics of the items, the supply sources, etc. In short, codification makes the exercise of standardisation easier.

Advantages

By combining the materials into standard groups it will no more be necessary to keep as high a level of inventory of items as was necessary when there was a variety of items in the inventory. With less variety (i) the purchase costs will be lower, and (ii) less stocks need to be maintained for current consumption as well as for safety stocks. Also (iii) the amount of paper work is reduced, in addition to (iv) streamlining the materials planning process.

MATERIALS HANDLING

Materials handling is one of the important activities in stores as well as in production. The handling problem is linked closely with the (i) number of items in the inventory, (ii) their location, (iii) the space availability, (iv) the layout of the stores and the production floor, and with the material itself in terms of (v) the nature of the material and the kind of handling suitable to it; and (vi) the packaging or container required for the material and the handling suited to it (or vice versa).

In Chapter 28, we have covered the economies of movement and therefore the optimal layout for the flow of material from one department to another. Besides (a) layout, the problem of materials handling is (b) to choose the proper method of handling the materials (manually or mechanically), and (c) to choose proper equipment for the movement of materials. There are a variety of equipments available for materials handling which we shall briefly discuss later.

Considerations in Materials Handling Procedure

While making a decision on materials handling methods and the choice of the materials handling equipment, the important considerations to go into the decisions are:

1. How much is the load to be moved? (In terms of the weight and number load/s to be moved).
2. The frequency with which the load is to be moved from one department to another.
3. The characteristics (physical, chemical, shape, weight, etc.) of the item to be handled.
4. The characteristics of the package which needs to be handled.
5. The existing or proposed layout of the stores and production areas.
6. The height, the length, and the width of the areas in which the materials handling equipment is to be used; also the breadth and height of gangways, passage-ways and doors for the stores house and for the production plant.
7. The already existing materials handling equipment.
8. An examination of the different probable materials handling equipment in terms of economic aspects such as (a) their price, (b) operating costs (power or fuel or batteries, if any, the spares, the labour-hours, etc.), and (c) their relative time saving potential and hence the savings in relevant costs.
9. Examination of technical aspects such as (a) speeds, (b) volume carrying capacities, (c) weight carrying capacities, (d) the requirements of spaces for operating the material handling equipments. (e) space-savings potential of the handling equipments, (f) their flexibility in terms of multiple uses, (g) ease of handling, etc.
10. While assessing the different alternative materials handling equipment, it is also essential to take into consideration many accessories that might be required such as pallets, drums, containers, racks, etc.
11. Consideration of the implications of having the materials handling equipment, in terms of either reduction or increase in the labour force. Not only the cost of labour, but also other human aspects need to be considered.

Based on factors mentioned above, a materials handling equipment should be evaluated. Unless all these factors are considered, a new equipment, however powerful it may be, cannot produce the kind of savings in labour-cost, space-cost, and in time, as would be expected.

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Materials Handling Equipment/Accessories

A few of the materials handling equipment often used in various industries are mentioned below:

Hand Truck This is a manually operated truck to carry small quantities of solid materials. In this there are some versions where a small platform is fitted sometimes with a hydraulic unit which helps to lower or raise the platform by a few inches so as to facilitate the loading and unloading of the truck. Another version of these hand trucks is the pallet truck where instead of a platform, a fork is fitted and therefore these trucks are of use in handling pallets on which oil containers, small barrels, component parts or other items can be kept and transported.

Pulley Blocks These are used many a time to lift heavy weights occasionally. The pulleys help in reducing the load on the operator.

Pulleys are quite common as a make-shift devise in construction places where heavy pieces of equipment have to be fixed at a height. For regular use, sometimes these pulley blocks are used in conjunction with mono-rail so that the load can be transported from one area to another.

Chutes Sometimes chutes are also used for dropping the material from the upper floor to the floor below. But this is suitable only for certain kinds of materials which can be handled roughly.

Roller Conveyors For heavy packages of goods, sometimes roller conveyors are used, when such movement is required on a regular basis.

Fork Lift Truck One of the most widely used and extremely helpful equipments in materials handling has been the Fork Lift Truck. This could be either battery-operated or diesel-operated. It has a fork (or two prongs) which can be inserted into the pallet and, thus, the load is lifted. The fork can move vertically in most of the versions of this truck; this helps in stacking the pallets at different levels in the store-house. Some machines have a 'reach' mechanisms, so that the fork can be moved horizontally while the rest of the machine remains stable. This is definitely advantageous when the material is to be handled in narrow aisles. However, the forklifts are not usually designed for heavy loads; also they are basically for short distance movements. Fork lifts require a suitable design of aisles; exits, doorways, etc. Needless to mention that the use of fork lifts would mean the use of associated pallets as well.

Pallets Pallets have been standardised and ISO (International Organisation for Standardisation) specifications are available for different varieties of pallets.
Pallets are of different types:

(a) Two-way pallet, where the fork can enter from only one direction (or from the opposite direction only).
(b) Four-way pallet, where the entry of the fork can be from any of the four (4) sides of the pallet.
(c) Single-decked pallet: This pallet has a flat top surface in contrast to the non-decked varieties which have strips of timber planks for the upper and lower faces.
(d) Double-decked pallet: Here, the top as well as the bottom faces have flat surfaces. The top deck takes the load and the bottom deck acts as the base.
(e) Wing pallet: Here the deck projects beyond the sides of the main body of the pallet.

There are various other kinds of pallets such as the box pallet, post pallet, reversible pallet.

The dimensions of the 2-way and 4-way pallets as recommended by the International Organisation for Standardisation (ISO) are:

	$36'' \times 48''$
$32'' \times 40''$	$40'' \times 40''$
$32'' \times 48''$	$40'' \times 48''$

In terms of millimetres, the same dimensions are:

	900×1200 mm
800×1000 mm	1000×1000 mm
800×1200 mm	1000×1200 mm

The height from the ground to the bottom of the top deck should be 127 mm (5″) maximum. Free height for the entry of forks should be 98 mm minimum $\left(3\frac{7''}{8}\right)$.

The pallets should also be rated in terms of 1 tonne, $1\frac{1}{2}$ tonnes or 2 tonnes. The pallets constructed from wood should be tested for lifting a load of 50% in excess of the rated weight. Pallets constructed out of steel should be tested for 25% excess load.

Palletising also means that it has to be accompanied by pallet-racks. The pallet racks are mainly of two types: fixed pallet-rack, and adjustable pallet-rack. Both these types should be made from a rugged skeleton of angle iron or steel sections. While the fixed pallet rack has fixed shelves, the adjustable one has shelves that can be set up in desired height and moved easily for this purpose. The latter type of pallet racks are of use while stacking items of different sizes and shapes, thus saving space.

Overhead Electric Cranes These are particularly useful for loading and unloading railway wagons or heavy items with box bodies. They are quite useful in stockyards, where a substantial tonnage of handling is involved. The two basic kinds of cranes are:

(a) floor-controlled
(b) cab-controlled

In the latter, the operator sits in the enclosure situated at the top of the crane. Weights up to 10 tonnes can be easily handled by the electric cranes; although the load handling capacity of a crane should be first noted before handling any heavy item.

Belt Conveyors In some of the industries, particularly those where there is assembly line production, electric-powered belt conveyors have been used. The belt could be made of canvas, rubber, PVC, etc. The belt conveyors are helpful in the assembly-line for transporting the semi-finished product from one work station to another. By a proper arrangement of conveyors, the material can be made to travel in different directions. Generally, the conveyors are supported on the floor and operated at a little more than waist height. It should be understood that once the conveyors are fixed in the production plant, they will not allow access by means of fork-lift truck or other vehicles. The arrangement of belt conveyors is to be accompanied by a proper arrangement of gangways for the movement of people and vehicles.

Pneumatic or Vacuum Lift In many chemical plants, products are transferred from one operation to another by means of the flow of high pressure air or by vacuum which carries the product to a higher altitude and at a distance. Of course, this can be useful only for powdery or powdered materials below a certain particle size and particle weight. In one of the companies manufacturing STPP, a sequestering agent and an important component of the detergent powder mix, the final product is conveyed to the storage bins pneumatically from the grinding machines.

STORES MANAGEMENT

An important component of materials management is the storage of materials. Basically the function of stores management is to be a custodian, looking after the items and controlling their flow. This is the component of the materials management with which the production department relates directly on a day-to-day or perhaps hour-to-hour basis.

In this custodial and controlling function, the important issue is that of having good information and record system on the (a) incoming, (b) outgoing and (c) remaining items of materials. A good MIS is the heart of stores management.

The various operations related to stores management are:

(i) Receiving and inspection,
(ii) Issue and dispatch,
(iii) Stock-records,
(iv) Stores accounting,
(v) Stock-taking and checking,
(vi) Stores preservation, and
(vii) Stores arrangement.

Receiving and Inspection

The important duties, here, are that of

(a) checking: supplies for quantity and quality,
(b) preparing documents: (i) posting to stock-records and stores accounts accordingly, and (ii) for providing evidence of receipt.

In order to help the stores personnel in the checking function, the stores may be advised about the items requisitioned (what, when, value of items). A copy of the purchase order would generally suffice. The supplier may also, for non-routine and high-value items, send in advance an advice note giving details of goods being shipped, quantity, mode of transport, date of dispatch, etc. The items, when they arrive, may also be accompanied by the supplier's packing information and the carrier's consignment note.

On the basis of the checking of the consignment, a Goods Received Note (GRN) is made by the store-keeper. Since this document will be used for settling bills, it should contain all the details such as, supplier name, his advice note number, purchase order number, date and time received, mode of transport, vehicle number, description of the item, code number, number and type of packages, shortage discovered if any, damage to the goods if any, excess items if any, and inspected by who. A separate damage/shortage report or a rejection report also needs to be prepared.

Since receiving and inspection operations control the entry point, proper information to and documentation by the stores person is important.

Issues

Since this is the outflow point, the authorisation for issue should be proper, carrying' details such as the code number, description, job number or cost code number for which required, quantity required, quantity issued, person authorising date of issual, and value of items issued. Such individual document is not always necessary for all items , for example, issues for assemblies or a

production batch—where only the number of assemblies or the particular production programme may be sufficient for the stores to supply all the necessary materials.

Stock Records

The purpose of record-keeping is to facilitate materials control by bringing information on actual stocks position, consumption rates, and order and supply position up to-date along with the proper pricing and evaluation of the usage and of the balance of stock. Whether the system is manual or mechanised or a combination of both, the important managerial control information should be provided by this stock-records system. The management should, thus, get information on:

(i) daily operations of the stores giving details on receipts, issues, direct deliveries, etc.
(ii) stock at each location—flashed at the location, as in 'bin cards', and also as a separate information document;
(iii) allocation of stocks for certain project or jobs;
(iv) review and provisioning of stock;
(v) order performance giving details on quantity ordered, supplier, delivery promised, progress-chasing action, when delivery received, etc.;
(vi) stocks consumption history and changes in consumption rates; and
(vii) money value of the movement/consumption of stocks and balances on hand.

Stores Accounting

This information system is necessary in order to:

(a) know, and show the value of stock in the balance-sheet, and
(b) help in production (and other functions') cost control.

The alternative methods of costing the issues are:

(i) cost price,
(ii) average price,
(iii) market price, and
(iv) standard price.

Cost Pricing uses actual purchase price paid (up to the point of delivery) of the items when accounting for receipt and issual of these items. Whereas, Average Pricing averages the price of the item and uses this average price figure while computing the issues and stock balances. Market Pricing involves pricing of all material issues (or stocks) at the prevailing market price at the time of issues (or stock-accounting). It is not very easy to get information on current market prices. Moreover, in a fluctuating price situation, the method of market pricing for issues results in faulty accounting of the stock balances. Standard Pricing avoids the latter problem by having a predetermined (standard) price fixed on the basis of the knowledge of market prices and trends.

For balance sheet purposes, the stock balance needs to be shown at either the market price or the cost price whichever is lower. However, for internal costing purposes, any method may be used. Due to its obvious advantages, standard pricing is widely used with a 'Variation Account' to take care of the difference between the actual purchase price and the standard price.

Stores accounting is an important feedback information for the production and other materials-using departments to assess their own efficiency in material usage. It is also important from the viewpoint of the valuation of the stock-balance and movement at any point of time.

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Stores Arrangement

Proper arrangement and documentation of the storage spaces and storage facilities is helpful in getting materials for production on time as requisitioned from the stores. The arrangement of the racks, shelves, bins, and spaces for movement of material-handling equipment should facilitate quick location, drawal and transporting of the desired materials. The important features of a good stores arrangement are:

(i) Correct knowledge of which particular item exists where;
(ii) Easy accessibility of the items;
(iii) Easy movement of the materials-handling equipment and men;
(iv) Minimal spoilage of the materials in store; and
(v) Proper utilisation of the available stores space.

The store should be so arranged that different types of materials (tubular sheet, heavy materials, bulky materials, small size materials, breakable materials etc.) can be stored in distinct areas.

Bars, tubes, rods, and such lengthy items may be stored in specially designed 'antler racks'. As the name indicates, these are a number of antler type of projections on a vertical frame. The bundle of tubes is held horizontally on the projection or antler. In order to save floor space and use the vertical space, in some cases these long items are stacked vertically. However, the latter type of stacking is not amenable to handling by machines. For plates and sheets of metal, the best form of storage is that of keeping them on the floor itself.

While making the arrangement for gangways, aisles, doors, inlets and exits, ceilings and floors, the material handling equipment used for this purpose should be kept in mind. For example, a gangway of 3′ to 3′6″ between a pair of shelves will be comfortable for an operator with a small hand-truck to collect the material. The main aisle should be wide enough to allow two people with hand-trucks. For fork lift operation, different dimensions may have to be used for the space between two rows of racks.

The location of the material should be appropriately numbered so that locating a location (bin, rack, shelf, etc.) would be easy. Care should be taken to store the same material at the same location and to document the material location.

Stock-taking

This is essential in order to verify the stock records with the actual count. Lacunae in stock-record-keeping and control are, thus checked. Stock-taking is either continuous or periodic. The latter is done once in a year generally, and the stores then have to be closed for the days of stock-taking. The former is done throughout the year in accordance with a predetermined programme. Each item should be physically verified at least once in a year. Advantages of continuous stock-taking are that (i) the normal business of the stores can go on as usual and (ii) more importantly, the discrepancies do not come out all at once as in the annual stock-taking, so there is time to investigate discrepancies thoroughly. However, continuous stock-taking can be done only if complete detailed stock records are kept showing receipts, issues, and balances.

Stores management is the vital and direct link between the production and materials functions. Therefore, it is necessary that adequate attention is paid to the management of stores.

QUESTIONS FOR DISCUSSION

1. How does codification help in standardisation? Explain.
2. When would the 'decimal code' as illustrated below be useful?
   520.2
   520.21
   520.214
3. Is there a difference between Standardisation and Variety Reduction? Discuss.
4. What are the merits of codification, in general?
5. How would you go about installing a new computerised codification system in an organisation? Discuss the steps involved, problems anticipated, if any, and your proposals to overcome these problems.
6. A company is deciding on suitable materials handling equipment for loading and unloading heavy cases. The cases are presently spread or dumped in an irregular manner on the floor. If the alternative handling equipments under consideration are: (a) Mobile Jib Crane, (b) Forklift, and (c) Overhead Crane, how would you help them go about selecting one of the materials handling equipment types?
7. How do codification and standardisation help reduce inventories? Suppose an item is kept in inventory under two separate names. Explain on that basis.
8. Explain the importance of good preservation, packing and marking of the materials.
9. You are asked by your superior to 'look after the problem of scrap'. What will your actions be?
10. Discuss the importance of documentation in Stores Management.

25 Physical Distribution Management

A customer is served by: (a) identifying an existing or potential need of the customer, giving concrete expression and shape to the need through advertising, designing the product, and pricing it; (b) manufacturing the product; and (c) making the product available to the customer at the right place and time, by a proper arrangement of the movements and local storages of the product. Physical Distribution Management function (also called Logistics) is concerned with item (c); in some cases, it also includes the movement of raw materials from the supply source to the manufacturing facility.

Physical Distribution Management (PDM) is the function that helps, in a big way, to provide the time and place utility to the customer. Thus, marketing function and PDM function are closely related to one another. PDM has to provide the desired level of product availability to the customer at lowest cost. In fact, PDM is efficient management of materials, their movement, storage and control—outside the manufacturing plant—which activity concerns the marketing objective of meeting customer demand.

The major job elements or decisions made in PDM are:

1. Optimal location and arrangement of fixed storage facilities such as the warehouses, depots, or supply centres so as to provide the customer/s with the desired product/s. Typical questions to be answered are: How many depots/supply-centres? Of what sizes? Where should they be located?
2. How should different customers be supplied from the different depots/supply-centres?
3. Inventory Control Systems and policies in these depots/supply-centres.
4. Optimal management of the transport/shipment of the product/s. Typical questions to be asked are:
   Which mode of transport?
   — Railway? Truck? Air? Water?
   What quantity and mix of the above?
   Which routes to be chosen for the shipment?
   What is to be the frequency of transport?
   What packaging to use in order to prevent damage during transportation?

All the above decisions are to be taken so that the desired level of service to the customers is provided at the lowest *total cost*. The expression for the total cost of a distribution system may be written as:

$$TDC = TFC + TVC + SFC + SVC + IC + PC$$

where TDC : Total distribution cost
TFC : Fixed costs of transportation
TVC : Variable costs of transportation
SFC : Fixed costs of supply centres
SVC : Variable costs of supply centres
IC : Inventory-related costs
PC : Packaging costs

PDM function has to be viewed in its totality. For instance, if speedy transport is used at higher costs, one may be able to manage with less number of distribution points or depots. If the transport is slow, then one would need more number of depots. If transport is fast, the lead-times are small, and consequently the inventory carrying costs are low. In short, each component of PDM interacts with another.

However, in what follows, analytical techniques will be presented independently for the following major areas of PDM:

(i) Warehouse/Distribution centre location
(ii) Allocation of warehouse capacities to customers' demands
(iii) Vehicle route scheduling

Once again it may be emphasized that all the components of Physical Distribution System interact with another. As long as the reader is aware of this, the independent presentation of the above mentioned reas of decision-making in PDM will help in understanding the implications of each one of them thoroughly.

OPTIMAL LOCATION OF WAREHOUSE

There are analytical methods available for deciding upon warehouse location, with the objective of minimising costs. This 'cost' depends upon the distances between the warehouse and the customers (being supplied by the warehouse) as also on the frequency or the number of loads carried to the customers. The warehouse location problem could be modelled (an analogue model) to a

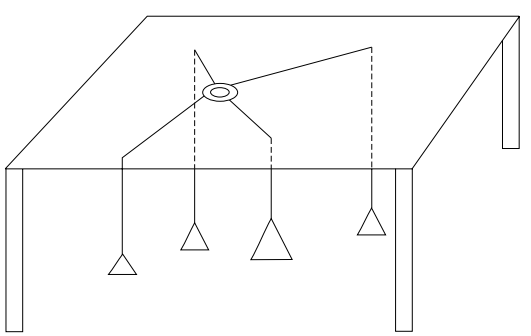


Figure 25.1 Strings and Weights Method for Depot Location

situation where a number of strings are tied to a ring and different weights are attached to the strings. These are all placed on a table in which a number of holes are drilled and strings passed through these holes. The holes correspond to customers' location and the weights correspond to the number of loads carried to the customers (or the weightage given to each customer). Due to the different weights, the ring will experience pulls in different directions and will stabilise at one point. This is the point of minimum potential energy which is analogous to optimal depot location. This method which is illustrated in Fig. 25.1 can also be applied mathematically.

The mathematical expression for the X and Y coordinates of the optimal depot location is given by the following:

$$X = \frac{\sum_{i=1}^{n} \frac{w_i x_i}{d_i}}{\sum_{i=1}^{n} \frac{w_i}{d_i}}$$

and

$$Y = \frac{\sum_{i=1}^{n} \frac{w_i y_i}{d_i}}{\sum_{i=1}^{n} \frac{w_i}{d_i}}$$

where w_i = weightage given to each of the customers,

x_i and y_i = coordinates of the ith customer,

d_i = linear distance between the customer and the depot location.

Proof: Refer to Fig. 25.2.

For equilibrium:

$$\sum w_i \cos \theta_i = 0 \qquad (1)$$

But,

$$x_i = X + d_i \cos \theta_i \qquad (2)$$

Therefore, Eq. (1) becomes:

$$\sum w_i \frac{(x_i - X)}{d_i} = 0$$

i.e.

$$\sum w_i \left(\frac{x_i}{d_i} - \frac{X}{d_i} \right) = 0$$

i.e.

$$\sum \frac{w_i x_i}{d_i} - X \sum \frac{w_i}{d_i} = 0$$

$\therefore$

$$X = \frac{\sum \frac{w_i x_i}{d_i}}{\sum \frac{w_i}{d_i}} \qquad (3)$$

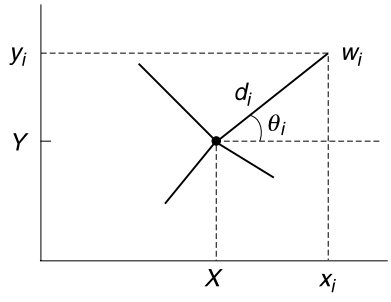


Figure 25.2 Vectors in Strings and Weights Method

Similarly, for equilibrium:

$$\sum w_i \sin \theta_i = 0 \tag{4}$$

Substituting $\sin \theta_i = \dfrac{y_i - Y}{d_i}$,

$$Y = \frac{\sum w_i y_i / d_i}{\sum w_i / d_i} \tag{5}$$

As we can see, in order to use the above formulae one has to know d_i which is the distance between the depot and the customer. Which means, the *initial* depot location should be given in the statement of the problem. This initial depot location then can be revised, the revised distances calculated, and the depot location re-revised. The iterations are carried out until the total 'cost' of transportation from the warehouse to all customers approaches a minimum. This is illustrated in Fig. 25.3.

The initial depot location can be found out by means of another simple method—Centre of Gravity Method. Accordingly, the initial coordinates of the depot location are found by means of the following expressions:

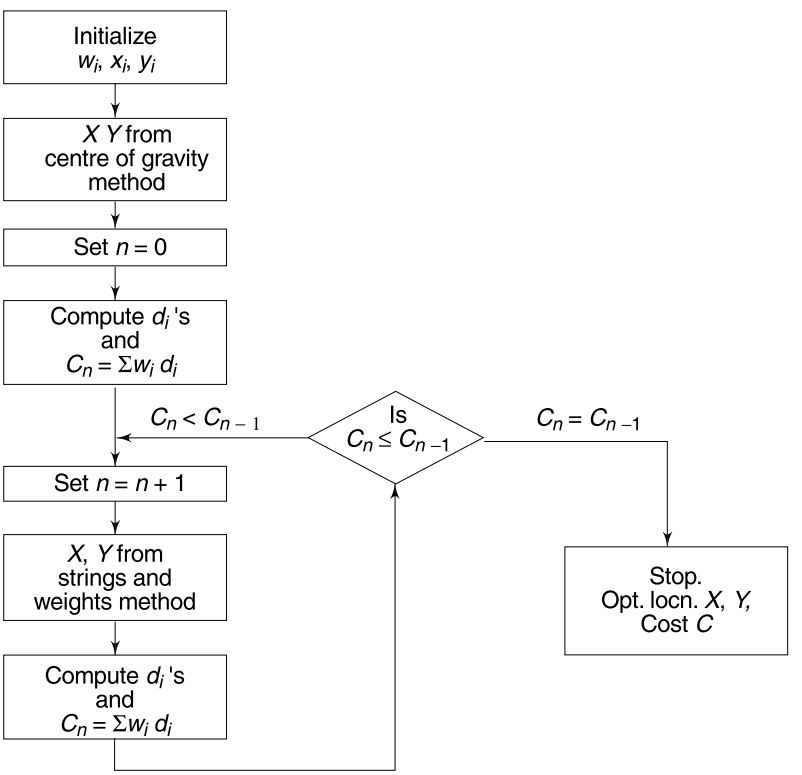


Figure 25.3 Flow Diagram for the Analytical Techniques for Optimal Location of a Warehouse

$$X = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad \text{and} \qquad Y = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} w_i}$$

Example Three customers I, II, III are located at coordinates (0, 0), (0, 2), (3, 0) respectively. The weightages, for these customers, in terms of the frequency of loads carried to them are respectively 2, 3, and 4. The problem is to choose the optimal warehouse depot location.

Solution (See Fig. 25.4.)

The initial depot location can be had by means of the Centre of Gravity method.

$$X = \frac{(2\times 0)+(3\times 0)+(4\times 3)}{2+3+4}$$

$$= 1.333$$

$$Y = \frac{(2\times 0)+(3\times 2)+(4\times 0)}{2+3+4}$$

$$= 0.667$$

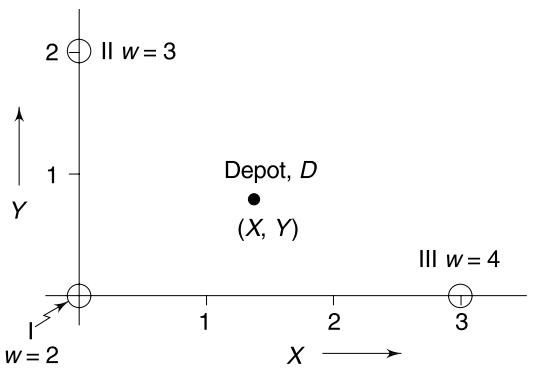


Figure 25.4 Example of Warehouse Location by Strings and Weights Method

From these initial coordinates, we can calculate the individual distances between the customers and the depot. These distances are given by the formula:

$$d_i = \sqrt{\{(X - x_i)^2 + (Y - y_i)^2\}}$$

Therefore,

$$d_{\text{I}} = \sqrt{\{(1.333-0)^2 + (0.667-0)^2\}}$$

$$= \sqrt{(1.777 + 0.445)}$$

$$= \sqrt{(2.213)}$$

$$= 1.491$$

$$d_{\text{II}} = \sqrt{\{(1.333-0)^2 + (0.667-2)^2\}}$$

$$= \sqrt{(3.554)}$$

$$= 1.885$$

$$d_{\text{III}} = \sqrt{\{(1.333-3)^2 + (0.667-0)^2\}}$$

$$= \sqrt{(3.223)}$$

$$= 1.795$$

The total cost of transportation is given by

$$C = \sum_{i=1}^{III} w_i d_i$$

$$= (2 \times 1.491) + (3 \times 1.886) + (4 \times 1.795)$$

$$= 15.817$$

Having got the initial depot location and the distances between the depot and the customers, we can now use the formula of the strings and weights method for a refined estimate of the depot location. The new values of the coordinates of the depot location are as follows:

$$X = \frac{\frac{2 \times 0}{1.491} + \frac{3 \times 0}{1.885} + \frac{4 \times 3}{1.795}}{\frac{2}{1.491} + \frac{3}{1.885} + \frac{4}{1.795}}$$

$$= \frac{6.693}{(1.341 + 1.592 + 2.228)}$$

$$= \frac{6.685}{5.161}$$

$$= 1.295$$

and

$$Y = \frac{\frac{2 \times 0}{1.491} + \frac{3 \times 2}{1.885} + \frac{4 \times 0}{1.795}}{\frac{2}{1.491} + \frac{3}{1.885} + \frac{4}{1.795}}$$

$$= \frac{3.181}{5.164}$$

$$= 0.617$$

The distances are recomputed and used to compute revised cost of transportation, as follows:

$$d'_{I} = \sqrt{(1.295 - 0)^2 + (0.617 - 0)^2}$$

$$= \sqrt{1.677 + \frac{0.381}{2.058}}$$

$$= 1.435$$

$$d'_{II} = \sqrt{(1.295 - 0)^2 + (0.617 - 0)^2}$$

$$= \sqrt{1.677 + \frac{1.913}{3.590}}$$

$$= 1.895$$

$$d'_{III} = \sqrt{(1.295-3)^2 + (0.617-0)^2}$$

$$= \sqrt{\begin{array}{r} 2.904 \\ +\,0.379 \\ \hline 3.288 \end{array}}$$

$$= 1.813$$

$$\text{Cost } C' = \sum_{i=1}^{III} w_i d_i$$

$$= (2 \times 1.435) + 3(1.895) + 4(1.813)$$

$$= \begin{array}{r} 2.870 \\ +\,5.685 \\ +\,7.252 \\ \hline 15.807 \end{array}$$

We see that there has been small change in the total cost and therefore we may have approached the optimal location. Let us try the next iteration and find out if this is really so.

Second Iteration Based on the distances obtained during the last iteration, the revised depot location may therefore be as follows (by means of the Strings and Weights method):

$$X'' = \frac{\dfrac{12}{1.813}}{\dfrac{2}{1.435} + \dfrac{3}{1.895} + \dfrac{4}{1.813}}$$

$$= \frac{6.619}{\left(\begin{array}{r} 1.394 \\ +\,1.583 \\ +\,2.205 \\ \hline =\,5.183 \end{array}\right)}$$

$$= 1.277$$

$$Y'' = \frac{\left(\dfrac{6}{1.895}\right)}{(5.183)}$$

$$= \frac{3.166}{5.185}$$

$$= 0.611$$

Therefore, $$d''_I = \sqrt{\left(1.277-0\right)^2 + \left(0.611-0\right)^2}$$

$$= \sqrt{+\frac{1.631}{\frac{0.373}{2.004}}}$$

$$= 1.416$$

$$d''_{II} = \sqrt{(1.277-0)^2 + (0.611-2)^2}$$

$$= \sqrt{1.631 + (1.389)^2}$$

$$= \sqrt{1.631 + 1.929}$$

$$= \sqrt{3.560}$$

$$= 1.187$$

$$d''_{III} = \sqrt{(1.277-3)^2 + (0.611-0)^2}$$

$$= \sqrt{(1.723)^2 + (0.611)^2}$$

$$= 1.828$$

$$\text{Cost } C'' = \sum_{i=1}^{III} w_i d_i$$

$$= 2 \times 1.416 + 3 \times 1.887 + 4 \times 1.828 = 15.804$$

Subsequent iterations yield the following results:

Iteration No.	*Coordinates*		*Cost*
	X	*Y*	
3	1.265	0.612	15.800
4	1.255	0.615	15.799
5	1.247	0.618	15.799

We see that further iterations will not make any material change in the total cost. The coordinates of the depot location are, therefore, (1.247, 0.618).

As seen above, five iterations were enough to find the optimum location. But, with many other situations, with each iteration, the depot location and the distances will change noticeably as also the total cost of transportation. After a number of iterations we may reach a stage where further iterations will not make a significant change in the costs of transportation. The warehouse location for this last iteration will be the ideal location.

Although the analytical method described above gives the so-called optimal location, it needs to be weighed and tempered in terms of other factors (similar to those described in Chapter 31) as well, which are of great practical significance. Some of these factors are the special regional problems, in terms of geography, in terms of the people residing in and around the area, the climatic and weather conditions, the availability of space, etc.

As mentioned earlier, the total costs of warehousing are in fact (a) the transportation cost, (b) the fixed cost of the warehousing, (c) the variable operating cost of warehousing, and (d) the in-

ventory cost of storing and handling the material. All these costs should enter into a really optimal analysis for the location of a warehouse or depot. In some cases, where the decision is regarding the location of a number of warehouses, the cost of lost sales for not having located a warehouse have also to be included (in addition to the other elements of costs mentioned above).

TRANSPORTATION PROBLEM

The other aspect of the warehousing problem concerns the allocation of goods demanded by different customers through different warehouses. A customer need not necessarily be serviced by one warehouse but by a combination of a number of warehouses depending upon the availability of the goods in the warehouses, the demand for the goods, and the transportation costs for the shipment of the goods. This problem is different from the facility location problem described above; it is concerned only with the allocation of the demanded services to different warehouses. The locations of the warehouses and therefore the costs of transporting a unit load of goods to a customer are already given. In operations research this problem is referred to as the Transportation Problem. The example below brings out the salient features of a transportation problem.

Example Umesh Kantilal & Co. has three warehouses in Hosur, Coimbatore and Salem where the stocks of particular commodity are available to the extent of 300, 300, and 500 tonnes respectively. Three customers, in Tumkur, Mysore and Bangalore whose monthly requirements for the item are respectively 240 tonnes, 480 tonnes and 380 tonnes are to be serviced through these three southern region warehouses.

The costs (per tonne) of shipping would be as presented in the table below:

	Customer		
Warehouse	*Tumkur*	*Mysore*	*Bangalore*
Hosur	Rs. 100	Rs. 200	Rs. 50
Coimbatore	Rs. 160	Rs. 60	Rs. 200
Salem	Rs. 180	Rs. 120	Rs. 90

How much of the item should be supplied by each warehouse to each customer? Find a solution minimising the total shipping costs, considering the availability of the item in the cities Hosur, Coimbatore and Salem and the requirements of the item in Tumkur, Mysore and Bangalore.

Solution The transportation problem is expressed in a matrix fashion as shown in Fig. 25.5. Note that the respective quantities required by customers in Tumkur, Mysore, Bangalore (city 1, 2 and 3) and the respective stocks available at Hosur, Coimbatore, Salem (warehouse 1, 2 and 3) are shown along with the total of 1100 tonnes. Within the squares (all the 9 different combinations of 11, 12, 13, etc.) small rectangles are drawn within which corresponding transportation costs per tonne are shown. The problem is to assign various quantities to each of these 9-different slots (squares), i.e. to decide from which warehouse to send how much quantity to any customer, such that the total of these costs of transportation is minimum. The availabilities, requirements and the interpoint transportation costs are the data supplied to any transportation problem. The matrix of these data is given in Fig. 25.5.

From \ To	1	2	3	Available quantities
1	100	200	50	300
2	160	60	200	300
3	180	120	90	500
Required quantities	240	480	380	Total 1100 / Total 1100

Figure 25.5 Statement of the Transportation Problem

As one may notice, any feasible (not necessarily minimum total cost, i.e. optimal) solution will have to satisfy the following availability and requirements equations (x_{ij} represents shipping quantity from warehouse i to customer j):

$$\begin{aligned}
x_{11} + x_{12} + x_{13} &= 300\\
x_{21} + x_{22} + x_{23} &= 300\\
x_{31} + x_{32} + x_{33} &= 500\\
x_{11} + x_{21} + x_{31} &= 240\\
x_{12} + x_{22} + x_{32} &= 480\\
x_{13} + x_{23} + x_{33} &= 380
\end{aligned}$$

(all $x_{ij} \geq 0$ where $i = 1, 2, 3$ and $j = 1, 2, 3$)

Actually, the first five equations are sufficient since the last equation can be derived from them. (In general, one can say that if m represents the number of rows and n the number of columns, then a basic feasible solution of a transportation problem has only $m + n - 1$ positive components.)

The optimal solution would require that the total costs of the transportation are minimum. We can write the objective function as follows.

Minimise $TC = c_{11}x_{11} + c_{12}x_{12} + c_{13}x_{13} + c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} + c_{31}x_{31} + c_{32}x_{32} + c_{33}x_{33}$

where c_{ij} = cost of shipping a unit quantity from warehouse i to customer j.

The optimal solution to the transportation problem is approached through three basic steps:

(i) Find a feasible initial solution. As mentioned earlier, the feasible solution will have $m + n - 1$ shipping assignments, i.e. $m + n - 1$ *occupied cells* in the transportation matrix.

(ii) Next, check to see whether the initial solution obtained is indeed the desired optimal solution. This is done by evaluating the opportunity costs associated with the empty cells (i.e. shipping assignment possibilities forgone).

If the opportunity costs of all empty cells are non-positive then the optimal solution has indeed been reached, whereas, if even one empty cell has positive opportunity cost then we must proceed towards step (iii).

(iii) Find another feasible solution which will achieve the objective better than the earlier solution. Repeat steps (ii) and (iii) till you find an optimal solution.

For finding the initial feasible solution, we shall use a method called Vogel's Approximation Method (VAM). There are some other methods also available, such as

(a) North-West Corner Rule

(b) Assignment by Inspection

VAM usually gives an initial feasible solution which is quite near optimal, if not optimal.

Vogel's Approximation Method

Vogel's method consists of the following steps which are illustrated below for the above example:

Step 1: We compute the penalties for the rows and columns. Penalties are defined as the difference between the lowest cost value and the second lowest cost value in any row or column. The 'penalty' is for not using the cheapest route for such origin and destination. The penalties computed for our example are as follows:

				Penalty
Row 1	—	50	…	(100 – 50 = 50)
Row 2	—	100	…	(160 – 60 = 100)
Row 3	—	30	…	(120 – 90 = 30)
Column 1	—	60	…	(160 – 100 = 60)
Column 2	—	60	…	(120 – 60 = 60)
Column 3	—	40	…	(90 – 50 = 40)

The transportation matrix with the penalties is shown in Fig. 25.6.

Step 2: Select the row or column with the largest penalty. In this row/column, assign as large a quantity as possible to the cell having lowest cost.

We observe that row 2 has the highest penalty and cell 22 has the lowest cost in that row. We assign the largest possible quantity to this cell which will be 300 tonnes.

Step 3: After having made the assignment, cross out that row/column completely satisfied by the assignment. Therefore, row 2 is crossed out in our example.

Step 4: Repeat steps 1, 2 and 3 for the remaining rows and columns.

Cust. → / W.H. ↓	1	2	3	Available	
1	100	200	50	300	50
2	160	60	300	300	100
3	180	120	90	500	30
Required	240	480	380	1100 / 1100	
	60	60	40	← Penalties	

Figure 25.6 Transportation Matrix with Initial Penalties

Figure 25.7 gives the revised penalties. The tie is broken arbitrarily and column 2 is selected. Cell 32 is assigned 180 tonnes which is the maximum possible under the rim condition for column 2.

Column 2 which is satisfied completely, is also crossed out and penalties recalculated for the remaining cells (see Fig. 25.8).

Accordingly row 3 is selected and 320 tonnes assigned to Cell 33 satisfying the availabilities of row 3 completely.

This gives the initial feasible solution by VAM shown in Fig. 25.9. (NOTE: There are $m + n - 1 = 5$ assignments.)

	1	2	3	Available	
1	100	200 X	50	300	50
2	160 X X	60 300	200 X X	300	
3	180	120 180	90	500	30
Required	240	480	380	1100	
	80	80	40	Penalties	

Figure 25.7 Revised Penalties after One Assignment

	1	2	3	Available	
1	100		50	300	50
2		300		300	
3	180	180	90 320	500	90
Required	240	480	380	1100 1100	
	80		40	Penalties	

Figure 25.8 Revised Penalties after Second Assignment

Cust. → / W.H. ↓	1	2	3	Available
1	240		60	300
2		300		300
3		180	320	500
Required	240	480	380	1100 / 1100

Figure 25.9 Initial Solution Obtained by Vogel's Approximation Method

The next step in the solution to the transportation problem is to test the initial feasible solution for optimality. If it is not optimal, then a better (and feasible) solution needs to be found.

Modified Distribution Method (MODI)

Modified Distribution Method (MODI) is quite efficient for these purposes. There is one more method called Stepping Stone Method, but for our example only MODI will be presented. The procedure for this is as follows:

(a) The dual variables or dummy costs (it will be clear soon what these are) are calculated in such a way that for all assigned cells, the following relationship holds good:
$R_i + K_j = C_{ij}$ K (where R_i is the *dummy cost* for row *i*, and K_j is the *dummy cost* for column *j*.)
C_{ij} refers to the cost figures for transportation (per unit tonne) given in the rectangles within the squares. One of the values of the dummy costs (also called dual variables) has to be arbitrarily assigned equal to zero.
For our example, let us assign $R_1 = 0$

Since

$$R_1 = 0 \text{ and } C_{11} = 100, \quad \therefore K_1 = 100$$
$$R_1 = 0 \text{ and } C_{13} = 50, \quad \therefore K_3 = 50$$
$$K_3 = 50 \text{ and } C_{33} = 90, \quad \therefore R_3 = 40$$
$$R_3 = 40 \text{ and } C_{32} = 120, \quad \therefore K_2 = 80$$
$$K_2 = 80 \text{ and } C_{22} = 60, \quad \therefore R_2 = -20$$

(b) The next step is to calculate, for each of the unassigned cells, the value of $(R_i + K_j - C_{ij})$ which is the opportunity cost. If all these values are negative then the initial feasible solution obtained is optimal. But if any one or more of the values is positive (+ ve), then follow the next step, i.e. step (c).

For our example we have the following for the unassigned cells

Cell 12: $R_i + K_j - C_{ij}$

$$= 0 + 80 - 200 = -120$$

$$\text{Cell 21: } -20 + 80 - 160 = -100$$
$$\text{Cell 23: } -20 + 50 - 200 = -170$$
$$\text{Cell 31: } 40 + 100 - 180 = -40$$

Since all the empty cells have non-positive opportunity costs, the initial feasible solution found by Vogel's Method is optimal.

Suppose the initial feasible solution was found by the Inspection Method by looking at the shipping cost values in each cell (see Fig. 25.10). Let us analyse:

MODI *Step (a):* Compute dual variables.

$$R_1 = 0, \quad C_{13} = 50, \quad \therefore K_3 = 50$$
$$K_3 = 50, \quad C_{33} = 90, \quad \therefore R_3 = 40$$
$$R_3 = 40, \quad C_{32} = 120, \quad \therefore K_2 = 80$$
$$K_2 = 80, \quad C_{22} = 60, \quad \therefore R_2 = -20$$
$$R_3 = 40, \quad C_{31} = 180, \quad \therefore K_1 = 120$$

MODI *Step (b):* Compute opportunity costs for empty cells.

$$\text{Cell 11: } R_1 + K_1 - C_{11} = 0 + 120 - 100 = +20$$
$$\text{Cell 12: } R_1 + K_2 - C_{12} = 0 + 80 - 200 = -120$$
$$\text{Cell 21: } R_2 + K_1 - C_{21} = -20 + 120 - 160 = -60$$
$$\text{Cell 23: } R_2 + K_3 - C_{23} = -20 + 50 - 200 = -170$$

The initial solution found by the Inspection Method is not optimal, since one of the opportunity cost value is positive.

Therefore we move on to step (c).

MODI *Step (c):* Starting from any one of the positive opportunity cost cells to be filled, draw a closed circuit path going back to that particular cell in such a way that

(i) only at the assigned (occupied) cells the path may turn at right angles;
(ii) the path may skip occupied as well as empty cells;

Cust. → / W.H. ↓	1	2	3	Available
1	100	200	50 300	300
2	160	60 300	200	300
3	180 240	120 180	90 80	500
Required	240	480	380	1100 / 1100

Figure 25.10 Initial Feasible Solution by Inspection Method

(iii) only horizontal and vertical movements are made; and
(iv) there will be one and only one such closed circuit.

Having drawn the closed circuit path, place a plus (+) sign at the cell to be filled, a minus (–) sign at the next cell where the path turns at the corner and alternate these signs at every turn of the path.

Of the cells having the minus (–) sign, select the one with the least number of items. Transfer all these items to the cell to be filled. This is done by adding the amount to the cells having + sign and subtracting from those having – sign.

Repeat steps (b) and (c) until optimality is achieved.

For our example:

Cell 11 has positive opportunity cost. The closed circuit path is drawn from Cell 11 as shown in Fig. 25.11.

Cust. / W.H.	1	2	3	Available
1	+ →		– 300	
2	↑	300	↓	
3	– 240	180	+ 80	
Required				

Figure 25.11 Closed Circuit Path

Making the transfers, we have (NOTE: the smallest of the – ve sign cells, namely cell 31 is emptied) the solution given in Fig. 25.12.

This solution is the same as that obtained by Vogel's Method and is optimal as already found earlier.

Cust. → / W.H. ↓	1	2	3	Available
1	240		60	300
2		300		300
3		180	320	500
Required	240	480	380	1100 / 1100

Figure 25.12 Final Solution

PROBLEM OF ROUTE SCHEDULING

Another problem encountered in logistics is that of scheduling the route a vehicle should take from the supply warehouse/depot to the various customers. There are usually constraints of the form: (1) the amount of mileage that a vehicle can perform in a day, (2) it has to come back to the depot at the end of the day, or (3) the amount of load that the vehicle can carry at a time, etc. With a limited number of vehicles available, the choice of an appropriate route to supply the various customers with the required quantity of goods becomes a problem to be investigated. The vehicle route chosen should optimally be such as not to exceed the daily mileage limitation and the total load carried by the vehicle and at the same time the total mileage should be minimum. There are some vehicle scheduling routines available which design feasible routes under the above mentioned restrictions.

Savings Criterion

Before we proceed with the illustration of one such procedure, we must note that in such scheduling routines the common sense criterion is that of minimising (or saving as much as possible) the distance travelled by the vehicle. During the early 1960s, Fletcher, Clark and Wright presented some simple-looking observations:

1. If customers X and Y are to be served from depot D, by linking the two points X and Y, the savings (in travel) generated can never be negative (– ve). See Fig. 25.13.

Savings by joining X and Y

$$= (2x + 2y) - (x + d + y)$$

$$= x + y - d$$

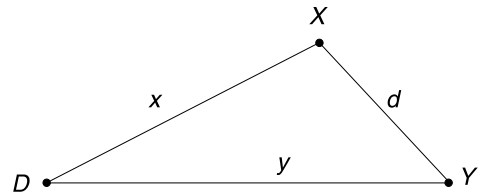


Figure 25.13 Savings by Linking Two Points

The two sides of a triangle always add up to more than the third side, and therefore the savings generated by joining the two customer points in the route are always positive (+ ve) or at the least zero (savings will be zero when the points X and Y are on the same radial line from depot D).

2. The savings are always additive, which means, if another customer point Z was to be added to the route, by making the route $D - X - Y - Z - D$, the savings generated by the earlier linking of X and Y and the saving generated by linking Y and Z add up to the total savings by the route linking all the three customers. See Fig. 25.14.

Savings $= (2x + 2y + 2z) - (x + d + d' + z)$

$= x + 2y + z - d - d'$

$= (x + y - d) + (y + z - d')$

$=$ (Savings by linking X and Y) + (Savings by linking Y and Z)

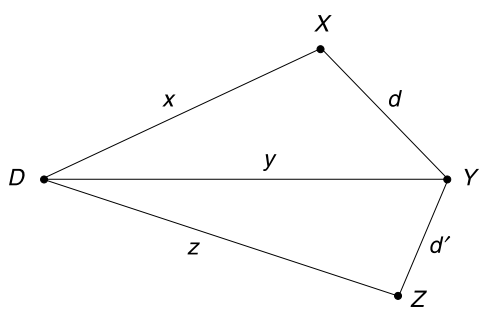


Figure 25.14 Additivity of Savings

3. Links between points on the circumference provide more saving than by linking points on the radius from the depot. See Fig. 25.15.

Savings by linking points X and Y on the circumference

$$= (2y + 2y) - (y + d + y) = 2d' + d$$

Savings by linking points X and Y' (at the same distance d) on the radius

$$= (2y + 2d') - (y + d + d') = 2d'$$

Therefore, savings are greater by linking points on the circumference.

The savings criterion of Fletcher et al., therefore implies that the vehicle routes should be so designed as to include as many customer-points on the circumference as possible. The vehicle should originate from the centre (the depot) so to say and cover as many customer-points on the circumference (something resembling a circumference, or points which are not on the radial line) as possible and come back to the depot making the route resemble a flower petal in contour as shown in Fig. 25.16.

Let us apply the savings criteria described above to an illustrative problem presented below:

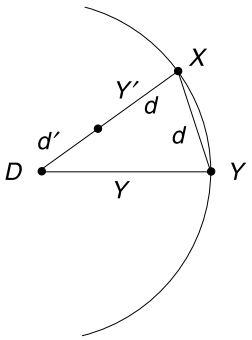


Figure 25.15 Linking Points on Circumference Versus those on Radius

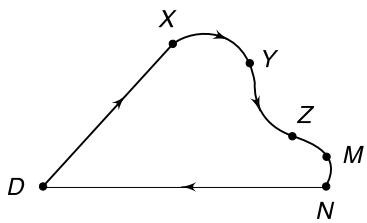


Figure 25.16 Fletcher et al., Savings Criterion for Vehicle Routing

Example Seven customers are to be serviced by a warehouse/depot. The distances between the depot and the customers, and between the different customers are all known and are shown in the matrix given in Fig. 25.17.

	0						
1	11	1					
2	16	11	2				
3	9	7	8	3			
4	10	8	14	10	4		
5	10	13	2	9	13	5	
6	19	9	15	13	10	16	6
7	2	10	11	4	9	7	18

Distance

Figure 25.17 Various Inter-point Distances

NOTE 1: '0' refers to the warehouse; 1, 2, 3, …, 7 refer to the customer locations.

NOTE 2: *Explanation of the matrix*
The distance between 0 (warehouse) and 1 (customer 1) is 11 km.
The distance between 3 (customer 3) and 5 (customer 5) is 9 km, etc.

	0						
1	0	1					
2	0	16	2				
3	0	13	17	3			
4	0	13	12	9	4		
5	0	8	24	10	7	5	
6	0	21	20	15	19	13	6
7	0	3	7	7	3	5	3

Figure 25.18 Various Inter-point 'Savings'

There are only two vehicles available and the vehicles can travel a maximum of 40 km in a day, at the end of which they have to be back at the depot.

What are the feasible vehicle routes?

Solution The first step is to compute the 'savings' for all the pairs of customers and express the savings in a matrix similar to that in Fig. 25.17 for showing the distances. For example, the savings by joining the pair of customers 5 and 7 is (10 + 2 – 7) = 5. Such figures are calculated for all possible pairs between the 7 customers. See Fig. 25.18.

Now, the 'savings' are ranked. The maximum savings are given the rank of No.1, the next best savings are given the rank of No. 2 and so on, and a matrix (Fig. 25.19) is constructed (similar to that in Figs 25.17 and 25.18).

According to the rank given in Fig. 25.19 each link (pair) is considered in constructing a route for a vehicle. The total distance of travel for such a route is computed which is checked against the maximum feasible distance of 40 km. If the restriction is satisfied, the route is feasible, and it becomes one of the actual routes scheduled. This procedure does not rule out the refinement of the feasible route found out earlier if another link can be added to the route without exceeding the given constraints. The point to be noted is a that we proceed as per the rank give in Fig. 25.19.

	0						
1	—	1					
2	—	6	2				
3	—	8	5	3			
4	—	9	11	13	4		
5	—	14	1	12	17	5	
6	—	2	3	7	4	10	6
7	—	19	15	16	20	18	21

Figure 25.19 Ranks of the Savings

This procedure applied to the given problem is shown below:

Rank	*Link*	*Route (Component links)*	*Distances of the Component Links, and the Total*	*Total Distance ≤ 40?*	*Actual Route*
1	2 – 5	0 – 2	16		
		2 – 5	2 } 28	Yes	0 – 2 – 5 – 0
		5 – 0	10		

(contd.))

NOTE This 0–2–5 – 0 becomes one of the feasible routes. This may be modified to include another link later if found to be feasible. We proceed to the next rank.						
2	1 – 6	0 – 1 1 – 6 6 – 0	11 9 19	39	Yes	0 – 1 – 6 – 0
NOTE Therefore, 0 – 1 – 6 – 0 becomes one other feasible route. The next link is 2 – 6 (Rank 3). We try linking up the earlier found two routes by means of this link. As shown below, this is not feasible.						
3	2 – 6	0 – 5 5 – 2 2 – 6 6 – 1 1 – 0	10 2 15 9 11	47	No	——
NOTE So far we have covered only customers 1, 2, 5 and 6. We have only two vehicles and have not covered customers 3, 4 and 7. We hope to add some more links to the above two routes or find alternative routes as we proceed with our procedure.						
4	4 – 6	0 – 1 1 – 6 6 – 4 4 – 0	11 9 10 10	40	Yes	0 – 1 – 6 – 4 – 0
NOTE It is possible to link up 4 – 6 with the earlier found link of 1 – 6.						
5	2 – 3	0 – 3 3 – 2 2 – 5 5 – 0	9 8 2 10	29	Yes	0 – 3 – 2 – 5 – 0
NOTE Thus the link 2 – 3 can be added to link 2 – 5. The two feasible routes 0 – 3 – 2 – 5 – 0 and 0 – 1 – 6 – 4 – 0 have covered all customers expect customer no. 7. Therefore, we skip the other ranks and go to the link 2 – 7 (rank 15, which is the lowest rank for a link with customer no. 7). But it cannot be added to any of the earlier found routes (it short circuits the path 0 – 3 – 2 – 5 – 0). Hence, we go over to the next lower rank which includes customer 7. It is link 3 – 7 with a rank of 16.						
16	3 – 7	0 – 7 7 – 3 3 – 2 2 – 5 5 – 0	2 4 8 2 10	26	Yes	0 – 7 – 3 – 2 – 5 – 0

The feasible routes have therefore covered all the customer points, and since the order in which the links were considered depended upon their savings potential, we need not consider other possible routes. Therefore, our feasible rotues are 0 – 1 – 6 – 4 – 0 and 0 – 7 – 3 – 2 – 5 – 0. The total distance covered will be only 62 km for the two routes combined.

This was a simple example where the routes could be found by going through only 6 ranks. But even if it had been a more complex problem the reader should not have much difficulty in going through different ranks until all the ranks are exhausted. Sometimes, under the given constraints, feasible routes cannot be found and in such cases the constraints have to be relaxed.

Many vehicle-scheduling problems are also solved by a network representation of the warehouse-depot and the customer points. In operations research literature many different problems of physical distribution are discussed. But the purpose of this book is only to introduce the reader to a few of these problems and solutions so as to generate the reader's interest.

The number of iterations encountered in the solution of the mathematical models of the problems of Physical Distribution Management, and the complexities involved when the practical considerations are included, can be handled by the use of computers. Some of the renowned computer companies such as ICL (ICIM in India, now Fujitsu) and IBM have come up with Application Packages such as XUVS, VSPX, SCAN and IMPACT.

LOGISTICS MANAGEMENT AND ITS LINKS WITH INVENTORY CONTROL AND OTHER AREAS

The scope of logistics management is wider than just optimising transportation costs. Decisions about logistics have their effect on inventories, on packaging, on materials handling and on purchasing and marketing (sales) decisions, and vice versa.

For instance, what is the point in producing small (but) economic batch quantities when the distribution facility dictates that a number of these batches should be accumulated before they can be shipped to the customers? Instead of carrying inventory inside the plant, one will carry it outside in the warehouse.

Moreover inventory control decisions have to take into account the inventories 'in transit' or 'in the pipeline'. The latter depends much on the transport facilities or logistics decisions regarding transport.

Decisions regarding the number of warehouses, their location, the number of customers serviced by each, etc. will have effects on inventory levels to be held at each warehouse.

Also, depending upon the transport activity envisaged, the number of warehouses and the inventory levels can be lower or higher. With more volume of transportation and a quicker mode of transportation, one may be able to manage with smaller investment in warehousing for the same level of service to the customers.

Decisions about the mode of packaging depend on the mode of transport, and the converse also is true. Quantities to purchase, quantities to sell, time of purchase and time of sales are all well linked with the decision regarding the transport and bulk storage of materials.

In short, the organisation's goal is to provide good service to the customers—in terms of quantity, quality, timely delivery—and therefore various aspects such as inventory control, service levels, package design, warehousing (capacity, number location), the mode, frequency and routes of transport will all have to be considered. Thus, Logistics is an integral part of the materials management system.

SUPPLY CHAINS AND PHYSICAL DISTRIBUTION MANAGEMENT (PDM)

The organisation's objective of providing service to the customer would be better served if the organisation realises the essential 'supply chain' aspect of today's business. Physical distribution function has a big role to play in the efficiency of the supply chain as this function is at one interface between the supplying and receiving organisations. PDM should result in optimality for the chain as a whole.

Of course, the ideal situation is the one where the inventories carried in any part or location on the supply chain should be minimal. That is, they should be minimal while being optimal for the entire chain and near-optimal (if optimality is not possible) for the different members on the supply chain. This requirement for optimality or near-optimality suggests that the material supplies in the pipeline, i.e. those that are on the trucks or in the goods train or other transportation mode, should be small in quantity. It means, the materials should land 'Just-in-Time' at the point of use and should not lie in large quantities at any point. The task before PDM is to make deliveries / pick-ups in small quantities that are economical to the transport service provider. All this flows from the supply chain concept.

Making Frequent Small Deliveries / Pick-ups That are Economical

This is feasible in two ways:

1. The distance between the supplier and the receiver (buyer) should be short. This would help in minimising the time spent in travel and would cut down the travel time related costs. However, most of the times it is not possible to find suppliers who are only a short distance away and who also meet the other criteria such as quality production, capability to produce enough quantity and price economy. This is similar to asking for a cow that yields much milk per season, the season lasting long, and one that has short horns which do not hurt. Since such a breed of a cow may not exist, the cow has to be genetically engineered or developed.

   Companies having the Just-in-Time system, therefore develop or prepare their suppliers from the small area surrounding the company—most of the time within a radius of 40 kilometers. This involves a yeoman effort on the part of the company—selecting, training and nurturing the locally available talent.

   Kirloskar Copeland, a company manufacturing compressors for the air-conditioners and refrigerators, has been using Just-in-Time principles and expects Just-in-time deliveries from its suppliers. The company has its plant in Karad—a small town far from the major industrial areas, and hence has a programme to develop suppliers locally from in and around Karad. The development is multifold— entrepreneurship, technical capabilities, plant infrastructure, employee (supplier's) development and managerial capabilities.
2. The trucking company (or the supplier company) has the truck full during these frequent and small deliveries / pick-ups. This requirement can only be fulfilled if the truck collects shipments from several suppliers / customers on its journey. This can be done in a few different ways:
   (a) *Multiple customers to a single supplier*
   The supplier makes deliveries to multiple customers. In other words, the truck gets the items from one supplier and makes deliveries to a number of customers in a short loop.
   (b) *Multiple customers and multiple suppliers*
   The truck is filled from a string of suppliers and the makes deliveries to a string of customers, all in a short loop so that the entire journey is completed in a short time.
   (c) *Multiple suppliers to a single customer*
   The truck is filled from a string of suppliers and makes delivery to a lone customer.
   These alternatives are depicted in Fig. 25.20.

Supply chain logic helps logistics in terms of keeping the number of transit points to a minimum. Because, the number of suppliers is kept to the minimum and these are as close to the buyer as possible. However, the deliveries would have to be made more frequently in small batches and without fail. 'Make it right first time, all the time' principle of quality management applies equally well to PDM function. In the supply chain context, the supplier–buyer–logistics provider relationships are commitments for a very long time. This puts additional moral and self-correcting responsibility on the logistics provider. Without constant improvements in PDM, the benefits of the cost economies, speediness, timeliness, flexibility and agility gained in the buyer-and-supplier organisations would experience impediments. B2B e-commerce may be achieved on the computer with the click of the mouse, but ultimately it has to be realised physically. Physical distribution management has a yeoman responsibility to 'deliver the goods', literally. Internet technology and its use in business are going ahead at a rapid pace. It would, therefore, be imperative for the PDM function to transform itself to match the pace of these developments.

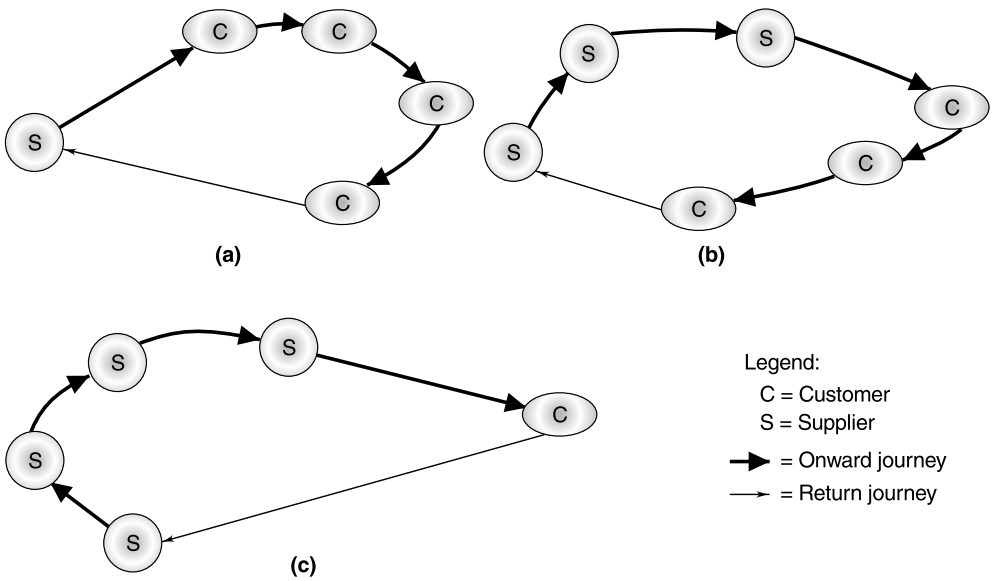


Figure 25.20 Strategies to Keep Truck/Train Full while Allowing Small and Frequent Consignments (Adapted from Nicholas, John M., *Competitive Manufacturing Management*, McGraw-Hill, New York, 1998)

SOLVED PROBLEMS

1. Under the Food Security Act, grains and other food articles are to be distributed free of cost to the poor population. State government is planning for a godown that would service the areas of Airoli (A), Belapur (B), Charkop (C) and Digha (D) located at x-y coordinates of (4,1), (1.3), (2,4) and (3,2) and with a poor population of 10000, 20000, 15000 and 5000, respectively.

Carry out the procedure for finding an optimal location by Strings and Weights method. While doing so, find an initial location by Center of Gravity method.
Show the first three iterations for the Strings and Weights method.

Answer

Step 1: Location by Center of Gravity method.
The population of the poor (in '000) in an area constitutes the weight corresponding to that area.
The coordinates of the godown are:

$$X = \sum_{i=1}^{n} w_i x_i / \sum_{i=1}^{n} w_i = (10 \times 4 + 20 \times 1 + 15 \times 2 + 5 \times 3)/(10 + 20 + 15 + 5) = 105/50 = 2.10$$

$$Y = \Sigma w_i y_i / \Sigma w_i = (10 \times 1 + 20 \times 3 + 15 \times 4 + 5 \times 2)/(10 + 20 + 15 + 5) = 140/50 = 2.80$$

Step 2: Calculation of the distances between the customers (areas given above) and the godown location.

$$D_A = \sqrt{[(2.10-4)^2 + (2.80-1)^2]} = \sqrt{(3.61+3.24)} = 2.617$$

$$D_B = \sqrt{[(2.10-1)^2 + (2.80-3)^2]} = \sqrt{(1.21+0.04)} = 1.118$$

$$D_C = \sqrt{[(2.10-2)^2 + (2.80-4)^2]} = \sqrt{(0.01+1.44)} = 1.204$$

$$D_D = \sqrt{[(2.10-3)^2 + (2.80-2)^2]} = \sqrt{(0.81+0.64)} = 1.204$$

Total "cost" of transportation = $\Sigma w_i d_i$

$$= (10 \times 2.617 + 20 \times 1.118 + 15 \times 1.204 + 5 \times 1.204)$$

$$= 26.17 + 22.36 + 18.06 + 6.02 = 72.61$$

Step 3: Use strings and weights method for a refined estimate of godown location.
First iteration
The X and Y coordinates of the godown location are given by

$$X = \frac{\sum_{i=1}^{n} w_i x_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$$= [(10 \times 4/2.617) + (20 \times 1/1.118) + (15 \times 2/1.204) + (5 \times 3/1.204)]/ (10/2.617 + 20/1.118 + 15/1.204 + 5/1.204)$$

$$= [15.285 + 17.89 + 24.92 + 12.46]/(3.821 + 17.89 + 12.46 + 4.153)$$

$$= 70.555/38.32 = 4\ 1.841$$

$$Y = \frac{\sum_{i=1} w_i y_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$= [(10 \times 1/2.617) + (20 \times 3/1.118) + (15 \times 4/1.204) + (5 \times 2/1.204)]/$
$(10/2.617 + 60/1.118 + 15/1.204 + 5/1.204)$
$= [3.821 + 53.67 + 49.83 + 8.31]/(3.821 + 17.89 + 12.46 + 4.153)$
$= 115.63/38.324$
$=3.017$

The coordinates, after the first iteration, are: (1.841, 3.017).

Repeat Step 2:

Distances of the godown location from the recipient areas are as follows.

$$D_A = \sqrt{[(1.841-4)^2 + (3.017-1)^2} = \sqrt{(4.661+4.068} = 2.955$$

$$D_B = \sqrt{[(1.841-1)^2 + (3.017-3)^2} = \sqrt{(0.707+0.000} = 0.841$$

$$D_C = \sqrt{[(1.841-2)^2 + (3.017-4)^2} = \sqrt{(0.025+0.966} = 0.996$$

$$D_D = \sqrt{[(1.841-3)^2 + (3.017-2)^2} = \sqrt{(1.343+1.034} = 1.542$$

Total "cost" of transportation = $\Sigma w_i d_i$

$= (10 \times 2.955 + 20 \times 0.841 + 15 \times 0.996 + 5 \times 1.542)$

$= 29.55 + 16.82 + 14.94 + 7.71 = 69.02$

Thus, the first iteration of the Strings and Weights method has given an improvement in the total "cost" of transportation. Hence, we proceed with the next iteration.

Second Iteration:

Repeating Step 2, we have the following:

The X and Y coordinates of the godown location are given by

$$X = \frac{\sum_{i=1}^{n} w_i x_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$= [(10 \times 4/2.995) + (20 \times 1/0.841) + (15 \times 2/0.996) + (5 \times 3/1.542)]$
$/(10/2.995 + 20/0.841 + 15/0.996 + 5/1.542)$

$= [13.355 + 23.781 + 30.120 + 9.727]/(3.339 + 23.781 + 15.060 + 3.243)$

$= 76.983/45.423 = 1.695$

$$Y = \frac{\sum_{i=1}^{n} w_i y_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$$= [(10 \times 1/2.995) + (20 \times 3/0.841) + (15 \times 4/0.996) + (5 \times 2/1.542)]/ (10/2.995 + 20/0.841 + 15/0.996 + 5/1.542)$$

$$= [3.339 + 71.344 + 60.241 + 6.485]/(3.339 + 23.781 + 15.060 + 3.243)$$

$$= 141.409/45.423$$

$$= 3.113$$

The coordinates, after the second iteration, are: (1.695, 3.113).

Distances of the godown location from the recipient areas would be as below.

$$D_A = \sqrt{[1.695-4)^2 + (3.113-1)^2]} = \sqrt{(5.313+4.465)} = 3.127$$

$$D_B = \sqrt{[1.695-1)^2 + (3.113-3)^2]} = \sqrt{(0.483+0.013)} = 0.704$$

$$D_C = \sqrt{[1.695-2)^2 + (3.113-4)^2]} = \sqrt{(0.093+0.787)} = 0.938$$

$$D_D = \sqrt{[1.695-3)^2 + (3.113-2)^2]} = \sqrt{(1.703+1.239)} = 1.715$$

Total "cost" of transportation = $\Sigma w_i d_i$

$$= (10 \times 3.127 + 20 \times 0.704 + 15 \times 0.938 + 5 \times 1.715)$$

$$= 31.27 + 14.08 + 14.07 + 8.575 = 67.995$$

Thus, the total "cost" found after the second iteration is lower than that after the first iteration. There is a significant improvement. Hence, we can go for the third iteration.

The coordinates of the godown location, after the second iteration, are: (1.695, 3.113).

Third Iteration

The X and Y coordinates of the godown location are given by:

$$X = \frac{\sum_{i=1}^{n} w_i x_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$$= [(10 \times 4/3.127) + (20 \times 1/0.704) + (15 \times 2/0.938) + (5 \times 3/1.715)]/ (10/3.127 + 20/0.704 + 15/0.938 + 5/1.715)$$

$$= [12.792 + 28.409 + 31.983 + 8.746]/(3.198 + 28.409 + 15.991 + 2.915)$$

$$= 81.930/50.513 = 1.623$$

$$Y = \frac{\sum_{i=1} w_i y_i / d_i}{\sum_{i=1}^{n} w_i / d_i}$$

$$= [(10 \times 1/3.127) + (20 \times 3/0.704) + (15 \times 4/0.938) + (5 \times 2/1.715)]/$$
$$(10/3.127 + 20/0.704 + 15/0.938 + 5/1.715)$$

$$= [3.198 + 85.227 + 63.965 + 5.831]/(3.198 + 28.409 + 15.991 + 2.915)$$

$$= 158.221/50.513 = 3.132$$

$$= 3.113$$

The coordinates, after the third iteration, are: (1.623, 3.113).
Distances of the godown location from the recipient areas would be as below:

$$D_A = \sqrt{[1.623-4)^2 + (3.113-1)^2]} = \sqrt{(5.650+4.465)} = 3.180$$

$$D_B = \sqrt{[1.623-1)^2 + (3.113-3)^2]} = \sqrt{(0.399+0.013)} = 0.642$$

$$D_C = \sqrt{[1.623-2)^2 + (3.113-4)^2]} = \sqrt{(0.142+0.787)} = 0.964$$

$$D_D = \sqrt{[1.623-3)^2 + (3.113-2)^2]} = \sqrt{(1.896+1.239)} = 1.771$$

Total "cost" of transportation = $\sum w_i d_i$

$$= (10 \times 3.180 + 20 \times 0.642 + 15 \times 0.964 + 5 \times 1.771)$$

$$= 31.80 + 12.84 + 14.46 + 8.855 = 67.955$$

There is only a marginal improvement over the previous "cost" (i.e. the cost after the second iteration). Hence, we may settle at this godown location, viz. at (1.623, 3.113).

2. Five customer plants A, B, C, D and E are to be served by a single vehicle starting from its warehouse located at place W. The data on the inter-point distances, in kilometers, is as given below. Obviously, the vehicle has to come back to its origin W after delivering goods at all the customer plants. If a maximum of 45 km. is allowed per one such round, find an economical feasible route for the vehicle.

From	W				
A	9	A			
B	5	10	B		
C	14	7	11	C	
D	10	4	14	8	D
E	8	3	11	9	12

Use Fletcher, Clark and Wright's "Savings Criterion".

Answer

The "savings" are calculated for various individual links A-B, B-C, etc. These are presented in the table given below.

Example: Savings by linking A-B = (distance W-A) + (distance W-B) - (distance A-B)

= 9 + 5 – 10 = 4 km.

From	W				
A	–	A			
B	–	4	B		
C	–	16	8	C	
D	–	15	1	16	D
E	–	14	2	13	6

Fig. No. 25.21 : Savings (km.)

Next, these savings are ranked (maximum savings getting rank 1). The matrix of these ranks is given below.

From	W				
A	–	A			
B	–	7	B		
C	–	1	5	C	
D	–	2	9	1	D
E	–	3	8	4	6

Fig. 25.22 : Matrix of Ranks

Based on these ranks, starting from rank 1, we start joining various links in order to construct the route for the vehicle. Thus, we select link D-C first.

The route, so far, is: W-D-C-W = 10 + 8 + 14 = 32 km.

Next, add the other rank 1 link C-A.

The route, so far, is: W-D-C-A-W = 10 +8 + 7 + 9 = 34.

The rank 2 link is D-A. This cannot be added, since points D and A have already been covered.

Next add rank 3 link A-E.

The route becomes: W-D-C-A-E-W = 10 + 8 + 7 + 3 + 8 = 36 km.

Next, add the remaining link E-B.

The route would be: W-D-C-A-E-B-W = 10 + 8 + 7 + 3 + 11 + 5 = 44 km.

Thus, we have found a feasible route within the maximum allowed distance of 45 km. It is: W-D-C-A-E-B-W.

QUESTIONS FOR DISCUSSION

1. What are the merits and demerits of an analytical method for the choice of location of a warehouse to serve the customers in a region?
2. For the decision to establish a warehouse or a number of warehouses, what are the relevant costs? What are the tangible and intangible costs?

3. What is a Transportation Problem? How is it different from the Warehouse Location Problem discussed in this chapter?
4. How would you go about optimally locating a given number of warehouses with given capacities to serve the customers whose demands are known? (The transportation costs per unit tonne-km are known.)
5. Compare the Transportation Problem with the Linear Programming Problem.
6. In scheduling the routes of transportation vehicles, why is a flower-petal contour for the route preferred?
7. What other methods of scheduling routes are available in the Operations Research literature?
8. What is the scope of Logistics Management?
9. What is the justification, if any, for including Inventory Control in Logistics Management?
10. In your opinion, what should be the objective of the Logistics Department?
11. How are purchasing and sales decisions influenced by logistics decisions?
12. If in the Transportation Problem the total capacity or availability with the warehouses does not match with the total requirements of the customers to be served, how would you go about formulating the Transportation Problem?
    Customers *W*, *X*, *Y* and *Z* are to be served by warehouses *A*, *B* and *C*. The requirements of the customers are respectively 200, 300, 400 and 350 tonnes. The availabilities with the warehouses are 150, 500 and 420 respectively. The transportation costs in rupees per tonne from a warehouse to a customer are given below:

	W	*X*	*Y*	*Z*
A	90	70	100	110
B	80	160	180	50
C	35	100	95	130

    Find the optimal allocation between the different warehouses and the customers.
13. In Question 12, if we reverse the availabilities for the requirements and vice versa, so that *W*, *X*, *Y* and *Z* represent the warehouses and *A*, *B* and *C* represent the customers, (the cost matrix remaining the same) how would your approach differ? Solve the problem.
14. Solve the vehicle routing problem given in the chapter with the following constraint in addition to the constraint given in the chapter. The new constraint is regarding the loading capacity of the vehicle, which is limited to 10 tonnes. The material required by different customers is as given below:

Customer	*Requirement*
1	1
2	3
3	1
4	5
5	2
6	2
7	6

Does this problem have a feasible solution? If so, what are the routes? If not, increase the availability of the vehicles to a total of 3, and find the optimal routes.

15. Three plants are supplying cement to 4 regional warehouses. The availabilities at the plants are respectively 2, 3 and 4 units, the requirements of the warehouses are 1, 4, 2 and 2 respectively. The cement could be moved from one factory to another, but it is not possible to do so between the warehouses. the costs of transportation per unit of this material are as given below:

Plant / Plant	*A*	*B*	*C*
A	0	4	13
B	4	0	2
C	13	2	0

Warehouse / *Plant*	*W*	*X*	*Y*	*Z*
A	2	5	10	4
B	1	13	11	7
C	11	3	9	10

Find the minimum cost allocation.

16. A warehouse caters to the needs of 3 customers. The tonnages catered to the 3 customers are 1000, 2000 and 2500 respectively. The customers are located at (2, 0) (7, 0) and (0, 5). Find the optimal location for the warehouse.

17. In the future when B2B and B2C e-commerce may be the predominant modes of conducting business, how should Physical Distribution Management (PDM) function have modified itself? What is your vision for the PDM function? Explain your answer.

18. A supplier has three customers. Deliveries are made daily. The point-to-point travel time is 1 hour each and the time to load/unload at each point is ½ hour. There is one truck and there are three drivers who can report to work only at the supplier's point and can disembark at supplier's point only. The workday for the drivers comprises 8 hours. Answer the following.

(a) How many deliveries can be made in a 24-hour day?

(b) If the drivers can report to duty and disembark at any point, how many deliveries can be made in a 24-hour day?

(c) If there are 4 drivers who can report to duty and disembark at any point, would that improve the number of deliveries? How?

ASSIGNMENT QUESTION

1. Study any transport company's operations. Present an actionable report on the service quality of that company.

26 Materials Management—An Integrated View

In the earlier chapters the various components of the management of materials were discussed such as:

Purchasing
Inventory Control
Storage and Materials Handling
Physical Distribution of Materials

Each of these are equally important and although some division of responsibility and authority is necessary for dealing with them, we cannot treat them as isolated water-tight compartments. The decisions taken by a purchasing executive will have to be tempered or modified by the consideration of inventory control; the decisions taken by inventory control have to be taken in the light of feedback provided by the purchasing department; similarly, inventory control has to reckon considerations of storage and handling of materials and vice versa. Physical distribution and its attendant problems have their own feedback effect on the control of inventories of finished goods and therefore on work-in-process and raw material inventories. In short, there is an interrelationship between the different functional elements of materials management.

Let us elaborate a bit. We have seen that the purchasing department has a major role to play as a 'window' to the external supply market. In fact, this is one of the most important roles of the purchasing executive. This sensitivity to the changes in the market should be utilised by the inventory control department. Certain circumstances may occur whereby the purchasing manager might advice the inventory control department to cut down or delay the procurement of certain raw materials and supplies; or he may advice the procurement of a larger than usual quantity of the bought-out materials at a certain point of time. In such circumstances, the inventory control department should not keep its mind closed to this information. It is true that the function of the inventory control department is to minimise the cost of inventory-keeping. But the point that may be sometimes lost, in the zeal to minimise the inventory cost, is to minimise the over-all organisational costs related to inventory—over a sufficiently long period of time.

The usual inventory control decisions are after all taken with certain routine or normal conditions assumed. It is possible that the underlying premises for the inventory control policies might

change due to the changes in the supply-market conditions; and therefore, a re-examination of the policies either temporarily, semi-permanently or for a longer period of time may be warranted. If the prices of commodities are showing an increasing trend in the supply market and if it is felt that their availability will be difficult and the prices will increase at a greater rate in the near future, there may be justification for the organisation to buy more of this material at present for future use. Conversely, if the prices of certain raw materials are expected to come down in a short while, it may be worth waiting and adjusting with the available quantity of raw materials. Considerations of only carrying cost and order cost may not be sufficient.

Even the usual safety-stock models and policies derived therefrom may not provide adequate protection in some special cases of changes in the supply market. After all it is to be understood that even the buffer stock is calculated for an irregular behaviour which in itself has some regularity. The basis of the calculation of buffer stock is the observation of the statistics of the past supply and demand situations and finding a pattern in past behaviour. So, even in the uncertainties, some amount of *regularity* is sought. Statistics is a science of averages and of average behaviour. The 'Mean' is a constant and the 'Standard Deviation' is also assumed to be constant. But, if the Mean and Standard Deviation were to show a change, either gradual or sudden; if there were sudden perturbations in the supply-market which lasted for as long as 5 or 6 months, it would result in shock-waves in the entire production and marketing system of the organisation. The inventory control system should therefore be flexible enough to accommodate such situations.

ADAPTABILITY CONSIDERATIONS

There should be enough adaptability in the system to take into consideration abnormal situations as and when they present themselves. In this connection a frequent interaction with other related departments such as purchasing, logistics, etc. is very essential to achieve the goals of the organisation.

Similarly, the purchasing department should be aware of the various components of costs related to inventories, the problems of inventory-keeping, so that their own job of getting information about the supply market and feeding relevant information back into the organisation is facilitated. Adaptability considerations necessitate integration of various component functions of the management of materials.

INVENTORY AS A PART OF PRODUCTION STRATEGY

The inventory control department is often (in various organisations) a part of production planning and control. After all, inventory of raw materials and work-in-process goods are kept to facilitate the production function. Therefore, inventories have to be considered along with the other costs and problems of production as the objective is to minimise the totality of production-related costs, of which the cost of materials is one component (and a major component). The whole gamut of production costs includes wages—regular and over-time, overhead costs, and the cost of materials. Optimising only the materials costs may result in sub-optimisation of the over-all production costs. Due to labour and machine capacity availability constraints, what may appear to be an optimal decision (given by an inventory control model) may not fetch adequate results for the production function as a whole. Inventory control and materials planning should form a part-and-parcel of the production planning exercise. The decisions about labour allocation, the

quantities of different products to be produced at different periods of time in the year, the allocation of machine capacity, and the inventory of work-in-process, finished goods and raw materials to be carried may be taken together.

Decisions of how much to procure and how much to store cannot be taken without a proper understanding of the availability of the storage space, of the characteristics of deterioration of materials, of the risks and costs of handling materials, of the costs of maintaining component parts and materials in the stores and warehouses. Stores, warehousing, and materials handling have inputs in materials-stocking or producing decisions.

As seen in Chapter 25, what may appear to be an economic batch quantity of production may not be so if the logistics are also considered. The mode of shipment, the in-transit inventories, the number-size-location of warehouses, etc. have a significant impact on inventory and procurement policies.

ORGANISATION EFFECTIVENESS

It should also be understood, that cost is not the only objective of the materials management function. As emphasised earlier, one of the primary objectives of the materials management function is to ensure a continuous or an uninterrupted supply as far as possible to production, the ultimate objective being that the customer is served to his satisfaction. Whether an organisation is using EOQ and safety-stock methods, or MRP, or any other system, the first requirement is that the supplies are adequate for production. To achieve this, it requires appropriate setting of service levels and reorder points, consideration of sourcing, planning and contracting of long or intermediate-term supply agreements, an effective physical distribution network with adequate number of warehouses or distribution points and facilities for movement. This helps the organisation to produce and deliver its goods on time as per the contracted schedule or as per the demands of the customer. This is besides the overall production cost considerations, since the production cost is also influenced by the discontinuities in supply of materials. In short, the organisational 'effectiveness' aspects should not be forgotten in the zeal to produce 'efficiencies'. Moreover, other considerations such as the 'norms' of current assets approved by the financing banks must also be taken into consideration.

A MULTI-LEVEL INTERACTIVE PROCESS

From purchasing to receipt, to inventory-stocking, to production and storage of in-process and finished goods, to the distribution of the produced goods is one continuous or integrated system of operation where the material flows from the external supply market to the customers of the company. The management of materials will not be effective if this entire flow is not kept in view. Policies for various components of this flow (or delays, storages or stoppages) have to be made, and there should be enough interaction between the different components of the management of materials as also enough flexibility or adaptability built into such a policy framework. The next chapter describes a much wider view about materials, supplies and organisations in general that is getting acceptability in business worldwide.

QUESTIONS FOR DISCUSSION

1. Suggest a few indices to judge the performance of the materials management function in an organisation.
2. What are arguments for and against having the logistics function under materials management?
3. Should the Inventory Control function be assigned to the purchasing department? Why or why not?
4. What is the meaning of 'integration'? In order to achieve 'integration' amongst the departments/sections, is it necessary to have all of them together in the organisational structure? Explain.
5. (a) What may be the merits and demerits of 'making materials management a profit centre'? (b) How will it help to take 'an integrated view'?

27 Supply Chain Management

The process from purchasing to receipt, inventorying, manufacturing and storage of in-process and finished goods, to the distribution of the finished goods is one continuous or integrated system where the material flows from the external supply market to the customers of the manufacturing company. However, integration is a frame of mind. In today's fast changing business world, it should not stop at the level of integration stated above. It is essential for the concept to be intensive and extensive in scope. In addition to the interfunctional (purchasing and inventory control linkage, or, inventory and production linkage) and other intra-organisational linkages (e.g. for a multinational company with several facilities and customer sites located in different countries), a company needs to look at the inter-organisational links as well, even for managing the flows of materials and services.

SUPPLIES ON A WAR FOOTING

Managing the flows of materials and services is a vital function in any organisation. History is replete with several examples where battles were lost because of the problems encountered in managing supplies to the armies. In India's history, the third battle of Panipat was a watershed. Marathas under the Peshwa of Pune were all powerful in those days. However, they experienced problems in getting *rasad* (supplies) in time at a crucial juncture in the battle. Ahmed Shah Abdali took full advantage of that and the Maratha army was almost decimated. After that battle, Marathas were never as powerful. The control taken over by the British in the later decades could be attributed to this sudden power vacuum in this sub-continent. Quaint as it may sound, management as a discipline owes much to the military operations. Even a project that is implemented expeditiously is said to be done on a 'war footing'. It is common knowledge that the Military Operations Research, performed during World War II, later transformed into Operations Research—the much useful discipline of management as a science.

As mentioned in the introduction to this section, the flow of the supplies (in the form of materials, services, information and finances) is a long chain extending from the company to its

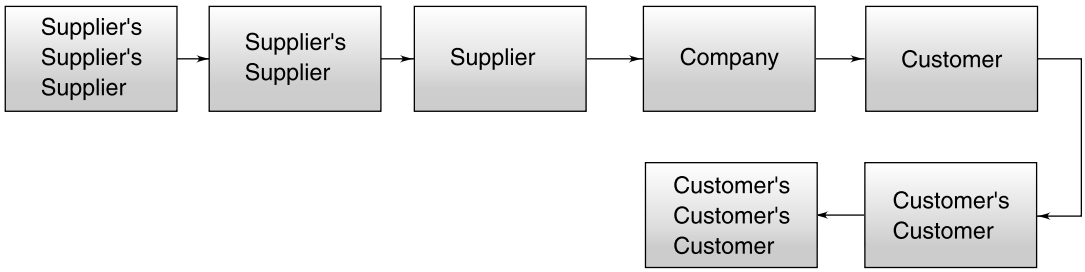


Figure 27.1 Supplier-Customer Linkages

supplier and further backwards to its supplier's supplier and even further backwards to its supplier's supplier's supplier and so on. The chain extends forwards from the company to its customer and further forward to its customer's customer, and even further to its customer's customer's customer and so on until the ultimate customer. Sometimes one may put a stop to this extension at some point beyond which it does not affect much. Figure 27.1 presents these linkages.

The chain is as much for the materials flow as to the equally important flows of information, services and finances. In a war, these things were intuitively realised and appropriate action was taken. But, this attitude did not spill over into the civilian activities like business and government for the simple reason that nothing was required on a war footing.

COMPETITION ON THE BASIS OF TIME AND QUALITY MAKES A CLOSER COORDINATION ESSENTIAL

Today, as global business has become extremely competitive, companies are feeling the need to look at business and its processes in a different way. Goods producing (manufacturing) companies—and the services providing companies as well—are competing more today on the basis of time and quality which have become the prerequisites for running any business. Hence, a very close coordination with suppliers and distributors has become essential.

When supplies do not arrive on time or have inferior quality, it becomes a big problem for the company which cannot afford to waste precious money in keeping inventories of items and thus push up its own costs. It cannot afford to pass this increased cost to its customer who, in turn, cannot do so to his customer. Thus, what is required for the customer's customer is as important as what is needed for the customer. It ought to be mentioned, in this context, once again that while there is always a need to be competitive on the basis of cost/price as well, that is not the sole determinant of a company's competitiveness in the market. Besides price, quality and timely deliveries (or timely service) a company needs to be competitive on various other dimensions such as variety, flexibility, adaptability, innovativeness, cordiality, courtesy and empathy, all of which or a judicious combination of which spell value for the customer, his customer and further the latter's customer leading to the ultimate customer.

A Multi-tiered System

A supply chain is a multi-tiered system as can be visualised from Fig. 27.2.

The supplier-buyer linkage is termed 'partnership'. The chain up to the first tier is called a 'basic supply chain'. Any chain having two or more tiers is called an 'extended supply chain'. Generally when one refers to a supply chain, he is referring to the extended supply chain. Of course, there could be more suppliers and/or customers at every tier. Moreover, there may be situations where company A might find company B to be a customer in one supply chain, partner in another, a supplier in the third and a competitor in the fourth supply chain.

Even a traditional organisation would be aware of its basic supply chain i.e. its supplier and its customer. Of course, being aware is not the same as being sensitive. It is easier to be sensitive to one's customer than being sensitive to one's supplier. So, even in the basic chain the mindset has to have evolved to a certain degree.



Figure 27.2 Supply Chain—A Multi-tiered System

Today one has to go beyond thinking of and being sensitive to one's supplier and customer. The extended chain (or simply called the chain) of these manufacturers and/or service providers has to provide the service as desired or appreciated by the ultimate customer while, of course, providing service or value to the various tiers of customers. When a company competes today, it is as though the entire chain is competing to deliver value to the ultimate customer. Competitiveness cannot come about through a single organisational unit but the supply chain as a whole. The competition has indeed shifted from single organisational units to supply chains

SUPPLY CHAIN AND "KEIRETSU"

This reminds us of the phenomenon of *Keiretsu* in Japan. Keiretsu is a group of business companies that are mutually dependent. It is like a large joint family having a head of the family and other members of different generations. Family implies that there is much empathy for each other. One tries to understand the other. Each has his own 'goods' to deliver in such a way that ultimately the family's objectives are achieved. In a family, the persons of senior generation may exercise much control over those of the younger generation, but the former are quite sensitive to the latter's needs and provide for them. Same is true of the Keiretsu, the needs here being the business needs. That keeps every unit within the Keiretsu healthy. Being a group of healthy organisations that are well directed and coordinated makes the group capable of being very competitive. An industry group that coordinates the design, production, distribution of parts and products for the final market can compete better than other industry groups that are not coordinated. 'United we stand, divided we fall' is an old adage. Supply chain is a similar concept applied in a very positive manner. The objective is to provide more and more service and value to the customers in the final market.

Keiretsu had been much maligned, particularly in the West. It was thought of as a cartel – several sharks ganged up by a big shark amongst them so that they beat the international competition by unfair means. It was seen as antithetical to *laisse faire* or the concept of free market and pure

competition which is known to be the basis of capitalism. The Japanese Keiretsu appeared akin to oligopoly which, in the West, was a much despised restrictive trade practice. During the 1970s and 1980s, Japanese goods swamped the American and European markets. They offered much better quality at significantly lower prices and were very popular among the consumers. For a while one could not understand as to how one could offer better quality, variety and lower prices consistently year after year.

There is a thin line between ganging up and teamwork. The major difference is that in the former the intention of the gang is to reap undue benefits, while in a team the benefits accrue to it because of its efficiency and the superior performance and advantages delivered to the customer. Authentically generated benefits due to the synergy and economy of a team are shared with the customer. This sharing is what makes the difference. It is a system of sharing between the business partners and with the customers as well. It is a 'benefit–benefit' situation and not 'benefit–loss'. Supply chain management is a concept of teamwork and sharing.

CORE COMPETENCE OF COMPANIES, COMPARATIVE ADVANTAGE OF NATIONS AND OUTSOURCING

The reason as to why supply chain management has become popular during the past decade is the phenomenon of globalisation. Increased competition has made businesses look for core competencies for enhanced performance. If a particular organisation in some country has the core competence for a certain product/component/service, it will get the business for that product/service. This is called global outsourcing. For instance, a substantial amount of software services work is outsourced from USA to India because several Indian companies have the core competence in providing those services. However, when the work is outsourced to several locations in the world, a high degree of coordination becomes imperative between them and the parent organisation and also between themselves. For instance, suppose an American company outsources its software services needs to India, Greece and China. There is a need to coordinate between the work being done in India and that in USA. Similarly, between Greece and USA, and China and USA. Also, there may be a need to closely coordinate between the work done in India, Greece and China. Thus, global outsourcing has compelled business organisations to look for more effective ways of coordinating the flows of materials/information/services into and out of the organisations. The appropriateness of supply chain management is accentuated when outsourcing globally.

MARKETPLACE UNCERTAINTIES AND CHANNEL RELATIONSHIPS

A characteristic of today's marketplace is uncertainty. Changes are taking place rapidly. Electronics, computer technology, telecommunications, biotechnology, and many applied sciences have taken rapid strides. Even within manufacturing, there are developments such as computer integrated manufacturing, computer aided design, flexible manufacturing system and robotics. Fast technological developments make the products and services of yesteryear to be outdated and obsolete in the current year. The variety of product offerings in the marketplace has also shot up sharply. At any point of time one may have a large variety of competing products and services, because the technology now makes it possible to have that many varieties.

Due to ever-changing services and/or products offered by the marketplace, there is a constant search for appropriate competencies globally. Therefore, the economic conditions keep changing.

There is another reason for changes in the economic conditions. It is due to increasingly efficient exploitation and utilisation of the resources. When the economic conditions change, the competencies and comparative advantages tend to change. The availability of low-wage skilled persons in the IT field is the current comparative advantage in India today. However, as the economy grows rapidly—particularly in the IT sector—the wages of the skilled personnel may shoot up, making India lose the present comparative advantage. This means economic conditions cause global outsourcing, and global outsourcing causes changes in the economic conditions. Thus one factor causing uncertainty enhances the other factor. The effect is compounded.

Market uncertainty on this scale requires greater flexibility on the part of the business organisations and on the part of their distribution and supply channels. More the flexibility, more enabled is the organisation to face uncertainty. Such needs for flexibility would necessitate a greater degree of coordination and cooperation from the various organisations in the market which encourages them to form a supply chain. Such coordination and cooperation, in turn, necessitates changes in the channel relationships.

How is Competitiveness Achieved?

Supply chains help to achieve competitiveness and deliver value to the ultimate customer. Performance of all units in the chain is important. Actions to extend improvements beyond one's company constitute the crux of supply chain management. This necessitates a fresh look at the way organisations could work together. Customer orientation and teamwork are fundamental in managing supply chains. Knowledge about one's customer and supplier in the chain and having empathy for them are central to it. The knowledge should go beyond just knowing quantities, quality, deliveries and cost structures and should extend to knowing the customer's/supplier's organisational culture, strengths, weaknesses, their current markets, market plans for the future, strategies, processes, the problems and prospects. Relatedness is the life line of supply chains. It is the vital cementing factor between two entities. The synergy of teamwork while each entity in the chain is delivering its core competence with a common focus on the ultimate customer is some of the reasons for a supply chain's competitiveness.

BUILDING A SUPPLY CHAIN

Two aspects are needed to build a supply chain

(a) Alignment of the organisations in the chain, and

(b) Improved coordination between them for flow of materials, services, information and finance.

The organisations in the supply chain need to be aligned with respect to the ultimate objective of providing value to the customer. Their strategies regarding this objective need to be aligned. Interorganisational collaboration has to be improved. Organisations, like people, have their own psychology. Aligning organisations is of primary importance in managing supply chains. The chains do exist; everyone knows about that. What is needed is managing them to produce the desired joint competitiveness. Alignment is one important task in this management of supply chains. This task deals with psychology, strategies and such other intangibles and broad aspects. Corporate cultures, corporate values, philosophies of the organisations in the supply chain have to be compatible.

Leader Company in the Supply Chain

It requires leadership to make two or more disparate organisations to work together closely. Although one may feel that the circumstances of the marketplace should make the organisations organise themselves to form a supply chain, in practice a leader organisation is essential. Self-organising polycentric actors forming a supply chain is only an ideal. In practice, the actors also have to be selected i.e. the partners on the chain have to be chosen, the strategy of the chain has to be decided upon and it has to be aligned. Hence, a leader organisation is essential. Generally the leader organisation or 'focal company' is one that has the largest financial power or superior technological knowledge or is the one that generates greatest share of values among all the organisations that are in the supply chain.

As was mentioned earlier in the context of Keiretsu, a supply chain is an effective hybrid of a hierarchical setup and free market competitive organisation. Each company in the supply chain performs according to its core competency. These companies do not compete with each other, like the members of a family would not. Instead, each member strives to enhance the competitiveness of the family as a whole i.e. of the supply chain as a whole. There is inter-organisational collaboration towards that objective.

What Keeps Them All Together?

What is the binding factor for these independent companies to form a supply chain? The simple answer is: there is a pay-off for everybody. For one, there is a committed business. To put it in another way, the companies in the chain are all committed to the success of all the members. Such assurance—nay, commitment—is hard to come by if these companies were looking for business by themselves. Commitment, trust, reliability and security are the biggest gains in belonging to a supply chain. Here, the business is performed like it was a social activity. The other tangible gains could be the financial and technical support provided when needed.

Mindset Thus, in building a supply chain,

(a) the participating (or partner) companies are to be chosen,
(b) the strategies and policies of the participating companies have to be aligned, and
(c) a culture of trust and cooperation has to be initiated and sustained.

The activities mentioned above could be classified as tasks pertaining to the mindset.

Coordination The next task in building a supply chain is to ensure coordination of the flow of materials, information and finance, the objective being to satisfy the ultimate customer and to do so with efficiency. This task deals more with physical or tangible aspects. It tries to bring in improved process orientation. The flows are not treated as isolated activities performed at different locations on the supply chain. Islands of efficiency are not desirable; it is the overall, joint efficiency that is to be enhanced. It should be a smooth flow up to the customer, without developing any hiccups along the supply line.

Sharing of Information In realising such a smooth flow along the supply line, information systems and the information technology play an important role. Electronic data interchange (EDI) is one such technology. Success of a supply line depends significantly on the necessary communication and sharing of information between partners, particularly between neighbours on the supply chain. The information exchanged could be about

(a) short-range requirements of materials or services and production schedules,
(b) long-range production/operations plans, changes in the design of the products in the supply line, changes in the product mix and demand of the product, and
(c) unanticipated problems at any point in the supply chain.

Sharing of Risks and Rewards While the satisfaction of the ultimate customer is the objective of a supply chain configuration, it must also be realised that each company is also a customer to its predecessor company on the chain. Therefore, each company should feel that it has got its appropriate share of the financial profits or other gains. A supply chain cannot afford to have even one dissatisfied member. The supply chain structure is vulnerable to the non-performance of even one partner. Hence, the chain as such or rather the leader of the chain should ensure that the rewards are shared equitably between the partners. This is a very important issue, because within the chain the organisations are very open. Their transparency can make them vulnerable. For instance, a supplying organisation's cost structure may be known to the buying organisation on the chain. Therefore the supplying organisation may lose some of its otherwise (traditional) bargaining power. The other area of transparency is in the area of technology. There are no more technological secrets, at least not to the extent that a company could keep in the traditional setup. Once a member's technical know-how has been dispensed, that member runs the risk of becoming a spent force or becoming unattractive. If this were to happen in the traditional setup, that company may lose its market power altogether.

Also, it should not happen that one member is exposed unduly to the risks in the external market (i.e. market external to the supply chain) while the others are not. Either the risks are to be shared amongst the members as equally as possible or if inequitable risks are unavoidable then the risk-taker has to be suitably rewarded.

Joint problem-solving Since it is a family, all the relevant partners in the supply chain participate jointly on issues like the final product, the product design, the parts design, the production process design and the logistics design. Concurrent engineering, TQM and total productive maintenance (TPM) could be some other programmes in which the partners may participate jointly.

POM OBJECTIVES AND SUPPLY CHAIN

The supply chain has the same objectives as the discipline of POM. This statement may appear like tautology. But, the point is that in a supply chain the very same objectives get accentuated. The objectives of a supply chain are :

(a) Service orientation (i.e. service to the customer) and thus ensuring that the customer gets value,
(b) Systems orientation i.e. looking at the supply chain as a whole and not in terms of its constituent parts (partner companies), and
(c) Competitiveness and efficiency.

The very basis of supply chains has been to provide superior customer service. Service is all about the value that the customer gets, which in turn depends upon his own perception about what constitutes 'value'. The design, the alignment, the integration of the companies on the supply chain and the coordination between them are all for the customer—the ultimate customer, and these are performed as such.

Systems orientation is at the core of the existence of any supply chain. Synergy due to cooperation and coordination is the main gain of a supply chain. This entails that while getting optimal results for the chain as a whole, the results for the partners on the chain may not necessarily be optimal; these could be less than optimal. But, as mentioned earlier, there are substantial gains for all the partners in working together. The apparent sub-optimal gains for a company in the supply chain could be far better than if it were to operate independently outside of the chain. Moreover, a systems thinking involves thinking about all the elements in the supply chain. Therefore, no one is neglected; no one's interests are undercut.

The supply chain is a business organisation. It provides value to the customer while being competitive. Competitiveness is essential for it to healthily sustain itself in order to be able to provide increasing value to its customer. Efficiency is an important element of competitiveness.

ORIENTATION AND IMPLEMENTATION OF SUPPLY CHAIN PRINCIPLES WITHIN A COMPANY

While all the above discussion was directed at the team of organisations forming a supply chain, the principles mentioned are equally applicable to and should be adhered to by the various functional areas of management within the individual organisations. The intra-organisational principles to be followed are similar to the inter-organisational principles.

The coming together of various constituent organisations as a supply chain does not eliminate the need for the traditional functions within those organisations. These functions do not vanish; they remain. Purchasing function will remain; so would the materials planning and stock control function. Physical distribution management and logistics also has to be there. The need for the marketing function does not vanish just because the partner organisations are all connected. The need for human resources function remains. Figure 27.3 depicts the pyramid of supply chain management with all its building blocks.

The management tools, techniques and analyses discussed in the earlier chapters on these functions for the traditional (i.e. those that are not a part of a supply chain) would still be valid. The only difference may be that the validity of some of those tools/techniques/analysis could be for a lesser or higher degree for organisations that are in the supply chain. In short, the functions remain, the analytical considerations remain; what would change radically would be the channel relationships, the way the interfacing functions between the organisations on the supply chain would relate to each other (e.g. the way a purchasing function of a company would interact with the marketing function of a partner company in the chain). The intra-organisational functions' relationships with one another would also have to change significantly.

PURCHASING FUNCTION AND SUPPLY CHAIN MANAGEMENT

Purchasing is one of those functions that are visible to all, as it is at the interface between two organisations. The inter-organisational relationship begins with this function. It has been rightly said that purchasing is the window to the external market. In many manufacturing companies, this is the only function that deals with the suppliers.

In a supply chain, the interactions between a supplier company and the purchasing company are of tremendous significance as has been discussed earlier in this chapter. The strength of a supply chain depends upon these interface relationships i.e. between the supplying company and the

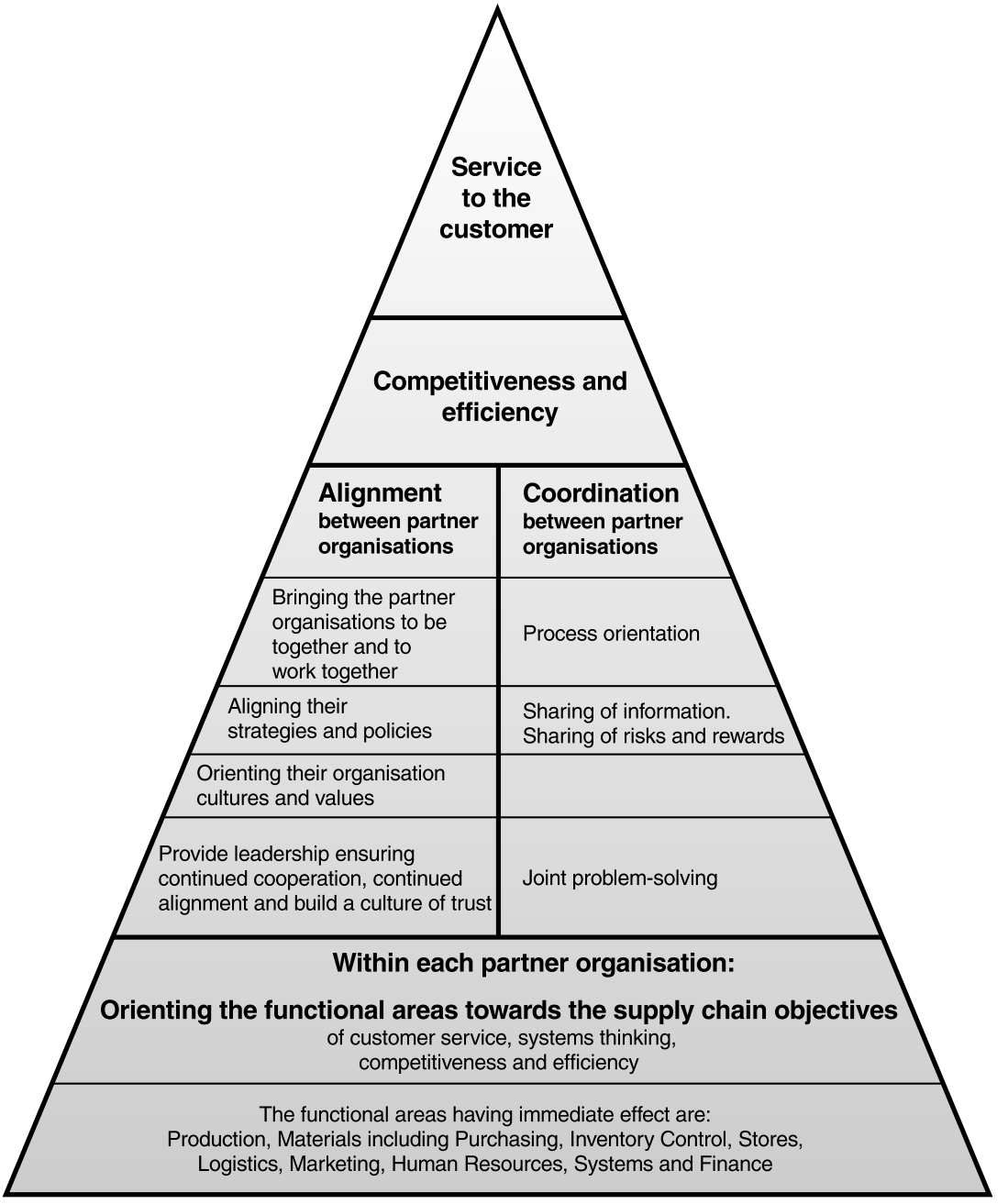


Figure 27.3 The Pyramid of Supply Chain Management

purchasing company. Purchasing, therefore, has a major and active role in supply chain management. Hence, purchasing function needs to be revisited in the context of supply chains.

Traditional Role of Purchasing

Traditionally, purchasing had the task of getting the right quantity of material of the right quality at the right time, at the right place, from the right source and at the right cost. For doing this task, it had to

(a) locate and select the right suppliers
(b) communicate (specify) to the supplier/s the requirements as sent by the manufacturing and/or other user sections
(c) negotiate the right price based upon costs, an analysis of the supply market environment, price forecasting and future needs of the buying company
(d) prepare contracts
(e) control the suppliers' performance through actions such as vendor ratings and supplier relationships

Role of Purchasing in a Company on a Supply Chain

All the above mentioned roles remain even in the companies belonging to a supply chain. Techniques (described in Chapter 20) such as Bayesian analysis, value analysis and learning curve analysis are useful in these companies.

However, a change is necessary on two counts:

(a) Inter-organisational relationships with other members of the supply chain are of paramount importance
(b) Intra-organisational relationships and communications (i.e. with other functional departments within the company) are also very important

There is an acute need to relate, to communicate and to work shoulder-to-shoulder with people inside and outside the organisation. In a traditional situation, the focus of purchasing is mostly inwards—for its own company. However for a company on the supply chain, its purchasing function's focus of responsibility also includes its supplier. It has responsibility for the supplier also.

Relationships with the Suppliers

Since the organisations in a supply chain belong to the chain as family members, the relationships between the purchasing and supplying companies need a radical transformation. Trust becomes an important binding agent between the two organisations. A partnership situation such as this is quite different from the traditional adversarial relationship seen between the purchasing company and the supplying company. For instance, price may be an issue even in the supply chain. However, a supplier is not coerced into offering a lower price. Instead the buyer may try to find out the reasons for the higher costs of the supplier and then suggest ways of controlling it. Moreover, since in traditional organisations there is little possibility of a buyer company exercising any control over the improvement in other dimensions of a supplier's output (like the continuous improvement in the quality of supplies, improvements in delivery times and changes in the product design), the only available control they exercise over the supplier is that of squeezing his price. But, this is generally counter-productive. A supplier who is so cornered carries resentment and would not

cooperate when it comes to quality or time or design changes. He feels no obligation to provide anything beyond the absolute minimum quality, delivery or service. He would believe in status quo and thus in getting the best out of a bad bargain. He cannot be expected to ever feel the necessity to improve the quality and delivery of his products. He would never do it on his own and would resist any suggestions from the purchasing company. As a consequence, the purchasing company finds itself in a bind—difficult to improve its own product quality, delivery and design. Its own competitive ability is affected.

Table 27.1 presents the customer–supplier relationships in traditional and partnership companies. It would serve as an indicator of the needs for a supply chain.

Table 27.1 Customer–Supplier Relationships*

	Traditional organisations	*Partnership organisations*
Purchase Criteria	Lowest price	Competency (quality, timely delivery, flexibility, willingness to improve, willingness to work with customer)
Duration	Short-term, as needed by customer	Long-term
Number of Suppliers	Several for each item	Mostly one (or a few) for any Item or group of items
Volume of Business for the Supplier	Limited, as several suppliers share the business	Large; one supplier gets all the the business
Type of Agreement	Contractual (purchase order)	Working relationship is the main form of agreement in addition to the contract
Type of Interaction	Formal (limited to customer purchase order or contract)	In addition to formal interaction, much informal exchange of production and other business plans, problems and thoughts. New products are designed with the participation of both the customer and the supplier.
Quality	Variable. Customer relies on inspection.	Right quality, at the source. Cost of quality for the customer is low.
Cost/Price	Price appears low initially. Actually high due to inefficiencies that are seldom addressed due to lack of motivation on the part of the supplier.	Effectively low. Cost savings from supplier improvements shared with customer.
Delivery	In large consignments. Infrequent, leading to large inventories.	Small lot, point of use and frequent leading to savings in inventorying costs for the customer.

* Adapted from Nicholas, John M., *Competitive Manufacturing Management*, McGraw-Hill, New York, 1998.

Purchasing Manager as a Coach

Since the purchasing function has a key role in managing supplier relationships and in building supplier partnerships, it is essential to have a shift in the attitudes of the people managing this function. They are no more just the conduits to convey the requirements. They can no more live in an insular environment protecting their company mainly by legal contracts. Purchasing managers must now work with suppliers as a part of the team. They must be reoriented to look upon themselves as a team member.

In a supply chain, the member organisations once selected, remain in the chain for a long time—almost forever—unless there is a very good reason for exiting. Therefore, the purchasing manager has less of the task of selection; it is required only when the business of the supply chain increases rapidly and in huge proportions requiring supplies in quantities and in variety not manageable by the existing members. The emphasis in a supply chain is to get the best possible results from the existing members. Therefore, developing the capabilities of the existing supplier/s (in terms of production capacity, product quality, product/service variety and cost economy, timeliness of supplies, market intelligence and agile response to changes) becomes a major responsibility of the purchasing managers. The purchasing managers have to learn to be good coaches.

It ought to be added here that the responsibility of managing supplier relations is not just restricted to the purchasing managers alone. All those who interact with the supplier/s, such as manufacturing and process engineers, product design engineers, people involved in managing quality, production managers and logistics managers are also required to do their bit.

Effective Communication within One's Own Company

Since a purchasing manager is in touch with the external market environment, it would be expected that he communicates with all the functions/people within his company who need this information (those who can react to the changes in the environment and produce desired results). Purchasing managers can no longer operate independently of other functional areas, the way they used to in traditional organisations.

Concurrent Engineering and Design for Manufacturability

Outside supply chains, this changed role is seen in the active involvement of the purchasing personnel in 'concurrent engineering' and in the new product design teams. They bring their knowledge about availability of components or other materials, the sources, their cost and quality. They can, therefore, contribute in DFM.

SINGLE SOURCE VERSUS MULTIPLE SOURCES

Trust being the distinctive element in the relationships between the members of a supply chain, generally there is only one supplier for any item or category of items. Supply chain would cease to be a chain if at every point in it there were multiple links. It believes in a single link. Or else, it will become too complex and will start having all the negativities of the traditional approach to business.

The traditional business corporations use multisourcing so as to keep prices down through competition between the suppliers. The basis of interaction between the customer and supplier

companies being a lack of trust, the purchasing company believes that the supplying firm would not be able to deliver the required materials in the required time, quality and quantity. Hence, the purchasing company protects itself from supply failures by having multiple sources for the same item. This becomes a self-fulfilling prophecy. The business volume per transaction being low for the supplier company, the latter has no incentive to analyse the problems/bottlenecks and thus improve its performance for the purchasing company. The supplier is not sure whether he should invest its time and effort for a customer who may after all withdraw the business from him the next day. It is indeed a vicious cycle. Table 27.2 presents the comparison between multi-sourcing and single source.

Table 27.2 Multisourcing versus Single Source

	Multisourcing	Single Source
Basis	Customer lacks trust in any one supplier. He believes that the supplier would be unable to fulfill on the dimensions of time, quality and quantity. He is suspicious of the intentions of the supplier. He is doubtful about the supplier's capabilities	Full trust in the supplier. Therefore, the customer conserves his efforts by dealing with only one company.
Volume of business for the supplier	Intentionally kept low in order to engender competition and in order to safeguard against supply uncertainties by having several alternative suppliers.	Large volumes (entire requirements)
Economies of Scale	May not be realised, unless several firms order the same item. In the latter case, the supplier will wait for bunching of orders from several customers, thus delaying the deliveries in some cases.	Present
Special attention	May not be able to give special attention to a custome as the volume of business with him is low. He has too many customers to attend to Lacks focus. Tends to provide. parts/material that serves the needs of all of the customers.	Can provide focused attention to the customer. Thus, he may produce specialised parts or material for the customer.
Quality	Cannot be expected to provide improved quality on his own initiative. Will go by what all of his customers generally want. Also it is difficult to pinpoint the source of a defective part when there are several suppliers.	Supplier would be willing to provide specialised qualty. Willing to improve quality as per the customer's specific needs.
Variability	Multisourcing increases overall variability in quality for the buying company. Variability is additive. It can be in quality, delivery (time and quantities) and many other interactions with a supplier.	Variability is due to one single supplier. It could be, hence, low. More importantly, it may be easier to control as only one supplier is involved.
Control over the Supplier/s	Difficult to control the output or any performance (e.g. variability in quality) as there are many players.	As mentioned above, it is easier to control.

Multisourcing and Errors

As is seen in Table 27.2 and also in Fig. 27.4, failures in all respects are compounded due to multiple actors (multiple suppliers for the same item). There are too many suppliers to attend to; therefore, specialised attention even from the buyer suffers. The buyer, therefore, goes by the manual and/or quality specifications, and becomes preoccupied with conformance to the specifications. Quality in any area cannot be improved by simple conformance to specifications or just by going by the rule book. What may be needed is to locate the source of process variability and reduce that variability. This needs a concerted effort from the buyer and the supplier, which may not be possible with multiple suppliers.

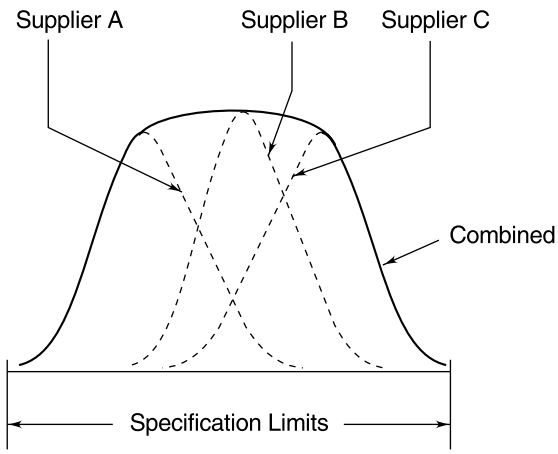


Figure 27.4 Variability from Multiple Suppliers*

Taking Care of Unexpected Problems

Having a single source for any particular category of material is the ideal for a supply chain. While there are several advantages of having only one supplier (for a category of items), at certain times such as a labour strike occurring in the supplier's plant, the buyer company could be put to much trouble due to the lack of the required material. Such a situation can be tackled in different ways:

(a) Since the buyer company knows the supplier intimately, they would have an anticipation of the strike. That being the case, they can build up inventory of that item when a strike seems very likely.

(b) Instead of a one supplier, have two. Some automobile companies have one supplier for the tail lamps on the left and a second one for the tail lamps on the right.

(c) When a company has multiple plants making the same product, each plant may have a single source for an item but each plant could have a different supplier. When the supply to one of the plants is suddenly cut off due to strike in its supplier's plant or due to some other uncontrollable factor, a supplier for other location could fill in.

A supply chain tries to prevent any such breakdowns. First of all, its single source (supplier) himself would have such business culture and values instilled in his organisation that a man-made thing like strike has very little chance of occurring. Just as one speaks of Six Sigma and defectives rate being in the parts per million (ppm) range in TQM (Chapter 11), the breakdowns in the supply chain should also be kept in that range.

When the Buyer Company is Small and the Supplier is Big

The ideal supply chain thinking would not entertain such distinctions. It would not see any problem. But, traditionalists worry about a small buyer company having small market power and,

* Nicholas, John M., *Competitive Manufacturing Management*, McGraw-Hill, 1998.

therefore, being dictated by a large supplier company. The remedy to the traditionalists' fear would be:

(i) Choose a supplier who himself follows TQM in quality or JIT in production or is ISO 9000 certified. Such a supplier, although much bigger in market power, would be responsive to the small buyer.

(ii) The small buyer company may cultivate a good relationship with the large supplier.

Once again, what these solutions given above have advocated is to infuse supply chain philosophy into the not yet totally transformed market.

SERVICE SUPPLY RELATIONSHIPS

Service organisations also need supplies of materials. A Hospital needs to procure surgical dressings, medicines, disinfectants, chemicals for pathogical testing, syringes and injection needles, bed linen, soaps and detergents among several other items of daily consumption and use. A school may need supplies of chalks, dusters, marker pens, pencils, and several materials to keep the premises clean and hygienic. A restaurant needs supplies of food items like grains, pulses, meat, eggs, vegetables and condiments. It also needs various other consumble items that help it keep the premised clean The basic principles of purchasing and inventorying are as much applicable to service organisastions as they are to a manufacturing plant. When to buy, how much to stock, how to prioritise (i.e. ABC classification) and similar issues are common across the manufacturing and service organisations.

However, for most cases, materials are not the number one concern for the service organisations, Materials are not the number one expense item either. Service organisations are not converting a certain material into another material like the manufacturing firms. The servers i.e. the employees—their skills, knowledge, motivation, attitude, concerns, and human interaction abilities—are of prime importance to the service organisation. Compared to that, supply management of materials is not a priority issue although it is not an issue that can be overlooked.

Materials Supply Chains in Service Organisations Generally Tend to be short

Services are characterised by the simultaneous production and consumption of the service. When a person visits a dentist, the supply relationship is compressed to a relationship between the person and his dentist. Perhaps the supply chain relationship for materials can include the supplier of the dental filling and other material to the dentist. Supplier relationship do not generally exceed such two levels. Service supply relationship is more like a hub than a chain because the service provider may act as the agent for the customer when dealing with outside suppliers. Partnering between service provider and its supplier is quite a common practice.

Supply Chain of Services

Service organisations do not have a product that is converted further into another product and so on. So, the question of forward links to the organisation—in a materials supply chain format—may not arise in most types of services. But again, the forward links cannot be ruled out. For instance, the airlie company may have promoted a tour package like 'Tour Malaysia'. In this case, what happens to the travellers after they disembark the plane is also a major concern for the airline. The latter has to oversee the links with the various hotels, and the buses and/or railways that railways that provide further services to the airline's customers.

The point to note in the above example is that the 'material' is now replaced by 'customer service'. Thus, it may not be a supply chain of materials as in the manufacturing context, but a 'supply'. Thus, it may not be a supply chain of materials as in the manufacturing context, but a 'supply chain of services' that needs to be organised. It is like one 'hub of Services' performed links to another hub of services to be done on/for the customer.

Material goods can be inspected upon delivery, but such opportunity does not always exist for purchased services. This being the case, there is much reliance on the suppliers of those services within a service. There is stronger bond between the supplier and the buyer than in manufacturing industries applying techniques like lean manufacturing and JIT.

Customer as a Supplier of Inputs

Many a time, customer himself may provide some of the inputs. For example, the students in a classroom with their case presentations. Thus, the customers himself can be a supplier in some service can depend upon the quality of inputs provided by the customer. For instance, if the students do not come prepared with their case study and analysis, it will affect the efficiency of the classroom delivery. Thus, the service provider has to deliver on his commitments while the inputs (from the customer) are questionable. This requires effective communication between the service provider and the customer. It also requires much training of the customers so as to effectively participate in the service generation and delivery. One may also recommend a 'customer management' system—with positive and/or negative incentives for the customers—so that customers bring inputs and act as per the plan of the service provider.

Supplier management, in the service context, should importantly include the customers and their training. Just as planning the schedule and sticking to the schedule are very important in the manufacturing industry, and therefore the supplies are arranged to be received on time, in the service industry it is necessary for the customers to be on time. Customers also need to be well informed because they do many of the functions that an employee would have done. For instance, airline customer carries his bag for the X-ray check. He puts his jacket, wallet, belt, and shoes in the tray while going to through the security check. Any delay by one customer, may delay the flight from taking off. Customer education is equivalent of the supplier education. Hence, in the service industry, it has much importance.

In the Chain of Services, Customer Himself is an Input

Supply chain of services was described earlier. In this chain, the customer is the primary input. If s/he is not appropriate for the service to be received or is delayed for the service, the entire chain of services can get affected. If the travellers in a cable car are unruly and jump about excitedly in the cabin, it could create an accident and endanger the safety of other customers/travellers and delay others waiting for the transport in the sky. Hence, customer education—and in some cases, customer selection—are vital elements to the service chain efficiency. Customer, as an input, has to be well prepared prior to and while receiving the service/s. He needs to be 'trained' by means of various communications like FAQs on the company's website.

LEADERSHIP: NEED OF THE HOUR

Doubts assail minds of several people as to how could the philosophy of supply chain management work in the present day business that involves cut-throat competition and uncertainties. In some

environments, they have written off any possibility of trust and confidence in either people and/or in the system. Countries such as India face this problem that seems endemic. It is argued, justifiable to some extent, that even if one were to trust a particular supplier or two, the other systems such as transport, communication, law and order, and regulatory authorities cannot be trusted to be free of uncertainties. While one can see the advantages of the concepts such as supply chain, how could one practice these concepts in the available environments? These queries do need a response.

While one can understand the state of business in these environments, it must be emphasised that if one desires to catch up with the business worldwide and make a mark, one will definitely have to practice trends that are world-class. The only way to break a vicious cycle is to start a virtuous cycle. Within the constraints posed by the environment, one has to practice the basics of supply chain management as much as it is possible. This calls for initiative and effective leadership by the businesspersons. Leaders do not wait for anyone. A beginning has to be made. Sustained efforts have to be put in. Trust begets trust.

There are several examples that can be emulated. TVS Motors, Sundaram Clayton and Sundaram Fasteners are such companies who have practiced these new principles with very encouraging results. In fact, Sundaram Clayton won the prestigious Deming Prize for quality, being one of the few companies worldwide to have won this award. Similarly, Amul with its Operation Flood has been a highly successful experiment in cooperation. Toyota Kirloskar Motors at Bidadi near Bangalore practices these new principles to a considerable extent.

It needs to be borne in mind that business worldwide is getting more and more relationship-oriented. The world is getting smaller, because of the technological developments. People are getting closer. Proximity has its problems and prospects. However, in the final analysis people would and do choose the latter. Supply chain management is an element of managing business in the direction of a better world.

Highlight

APPLICATION OF SUPPLY CHAIN PRINCIPLES AT TITAN INDUSTRIES LIMITED

Titan Industries is India's leading manufacturer of watches, which it markets under the *Titan and Sonata* brand names. It enjoys a 25 per cent share of the total domestic market—more than three times the size of its nearest competitor—and close to a 50 per cent share among nationally recognised brands.The company's watches are presently sold in about 40 countries of the world through marketing subsidiaries based in London, Dubai and Singapore. They enjoy a reputation for being excellent value for money.

During 2003–04, Titan took many measures to further improve its effectiveness with respect to the customers and to boost its internal efficiencies. The measures that stand out amongst the several are those pertaining to Supply Chain Management and the related Forecasting process.

Supply Chain Management

The supply of Titan is as shown in Fig. 27.5. In domestic trade, the Redistribution Stockists and the World of Titan outlets account for almost 50 per cent and 30 per cent respectively.

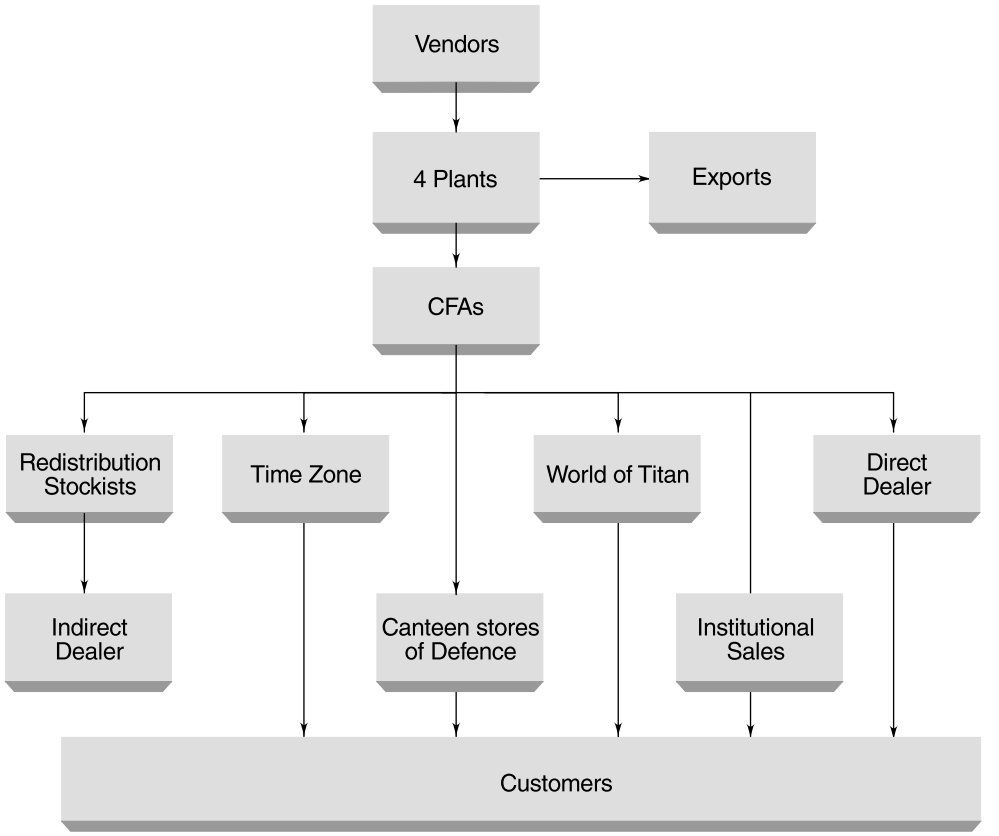


Figure 27.5 Supply Chain of Titan

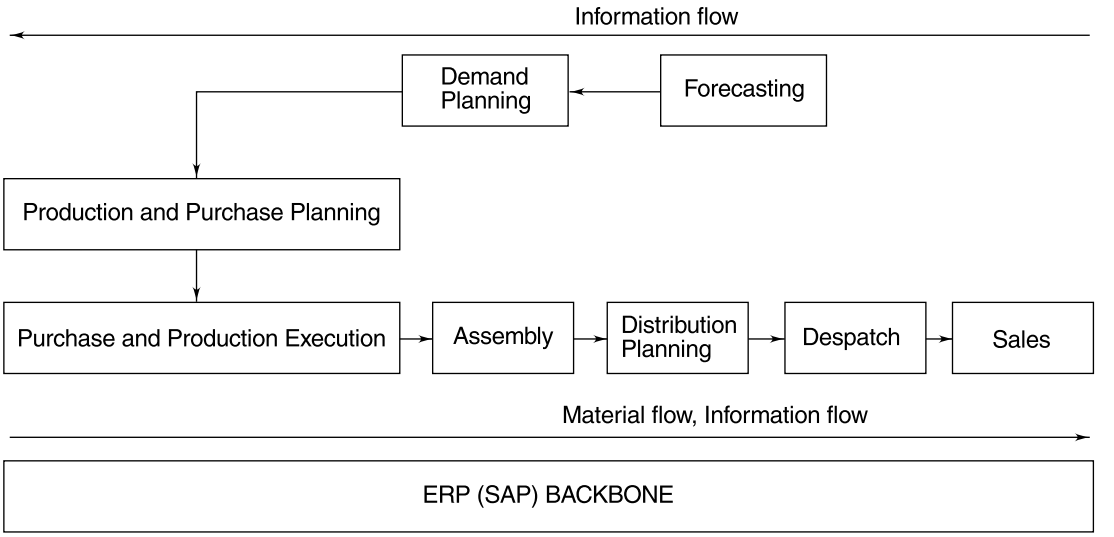


Figure 27.6 Earlier Organisation and Flows

Prior to the initiative taken during 2003–04, the flows of materials and information had been as depicted in Fig. 27.6. As seen therein, the activities of Forecasting, Demand Planning, Production and Purchase Planning, Distribution Planning and Dispatch were being performed by different functions.

Since August 2003, the entire internal supply chain of the company has been reorganised as a single function. Accordingly, the functions that have been integrated are: Forecasting, Demand Planning, Production and Materials Planning, Distribution Planning, Stores, Imports and Exports, and Excise. The unified function has been named as Supply Chain and Logistics Organisation. A

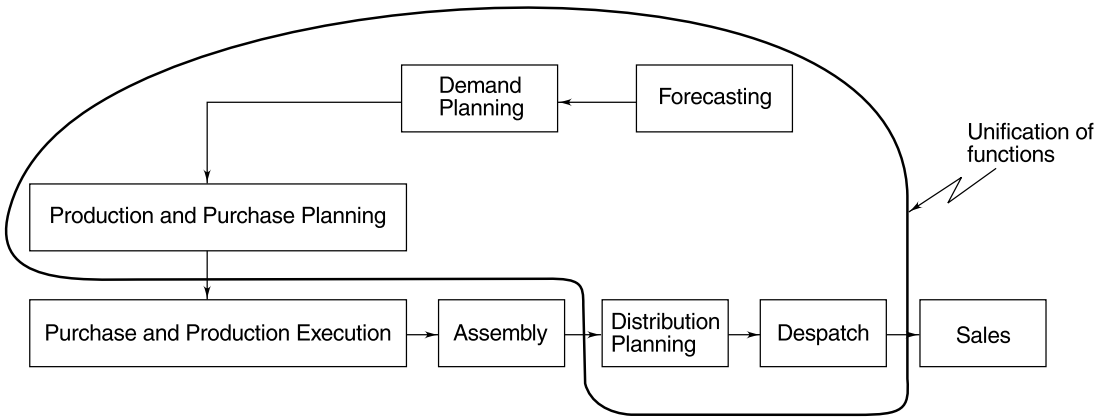


Figure 27.7 Integration of Earlier Functions into a Unified 'Supply Chain and Logistics Organisation'

General Manager heads this function. (Refer Fig. 27.7.)

The objective behind this grouping is:

- To optimise inventories.
- To improve the availability of the items as per the sales forecast.
- To ensure uniform supplies from Production department across the different weeks in a month.
- To monitor and control Logistics cost.

Collaborative Forecasting Process (for domestic trade)

In line with the Supply Chain Management ideology, the new forecasting process includes and integrates information inputs from the related functions/people. Brand managers, the Supply Chain and Logistics team, and key business associates provide the inputs. The process consists, *inter alia*:

- Regional Sales Managers identify a small number of Redistribution Stockists and WOTs (World of Titan) from each region for giving the needed input.
- These selected business associates give their requirements for a designated months ahead, each month.

- Product Management Group give its Regionwise/Productwise New Product plans for the same number of months ahead, each month.
- Supply Chain Officers take inputs from key Sales Officers and Regional Sales Managers.
- Based on these inputs, the Supply Chain Officers and the Regional Sales Managers together compute the Region's forecast for both the brands of watches.

This new process brings in much integration across the Company's Field Sales people, the Product Managers, the Business Associates and the Planning and Logistics people. A sense of 'ownership' and commitment to the goal gets promoted among all these groups. Sharing of information and improvements get a fillip.

Supply Chain Management is a vital aspect for an internationally competitive consumer article such as a watch. Titan has taken the right step to serve its customers better and strengthen its competitive position in the domestic and the international markets.

Courtesy: Titan Industries Ltd., Bangalore.

QUESTIONS FOR DISCUSSION

1. Is supply chain management a philosophy? Discuss.
2. What have the recent technological developments got to do with supply chain management? Discuss.
3. Describe the use of information technology in supply chains.
4. If a supply chain is a multi-tiered system, where should the chain stop?
5. Discuss the similarities and dissimilarities, if any, between Japanese Keiretsu and supply chains.
6. How does a supply chain make any company more competitive?
7. What are the comparative advantages of India? How are those useful in building supply chains with international partners?
8. Referring to Question 7, how are those comparative advantages likely to shift in the short-run and/or long-run? Discuss.
9. Discuss the concept of 'core competence' in relation to the supply chains. What if the core competence of a member company in a supply chain were to change after some time?
10. Are there risks in sharing information with other business partners? What are the safeguards for the same in the supply chains?
11. Can the principles of supply chain be applied within an organisation? How? Discuss.
12. Do you see similarities between the concepts and practice of Just-In-Time (JIT) system and that of supply chain management? Can JIT be applied in supply chain management? Give examples.
13. Can the designing of a product be outsourced? Discuss.
14. Are there any demerits of relationship-orientation in business? Certain countries are said to have too much of relationship-orientation. Is it an advantage or a disadvantage? Discuss.
15. In selecting suppliers, other than the criterion of price what should a company look for?
16. In this chapter, in the context of supply chains a purchasing manager is described as a coach. What is the significance of the word 'coach'? Discuss.

17. How can the services sector use the principles of supply chain management? Can there be supply chains in the service industry? Discuss.
18. Have the objectives of production and operations management changed over the years? Is supply chain management just another short-lived management fad? Discuss.

ASSIGNMENT QUESTION

1. Visit ancillary industries of a large organization. What is their operational relationship with the parent organization ? Present a management report including your recommendations for operational improvements.

28 Outsourcing

In the context of Supply Chain Management, outsourcing assumes much importance. After all, a supply chain is about a company and its vendors to who some of the component manu¬facturing or some other service/s are outsourced. In the modern day globalised world, 'supply chains' and 'outsourcing' are phrases that seem to be commonly known and talked about. In fact, 'outsourcing'—particularly when the developed country-based firms give a part of their work to the supply firms in the industrially less developed countries like say India or Bangladesh—has come in for much flack from the citizens of the developed countries. There has been much discussion about the job losses in latter countries—as perceived by the citizenry of those nations. There are many counter-arguments by the less developed 'supplier' nations.

WHAT IS OUTSOURCING?

If 'outsourcing' involved only purchasing components/material inputs or services from an outside company, like a phosphatic fertilizers company would buy rock phosphate, there would not have been any arguments regarding it. Behind these arguments and heartburn is the premise that the 'outsourcing firm' or country could have provided the input/service for itself; that the purchased service could have been provided internally—by the firm itself or by the nation (i.e. another firm, but within the nation) itself. It is this 'make or buy' decision that is being contested. Moreover, if it is a one-time or infrequent occurrence such as employing a management consultant to provide advisory services or other inputs, it is not called 'outsourcing'. Similarly, projects—got done by outside agencies—cannot be considered 'outsourcing' because these are one-time activities. For an activity to be called as 'outsourced', it has to be:

(1) a recurring activity and

(2) an activity that the organisation currently provides for itself or is normally expected to provide for itself.

The following Box No. 28.1 defines Outsourcing.

DEFINITION 28.1

Outsourcing can be defined as purchasing some of an organisation's recurring internal activities/services—which the organisation currently provides for itself, or most organisations normally provide for themselves—from an outside firm.

Therefore, when a firm buys some manufactured components from an outside supplier— when earlier it has been making those components in its own plant internally—or when a firm transfers its customer contact services to an outside service provider, the firm is said to have 'outsourced' those inputs/services. A certain firm may not have ever manufactured a particular item; but, if firms of that type can generally be expected to have their own manufacturing operations for such items, then it can be said that the firm 'outsources part of its manufacturing'. In fact, some firms never manufacture anything—for instance, the cosmetics firms like Avon and Amway, which concentrate on marketing. But, these firms are said to be 'outsourcing their manufacturing'; because, most companies generally carry out their own manufacturing operations.

However, when garbage is collected by certain agency, one does not say that the garbage collection is outsourced. Similarly, auditing is generally performed by outside agencies; but auditing is not said to have been outsourced. Thus, the definition of 'outsourcing' hinges on the 'accepted practice'. What is an accepted practice can change over time and so can the definition of what constitutes outsourcing.

Several times, the resources that make the component or service happen (like plant, machinery, technology, people, and information) are also transferred. So also, the decision-making responsibility over certain elements of the service could be transferred (i.e. given over) to the outside service/input provider. These things do happen between a company and its suppliers in a small or bigger way. In fact, the crux of a supply chain is in its 'integration' of activities between the various firms in the chain. In a strong supply chain, the resources and decision-making responsibilities are transferred in a large measure to the suppliers.

Offshoring

Globalisation is a rather recent phenomenon. A part of globalisation consists of outsourcing internationally i.e. the suppliers for the input/service could be firms based in foreign countries. This is called as "offshoring". While for the companies it makes sense to 'offshore' some of their operations and therefore they may take it as an accepted practice, the general population may not yet accept such a concept of transferring the factors of production—mainly, the jobs. This is one of the reasons for the opposition to 'offshoring' in the company's country. There may be other reasons also, which will be reviewed in a later section of this chapter.

THE BEGINNINGS OF OUTSOURCING: OUTSOURCING THE MANUFACTURING ACTIVITIES

Up until about 20 years ago, 'outsourcing' was minimal almost all over the world. A firm used to carry out almost all of its normally expected recurring activities internally.

However, manufacturing or production was one area where a firm would buy many of the

required components or other material inputs from the outside suppliers. Some of these components could have been made internally but the 'make or buy' decision came into play and the cost economics favoured these few components to be obtained from outside suppliers. A case on 'make or buy' decisions has been presented earlier in Chapter 2. Of course, several other components had necessarily to be obtained from outside sources, because the firm was not expected to be in the business of making those components. For instance, a company making engines was not expected to have its own foundry for the castings it required. The reason was: such a company's requirement of complex castings was small in numbers to justify its investing in a large foundry. To quote another example: Companies like Johnson and Johnson, in its business of Baby Products, or Ponds in its cosmetics products, are not expected to make their own perfume. These companies would buy these perfumes of desired specifications from their outside suppliers. Making perfumes is not their 'core' business; a perfume is one of the ingredients used in the manufacture of their Baby Health or Skin Care products.

Thus, "what is the 'core' business of a firm?" is a relevant consideration in answering the question as to "what can be outsourced?" A couple of decades ago, in most of the industries, manufacturing was a major function that used a large fraction of the firm's capital investment, personnel and management time. Therefore when cost-based competition increased, firms started looking at outsourcing options for some of the items or components that were until then manufactured internally. Cost economy and 'core business' were the fundamental considerations in such outsourcing decisions. If some item or component was available cheaper if procured from outside and if such an action was not in any way tantamount to 'giving away' its core business, the firm might decide to outsource that part of its manufacturing.

Merits and Demerits of Outsourcing Manufacturing

A consideration of primary merit is that the supplier is more efficient in producing an item. He can provide the same item/component of the required quality level at a price that is significantly less than the cost to manufacture internally. A reason for the lower costs could be that the wages for labour are lower in the supplier company. The latter may be situated in a different country, state or county where such lower wages are possible. In an international context, a foreign outsourcing arrangement may sometimes mean reduced tax liabilities. A foreign manufacturer may also be eligible to receive the local government's subsidies.

Another reason could be that the supplier may be catering to a number of other firms and can obtain his raw materials at lower costs because he purchases them in large quantities. Moreover, the fact that he supplies to a number of customers would allow the supplier to operate at almost 100 per cent capacity; this results in high production efficiency as the overheads are spread thin over a large volume of production.

Over time, the supplier may become so proficient in the item that he may develop special skills in manufacturing it; this would result in further cost economies and/or better quality. He may even develop a novel technology in producing the item, thus being able to supply a better quality item and a more improved version/design of the item at lower cost.

Some supplier firms may be able to manufacture the item at a significantly higher speed than the buyer firm could. By outsourcing a part of its manufacturing to this supplier, the buyer firm, therefore, becomes that much faster in meeting its market needs. That is, a supplier can add to the 'agility' of a firm.

Since the supplier has taken away a part of the buyer firm's portfolio of activities, the buyer firm can now devote more management time and attention to other more important (nearer the 'core') activities. Its 'focus' improves.

For a start-up company, outsourcing of a part of its manufacturing activities gives immediate access to a large production capacity that it otherwise would find difficult to have due to limited capital availability.

Of course, the choice of a supplier and the orientation and integration of the supplier into a firm's supply chain are very important considerations. If the supply chain considerations have not been given their proper due, the demerits of the old production and materials supplies system could manifest. These are mentioned below.

For the supplier, the purchasing firm may not be a large customer amongst his several customers. If so, the supplier may neglect the small customer in favour of the larger customer. This could result in problems in coordinating production for the purchasing firm. Also there could be the old syndrome of supplier playing one customer against the other. In a very different but scarier scenario, the larger customer—if it is a competitor—may buy out the supplier thus throttling the production process of the smaller purchasing firm.

If a firm gets certain items made through a supplier, there may be a lurking fear that the supplier may steal the technological and other secrets and may pass them on to the buyer firm's competitors. Outsourcing of manufacturing is not desirable for a firm that has developed a cutting-edge technology, design or other expertise. Keeping the production 'in house' would be a wiser course. Of course, all this is true under a scenario where trust is lacking between the supplier and the buyer firms. To the extent that a supply chain has these weaknesses, these concerns will be justified. To that extent, the more routine items could be procured through the supplier while retaining manufacturing of the cutting edge technology items 'in house'.

The other aspect of giving over the control of a part of the production to the suppliers is a concern that the supplier/s may engage in illegal activities sullying the reputation of the parent company. For example, it was reported that the multinational giant Gap employed child labour in the manufacture of some of its products. Gap depends on suppliers in many developing countries who may be involved in employing child labour, as it is cheap. The practice may be socio-economically acceptable in those countries but highly unacceptable to the parent company and/or to the markets/countries where the goods are sold.

Another concern would be regarding the political risks in the country/state where the supplier is situated. When a supplier is inducted into the parent company's team, the political risks are also a part and parcel of the deal. To that extent, the parent company loses control over a part of its production.

The rapidly and expanding telecommunications and information technologies have, in the recent years, made the coordination between different firms far easier. The increase in the speed and facilitation of transport globally has effectively reduced the 'distances'. Technologies now no more remain for long in one firm or in one country. The flow of finances across regions and nations has also increased substantially. These factors have facilitated the formation of supply chains, nationally and globally. Outsourcing of manufacturing has become a useful strategic option. Speaking about the business culture, businesses have grown to include 'trust' as an important part of the deal between each other. Merits of outsourcing now tend to overweigh the demerits.

The following table (Table 28.1) presents a summary of the merits of and concerns regarding outsourcing of manufacturing.

Table 28.1 Some Merits of and Concerns Regarding Outsourcing Manufacturing

Merits	*Concerns*
Increased efficiencies - mainly in cost; sometimes, in quality.	Concerns regarding a loss of control over (outsourced) operations—the methods and means used, the actual speed of delivery, the quality of products.
Increase in 'speed' to market.	Concerns regarding theft of technology.
Immediate access to additional production capacity—particularly important for a start-up company.	Concerns regarding betrayal of trust and defection to a competitor.
Capital investment in production facilities is avoided. Frees up the capital for other more important purposes.	Political risks associated with the supplier's country/region.
Converts fixed costs into variable costs.	
Frees up management time to focus on more important issues/aspects of the company's business.	

Different Ways of Outsourcing the Manufacturing Process

Manufacturing can be outsourced in a number of ways. All of these options of outsourcing are in operation today, different companies adopting a different option.

I. ***Outsource the manufacture of components*** This is the age-old way of outsourcing. For instance, the automobile producers have always relied on such an option. Aerospace and defence industries, electronics firms are found using this type of outsourcing. In pharmaceutical formulations, several medicinal ingredients are obtained through such outsourcing method. (Refer to Fig. 28.1 below.)

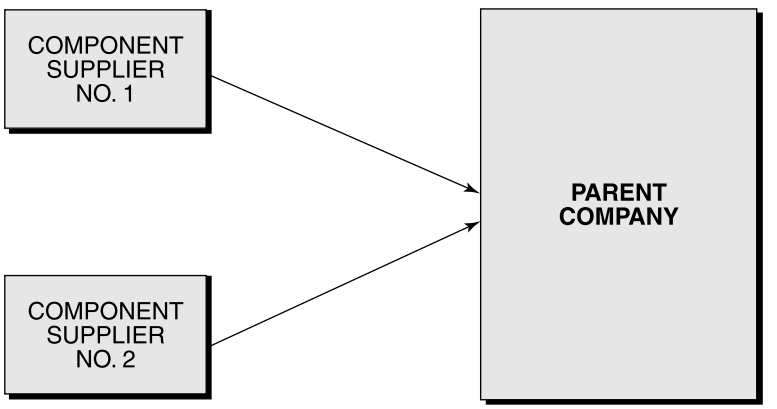


Figure 28.1 Outsourcing Components

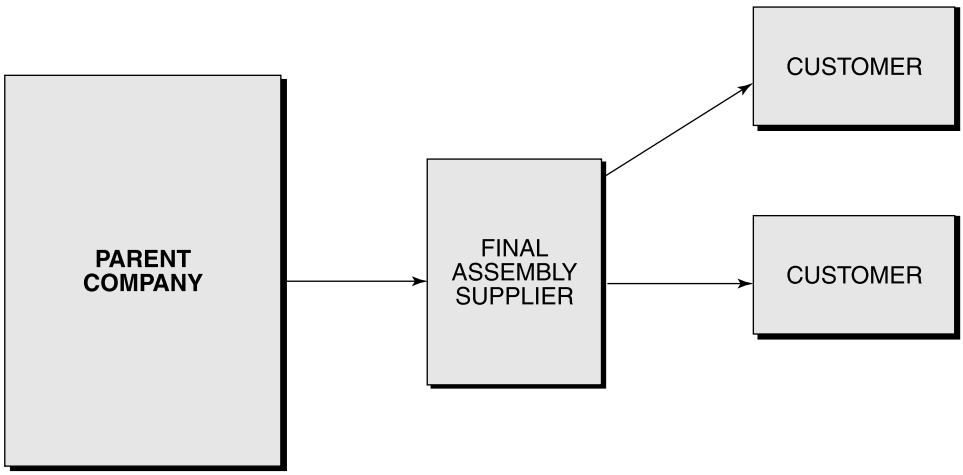


Figure 28.2 Outsourcing Final Assembly

2. ***Outsource the assembling of the final product*** In the personal computer industry, this option is quite common. An outside firm—a distributor—assembles the final product (personal computer) according to the requirements of the customers and ships it directly to the customer. Figure 28.2 given below depicts the same. In this mode of outsourcing, the parent company avoids the cost of having a stock of finished goods inventory. It also avoids the risk of holding a stock of finished goods that could go obsolete. The parent company manufactures (and also sources) the parts and supplies the same to the assembler. The parent company is not abdicating its marketing and customer contact functions. It is only using the vendor (the distributor) to serve the inventory holding and shipping (to the customer) functions, thus increasing the speed of the customer service, in addition. Final assembly, logistics and customer-facing (the vendor is the face of the parent company to the customer) are the main functions served by the vendor.
3. ***Outsource the entire production (manufacturing and sourcing of parts)*** The parent company relinquishes all of the production function. The 'supplier' handles the entire manufacturing and sourcing of the various components and the final assembly work. Figure 28.3 given below depicts the same. This practice is quite common in the electronics industry today. Hewlett-Packard and Cisco outsource the manufacturing of their entire product lines to companies such as Flextronics, Solectron and Celestica. The latter companies may be called as 'Contract Manufacturers'. The 'contract' to manufacture is preferably for a long period of time; but that need not always be so. Some contract manufacturers may buy out the existing production facilities of the parent company and contract to manufacture the products for the parent company at that location under a long-term contract. Generally, contract manufacturer would have his own manufacturing facilities.

In addition to the electronics industry, contract manufacturing is used in the white goods (consumer durables) industry.

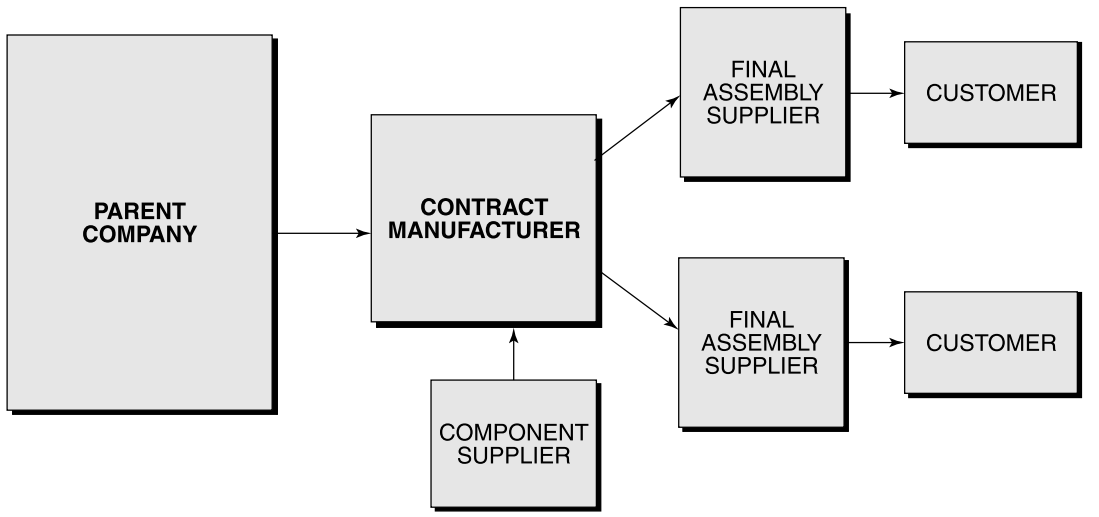


Figure 28.3 "Contract Manufacturing" or Outsourcing Entire Manufacturing Function

Personal care products is another industry where 'contract manufacturing' is commonly used. The parent company hands over the entire manufacturing and logistics (supplying the products to the distributors or retail outlets) of its line of products to another firm. The contract manufacturer firm obtains the required inputs from other sources, produces some of the needed ingredients, blends and/or performs all other manufacturing operations, packs the products and sends the finished-and-packaged final products to the destinations in the market as desired by the parent firm. The parent firm provides the design or formulation of its line of products and in some cases also specifies the process. What the final product should be, in what mode it should it be packed, stored and transported is the decision of the parent firm. Most of the time, the ingredients—including their quality—that make the final product are also specified. The parent company handles (or owns) the design and IPR—i.e. the concept of the product—and the marketing functions. In some cases, the contract manufacturer takes the responsibility of marketing the product/s using the parent company's brand and provides after-sales support as well.

Food products is one more industry where contract manufacturing is used. The reasons could be related to the perishability of the input items and the regional availability of the ingredients. There is perishability of another kind. In the food industry, innovation and new product introduction have been the key drivers. New snack foods, specialty cereals, and candy-bars come and go. The production volumes of one company may not justify investment in plant and equipment. The company needs to focus its energies into innovating, advertising, marketing, managing the brand and ensuring effective distribution of the items. Hence, contract manufacturing makes much sense to that company.

Contract manufacturing is not yet popular in the automobile manufacturing industry. Many auto-makers get all the components from the suppliers and do mainly assembling and painting. But they stop at that.

CONTRACT MANUFACTURING IN THE COMPUTER HARDWARE INDUSTRY 28.2

In the computer industry, Solectron, SCI, Flextronics, Celestica and Jabil have emerged as large contract manufacturers. Globally, contract manufacturing in the computer hardware industry is very large—of several hundred billions of U.S. dollars—and is growing rapidly. The five firms mentioned account for over one-third of the global contract manufacturing market. India has a few firms that are making a foray into this contract manufacturing business. TVS Electronics with an infrastructure to make computer printers, power supply units and other hardware, and WeP Peripherals—which manufactures dot-matrix printers and electronic typewriters—are two such examples.

The contract manufacturer's cost economies and quality depend upon the availability of quality components at low costs from the local component suppliers. Also significant would be the availability of good ports for quick shipping of manufactured items to the international destinations. At the present, Indian contract manufacturing suffers from a drawback on these two counts. The volumes of electronic and computer related components are not large enough to generate economies of scale, and ports are nowhere near world class.

Why Do Some Companies Give Away Entire Manufacturing on Contract?

A question may be asked as to "why does the parent company hand over the entire manufacturing function to another firm?" The answer lies in what the parent company perceives as its 'core' and 'non-core' activities or functions. If a company's strategy is to concentrate on its research and development and design strengths and on marketing the product, the company may outsource the entire manufacturing to another firm who provides efficient and quality manufacturing services. The manufacturing process, in such cases, may not involve any new manufacturing technology. The problem of the leaking of process secrets may be relatively unimportant. Most of the uniqueness of the company may lie in its product design (which would be patented) and marketing. Manufacturing function may be seen as a 'non-core' activity, which if outsourced to a reliable partner would do no harm—instead it would free the company to focus all its energies on its main or core activities that majorly contribute to its competitive strength in its genre of industry. Today's industrial climate is such that a company needs to mainly do what it does best. 'Core'-and - 'Non-core' has emerged as an important consideration/concept in today's competitive business world.

Moreover, with the business activities expanded across the globe, it is possible to get different kinds of specialist firms to perform specialist functions. For instance, if the Indian pharmaceutical firms are efficient at the bulk production of drugs, it makes competitive business sense for a multinational pharma giant to give away contract manufacturing of several of its lines of pharmaceutical products to an Indian pharma company, while retaining the manufacture of 'core' products and product lines in house. Many Indian pharmaceutical firms are contract manufacturing product lines such as tablets, injectibles, syrups, etc for multinational drug companies. This proves cost efficient for the parent multinationals without compromising on quality and good manufacturing practices and with relatively less risk of the infringement of Intellectual Property Rights. Moreover, the multinational drug company can concentrate on what it does best viz. development of new drugs and formulations and marketing-and-distribution of the same all over the world.

India as a Destination for Contract Manufacturing in Pharmaceuticals

Worldwide, as the patents for the active pharmaceutical ingredients (APIs) expire and competition is hotting up with several new players entering the arena, pharmaceutical global giants are

increasingly focusing on low cost manufacture of APIs and looking for contract manufacturing partners. India is emerging as one of the desirable destinations for the same due to the lower costs of production, acceptable quality, and ready availability of expertise in pharmaceutical product development. India never had 'product patents' for pharmaceutical ingredients; it had 'process patents'. Hence, drugs manufacturers in India had much expertise in the manufacture of many drugs—including APIs—that were patented in other countries. Today India has a good base of pharmaceutical industry and has a pool of talented personnel in pharmaceutical and biotech research. The industry has always made pharmaceuticals (bulk drugs as well as formulations and preparations) that were affordable for the general Indian population.

DISHMAN: AN INDIAN CONTRACT MANUFACTURER* 28.3

Dishman Pharmaceuticals & Chemicals Limited, headquartered in Ahmedabad, India, is a globally focused company, involved in the manufacture of APIs (active pharmaceutical ingredients), API intermediates, quaternary compounds and fine chemicals. The company is set to emerge as one of India's leading contract manufacturing organisations for GMP and non-GMP pharma intermediates and actives.

The rapidly evolving pharmaceutical market scenario has necessitated the multinationals to focus on their core competencies and to outsource chemical manufacturing and research services for New Chemical Entities (NCEs). Since Dishman has experience in process innovation, as well as being able to provide required manufacturing facilities, it has been able to cater to the outsourcing needs of such multi-nationals.

Dishman's strategy is to emerge as a strong contract manufacturing partner by working closely with global chemical and pharmaceutical inventor/patent holder companies only. Also its focus is on manufacturing only APIs and intermediates and not formulations, thereby avoiding any conflicting business situation with the client.

Dishman has a very systematic approach towards the execution of contract manufacturing projects. In order to plan and control the execution of the relevant project activities in such a way that the goals of the project are achieved in the set time frame, a Joint Project Team (JPT) is formed. The team is headed jointly by project leaders at both the ends and constitutes members from each side for all responsible departments namely, QA and RA, chemistry, analytical development and technology. The composition is such that for every member from the customer's side, there is a counterpart and direct contact from Dishman. Emphasis is on direct communication between the counterparts to discuss related issues, keeping both project leaders informed. The JPT meets on a regular basis to review the progress of the project, by means of face-to-face meetings, teleconference and video conference. Minutes of all meetings are recorded properly and the action lists are reviewed and updated regularly.

Dishman's site at Bavla, Gujarat, was developed keeping in focus the company's contract manufacturing and research activities. The company has also acquired 80,000 sq.m. industrial plot in Shanghai Chemical Industry Park (SCIP), China, with the same purpose in mind. Products are dispatched from its factories and can be transported directly to its customers' airport or seaport of choice, or else delivered to a nominated inland destination. Based at headquarters in London, Dishman Europe's dedicated Logistics Division manages the flow of products across the company's international supply networks in an efficient, compliant and timely manner.

* Courtesy : Dishman Pharmaceuticals & Chemicals Limited, Ahmedabad.

Contract Research Outsourcing (CRO)

In order to give impetus to the contract manufacturing assignments—both in the pharma and non-pharma segments—and to capitalise on the potential outsourcing market related to the pharmaceutical and chemical industries, Dishman has developed and strengthened its contract research capabilities of APIs and intermediates. Contract research and process improvement of contract manufactured molecules form an integral part of Dishman's R&D focus. Towards this end it has state of the art R&D and pilot facilities, and highly skilled research teams headed by project leaders, dedicated for individual projects. These teams work in a '24/7' system.

Contract manufacturing could thus be a part of the business strategy. Such a move can increase the reach and the speed of response, and decrease the cost to the customer without compromising on the basic strengths of the company. In fact, such a strategic move helps the company to concentrate on its basic or core strengths and to develop them further in order to get an unassailable lead over its competitors.

Conventional Outsourcing and Transformational Outsourcing

Outsourcing is being generally used by companies when:

(a) The outsourced activity is "non-core" i.e. when the partner firm runs only a 'support function or activity'.

(b) Outsourcing offers cost benefits (e.g. by outsourcing the manufacture of certain items to China or Philippines—low wage countries—would offer substantial cost benefits).

(c) Outsourcing less important activities makes available to the parent company more time to attend to more important "core" activities.

All of the above has been the conventional thinking. The benefits accrued by outsourcing on that basis would also be equally conventional or conservative. To take a simple example: If the payroll work of a company is outsourced, there may be cost savings—a reduction in the number of staff to handle and perhaps less of hassles—but, the impact on the long-term business of the company may only be negligible. Neither the bottom line nor the top line of the company will be radically changed. On a similar note, if a multinational company outsources the manufacture of some components to an Indian auto-parts company, there are obvious cost reductions. But, we cannot say that there would be a long-term impact on the business of the multinational. The decision to outsource, in the present day circumstances, is still—in a large majority of cases—treated as a tactical move; it is not perceived as a strategic decision.

Outsourcing has to do with effective partnering. It is after all a part of the supply chain concept. Supply chains can be used for a bit-by-bit improvement or they could be used for a radical improvement in the competiveness of the firms. The "why" of supply chains or of outsourcing is very important. The "What" and "How to" of outsourcing follow the response to the "why" question. Organisations have to decide as to whether the outsourcing is for:

(a) Running a support function/activity or for

(b) Collaborating to transform the business.

In case (a), the intensity of integration between the partner firms will be much lower than in case (b). Critical skills, capacities, plans and strategies are shared in case (b). In the latter case, there is much synergy between the partners in terms of the systems, processes and culture.

A question may be asked: "Isn't case (b) type of outsourcing akin to a joint venture?" The answer is a "no". While a JV has the critical capabilities segregated, in a strategic outsourcing these capabilities are integrated. Then, is it akin to 'acquiring' a company? The answer is, again, in the negative. If the parent company were to acquire the 'outsource' company, it will only lead to the parent company's managers managing the critical skills/activities, which is not what is desired to begin with. Then, is it a 'strategic partnership'? It is not even strategic partnership, which has a connotation of being in partnership 'as long it suits either of them'. Strategic outsourcing is a unique way of long term partnering where the critical business activities, information, plans and skills are shared, yet for bringing out the best in both partners, there is little confusion as to who will do the critical activities—the strategic initiatives mainly rest with the parent company while the special skilled activities are left to be done by the outsource partner firm who is an expert in these activities. The objectives and roles are clear on either side. The drive is towards transforming through partnering to achieve rapid, radical, enterprise-level performance improvements.

Let us take the case of contract manufacturing. If a company uses this vehicle for just cutting costs, it may yield short-term results. But, with increasing competition, the margins get thinner and thinner for the contract manufacturer—because competitors are doing much the same thing—until a situation arises where he is almost driven out of business. This is not tenable. Therefore, it would be preferable to have a long-term relationship between the two wherein the two firms are welded together so that this permanency allows the supplier to make capital investment for process improvement that is beneficial for both firms. Thus, the two firms collaborate to transform the business together. An excellent supply chain involves these kinds of transformational collaborations between the links of the chain. Transformation means a considerable, rapid, sustainable, step-change improvement. It could be in various areas: cost efficiency, quality, speed (time) to the market, innovation in product design, service features, customer reach, service quality, customer loyalty, customer addition, and the top line and bottom line.

There are different stages in the life cycle of a company and transformational outsourcing can be used appropriately in each stage.

I. ***Start-up Stage*** For new-startup-companies the speed to market is vital. Outsourcing can help them put well-oiled operations in place quickly. They need to have a mature production facility where none existed, create a market when nothing existed, and compete with the established players without spending much of the scarce capital—all at a rapid pace since the time taken to do all these is very critical for their success and even for their very survival.

2. ***Growth Stage*** For companies that are in the growth stage, their need is to ensure that the growth is rapid and smooth. Outsourcing can help these companies to remove any hindrances or obstacles in the way to their growth. The partner should help them by supplying the missing or deficient capability—it could be anything from specific manufacturing skill, cost efficiency, flexibility and agility, quality management expertise, developing new products, to marketing or information technology.

3. ***Maturity stage*** Companies that have reached the flat of their growth curve need to be infused with new competitive ideas in order to put them into another growth trajectory. They need new blood—a process of rejuvenation or reinvention—possibly through outsourcing. These stages are shown in (Fig. 28.4).[1]

[1]Adapted from Linder, Jane C, "Outsourcing for Radical Change", Amacom, NY, 2004.

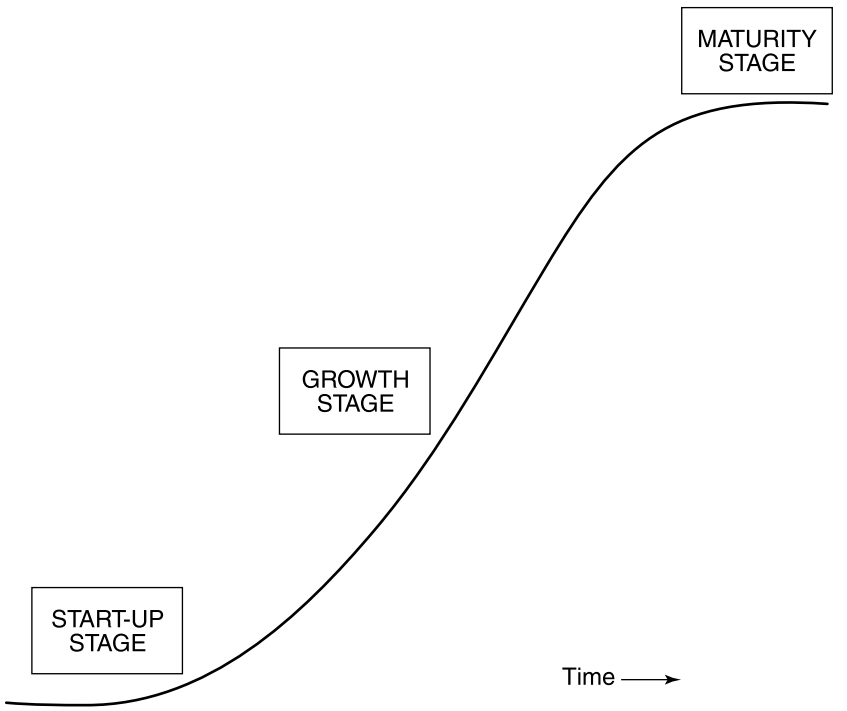


Figure 28.4 Growth Curve for a Company

BUSINESS PROCESS OUTSOURCING (BPO)

Manufacturing is only one amongst the many processes of the entire business of a company. Several other business processes can be outsourced. There are, as we all know, various services needed in any firm or organisation. People contact, customer contact, marketing, order handling, after-sales support, logistics (distribution and delivery), human resources management, accounting, account recoveries, payrolls, purchasing / procurement of materials and equipment, inventory management, warehousing, IT services and electronic data processing, facilities management, are some of the processes in an organisation.

A large number of organisations are 'service' organisations and not manufacturers. For instance, airlines, railways, hotels, hospitals, schools, telecommunication companies, media, entertainment industry are all organisations that are in the business of providing various services. But all these organisations have sales, marketing, order handling, customer contact, human resources, payrolls and accounting, account receivables handling and IT as a part of their business activities or business processes.

One or several of these business processes can be outsourced—handed over to an external service provider—if such a move is advantageous to the organisation. The various kinds of business process outsourcing (BPO) are depicted in Fig. 28.5.[2]

[2] Gartner, as quoted in Patel A.B. and H. Aran, "Outsourcing Success: the managerial imperative", Palgrave, NY, 2005, pg 7.

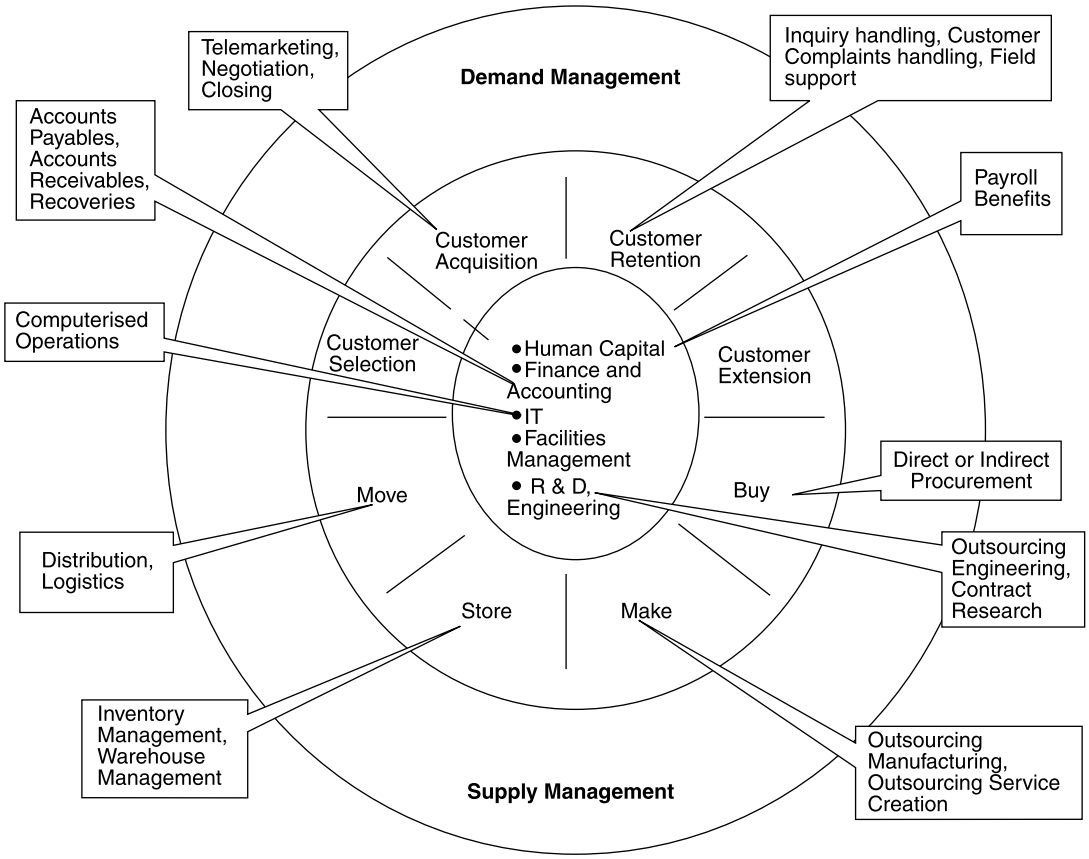


Figure 28.5 Various Business Process Outsourcing (BPO) Options

Popular Misconceptions about Outsourcing and BPOs

While that is so, the popular perception about BPO is that of a call centre where customer complaints are handled on behalf of the parent company. For instance, if a refrigerator were to malfunction or if there were queries regarding insurance claims and if a complaint was to be registered, one would interface with a call centre or BPO that is appointed by the equipment manufacturer or the insurance company. A customer would not directly interface with the original equipment manufacturer or original service provider. The BPO industry started with these basic customer complaint management services and hence this perception. These were called IT-enabled services because the call centre depended largely on the computerised records and registers regarding the customers and the complaints.

Information Technology (IT) services outsourcing started during the 1980s and grew rapidly during the last two decades. One of the first developments was the handling of payrolls—a service that could be easily computerised. Companies were relieved of the drudgery of preparing the payrolls month after month. This was purely sub-contracted electronic data processing. IT services moved further as many companies—manufacturing, transport, telecommunications, etc.—got

the computer software for their services developed and maintained by low-cost countries such as India where there were large number of graduate engineers available who could handle computer software development with ease. For instance, as early as in the late 1980s, an Indian company did the entire scheduling and controlling of London Underground (trains) network.

With the rapid growth in the IT services outsourcing (rather offshoring, as the work came from the developed countries to the developing countries such as India and Philippines), the offshoring of the IT-dependent services also grew at a fast rate. For instance, Network Rail in UK outsourced timetable enquiries to India in 2003. This is indeed the work of a call centre.

But, not all BPOs are call centres. People generally tend to equate outsourcing to two entities: IT services and the call centres. This is a misconception. BPO is a concept that encompasses all kinds of processes—many of them involving specialised expertise. It would be incorrect to think of all BPOs as call centres.

There are several operations (rather, 'business processes'—as these are customer oriented bunch of related operations) in different areas that can be outsourced. As Fig. 28.5 shows, in the area of production itself, warehousing and inventory management can be outsourced. Warehouses need neither belong to nor be managed by the producing company. For overseas marketing operations, when the volumes are not conducive to cost efficiencies, it may be wise to opt for outsourcing the warehousing operations. Logistics is often outsourced in several organisations; and distribution may also be outsourced. Procurement can be outsourced when the organisation to who it is outsourced can do a better job at bargaining, getting discounts, searching for right quality input materials, getting timely and reliable supplies, etc because of the large volumes and/or expertise in the particular input materials market. Specialist compa¬nies may do a better job in several dimensions. They not only perform the physical operations, but also provide the critical knowledge—tacit and/or explicit.

Deciding on Outsourcing

As mentioned earlier, several processes or activities can be outsourced. The dictum in the modern day business world is: If any particular business process is merely a commodity to the organisation, and if that organisation could buy it from another supplier without possibly affecting the quality of its products and services—in the short-run or in the long-run, that business process could be a candidate to be considered for outsourcing. This is basically nothing but the 'core' versus 'non-core' processes concept. Whatever is the 'core competence' of the firm should be kept in house.

The processes that are not part of the organisation's core competence or the fundamental value proposition should be outsourced if there is competitive advantage possible in so doing. 'Competitive advantage'—a mental concept—is figured out by taking a sum total of the advantages minus the risks in the context of the prevalent and expected competition. Microsoft Corporation by itself virtually does nothing other than Research in software development. Rest of the processes of this huge organisation are all outsourced. Research in software is its fundamental value proposition and the core competence.

It would be interesting to note that in some other IT software services companies, the competence is now seen as marketing and selling. Domain skills are not necessarily 'core' for these IT companies.

It must be added that certain activities that are part of the 'core' processes can also be outsourced if there is a clear and overwhelming competitive advantage in so doing. One need not be a purist.

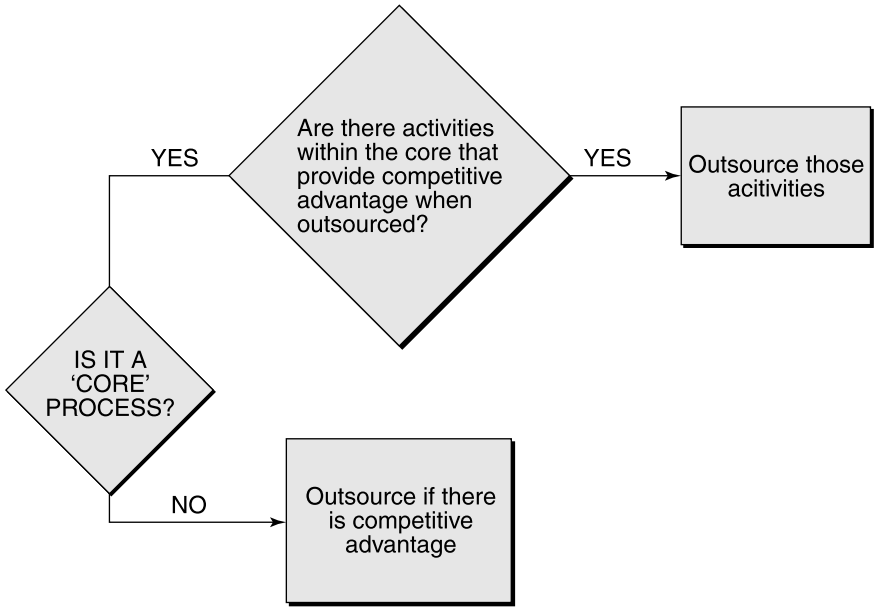


Figure 28.6 Outsourcing Decision

For instance, some activities within the research & development at Microsoft are outsourced. Some software development and support work is outsourced to Indian software and services companies. Microsoft has a product development centre in Hyderabad in India. Its Bangalore lab will collaborate with and fund research at key educational institutions in India. Outsourcing is not just for short-term gains; it can be for long-term 'transformational' benefits.

Hence, the basic questions that should be asked before outsourcing the processes or activities are:

(1) What is the firm's fundamental value proposition?
(2) What is the firm's 'core competence'?
(3) What are the firm's 'non-core' processes?
(4) Is there a 'competitive advantage' in outsourcing some or all of these non-core processes?
(5) Is there a competitive advantage in outsourcing some of the activities of even the 'core' processes?

'Core' and 'competitive advantage' are the two touchstones in the "what may be outsourced?" decision. Figure 28.6 depicts the same.

OUTSOURCING OF SERVICES

Few decades ago, firms worldwide did not seriously think about outsourcing of services. While one could outsource the physical parts and components that could be assembled in the parent company's factory, one could not imagine as to how the same could be done with respect to the multitude of services. Therefore, most of the services remained in house.

Industrialisation of Services

But now, with the explosion of the information technology and telecommunications technology, there is a sea change. As Professor Uday Karmarkar of the University of California mentions, "the industrialisation of services" has taken place. He says that technology has created an "information assembly line". Information can now be standardised, built to order, assembled from components, picked, packed, stored and shipped, all using a process resembling manufacturing's assembly line. Information technology has revolutionised service industry and services in general.

Industrialised service value chain can now be treated almost just like the physical products value chain of a manufacturing industry. Several services, *in toto* or in parts, can now be outsourced for improved efficiencies, reduced costs, better quality, and faster and agile response to market situations.

Types of Services Outsourced

Services that can be outsourced can be classified into two classes:

1. Horizontal services and
2. Vertical services.

Horizontal Services

These are the spectrum of services within an individual organisation. For instance, a firm has demand management functions/services like customer selection, customer acquisition, customer retention and customer extension. The firm also generally has other central functions like human resources management, finance and accounting, administration, and in some cases, design and research & development. Any of these is a candidate for outsourcing; whether and where it is outsourced depends upon the outsourcing decision as depicted in Fig. 28.6 earlier.

Sales and Marketing

Globally, maximum spend on outsourcing takes place in sales and marketing processes. This business process is highly contracted out by firms whose customer base is very wide and spread out. For instance, many financial services (e.g. home loans, personal loans) companies use outsourcing in a large measure in order to catch a large number of desirable kind of customers into their net. They find that outsourcing is cheaper, produces good results and generally keeps them away from the hassles of selling which is not their core competence. All that they need to do is to lay down ground rules for customer selection and for customer-salesperson interaction.

Some companies need 24/7 contact with their customers and potential customers, for instance, the airline companies (e.g. reservation services), on-line information services, and several Internet services. Outsourcing may be essential in these cases.

Customer care is a major service offered by all kinds of industries. This involves technical or other advice, offering information on products/services and on customer transactions, registration of customers' complaints and tracking progress, etc. These interactions need special skills, training, dedicated staff and accessibility to the customer at all times or during a large portion of the day.

Human Resources Management

Human resources management is one of the majorly outsourced processes worldwide. Although it is a very important function as far as the employee motivation and leadership is concerned, there are many activities in this function that are repetitive and do not substantially contribute

to the firm's competitiveness. For instance, employee payroll and benefits administration involves non-core activities like preparing statements on pay, incentives, commissions, bonus, reimbursement of expenses on telephone and travel, housing rent reimbursement and other benefits to the employees. Employee leave and other personnel records—including their performance related records—also need to be maintained.

Many a time a large portion of the recruitment process is outsourced to head-hunters and recruitment consultants. Only the last stage of interview and finalisation of the compensation and other terms may be done by the parent company.

Employee training is another activity that is outsourced in a big way by the companies. When certain new specialist skills and knowledge are to be imparted to the employees, it makes sense to hire a consultant who is a specialist in those fields. Routine training can also be handled by an outside agency provided the parameters have been clearly laid down by the parent company. Perhaps, what might remain for the parent company to do would be the on-the-job training.

The core activity of the human resources department would be to decide on the goals of HR action and on the plan of action—in the light of the company's business and strategy—and to orchestrate the different activities so as to achieve the desired goals.

Therefore, a firm should ideally outsource several human resources (HR) activities wherever it is advantageous to do so. Worldwide there is a new trend towards comprehensive HR outsourcing contracts. HR outsourcing is witnessing a rapid growth.

Transactions Processing

Organisations, particularly the service organisations, have several transactions with customers to be processed. For instance, banks have a lot of cheques to process every day, in addition to loans related transactions, and credit card transactions. These back-office operations are good candidates for outsourcing. Many Indian BPOs are involved in this business for several banks based abroad.

Finance and Accounting

Keeping a track of accounts payables and accounts receivables and managing them is, generally, a non-core activity. Similarly funds flows accounting and cash flow management need not be core to a company. Keeping a tab on the fixed assets may also be non-core. Periodic auditing, financial reporting (e.g. quarterly financial reports), and managing the IPOs (initial public offerings) of the company's equity can also be outsourced.

Financial Research

Financial analysis and financial modelling are some of the activities that are outsourced these days. Global financial services majors such as J.P. Morgan, Morgan Stanley, HSBC and Merrill Lynch have, in recent years, established research bases in India. Indian financial analysis and research personnel come at a fraction of the cost in the US or other western countries. Much of the research process involves obtaining/collecting data, routine scrutinising, standard analysis and modelling which might be non-core and non-confidential to the parent company. It is predicted that by 2011 India will have more than 20,000 qualified financial analysts. This country already has over 100,000 certified chartered accountants. In addition, there are several MBA graduates with finance as a major. With a growing number of Indian companies listing on American stock exchanges, Indian finance professionals are acquiring domain knowledge in US GAAP and are getting conversant with evolving regulatory guidelines such as Sarbanes-Oxley and other requirements. Research is probably the easiest investment banking service that can be duplicated in India. Technology has

reduced the need for physical presence. Hence, these activities are being increasingly outsourced to countries like India. According to a study by the renowned management consulting firm A.T. Kearney, the US banks and other financial institutions may offshore more than 500,000 jobs. Although the global financial meltdown of 2008-2009 may put a dampener on this figure, the latter shows the scope for such outsourcing.

Engineering, Design and R&D

One obvious question that arises is that how safe is it to outsource a crucial function such as either Engineering or R&D to an outside firm. Engineering development, new designs, and research breakthroughs may be the competitive strength of a company. Would this vital information not find its way to the competitors through the suppliers? Wouldn't a supplier of such services hold the parent company to ransom as he holds the keys to the very survival of the company? No doubt, these objections are valid.

But, sometimes there are situations like a rush order to a customer to be fulfilled requiring new design in a short period of time. It may be better to fill the order by outsourcing to a firm that is an expert in engineering design of the needed product, rather than losing the order itself. New business opportunity outweighs the risk factor of possible knowledge-leaks to a competitor. Such outsourcing options are helpful to smaller firms that cannot afford a full-fledged large engineering establishment in house.

Flextronics is a large contract manufacturer; but this company is also an original design manufacturer (ODM) i.e. the company converts a customer's marketing concept into a product design and then produces it also. This, indeed, shows what the future can hold for the outsourcing of engineering function. When a firm has a poorly managed engineering function, when fluctuations in the number of engineering jobs are very large and when a specialist supplier's engineering staff is obviously better versed it may be worth considering outsourcing of the engineering jobs.

Contract Research

But, the interesting developments these days are that of Contract Research. This is particularly gaining ground in the pharmaceutical industry. Within drugs research, there are many non-core activities including pharmaceutical formulations, drug trials on people/patients. Several of these activities may not carry much risk of the competitors obtaining crucial information. This is not breakthrough research, but routine investigations. Several Indian pharmaceutical firms have taken up contract research work for major multinational drug companies. Because of the availability of highly educated scientific talent in India—at a fraction of the pay packet for a similarly qualified and competent person in the western countries—'contract research' has a huge potential in India. The only damper is that the Intellectual Property regulation is not very tight in India. If the government gets the act together in that respect, India can become a major destination for such outsourcing.

Legal Consultation

Many corporate legal processes are now being outsourced. In addition to the routine legal issues, the outsourced processes include patent reviews, patent infringement cases, due diligence, and compliance with the regulations in different states and countries. Countries like India that have highly qualified talent present a huge cost advantage; a lawyer in India starts at a salary of about Rs. 400,000 (about US $ 10,000) per annum, compared to $ 150,000 in the USA.

Knowledge Process Outsourcing (KPO)

KPO involves outsourcing high-end knowledge work. This includes technological research including engineering design, computer aided simulation, research on equity and finance, analytics, work on intellectual property and patent documentation, legal advisory and other services, market research, data mining, and analysing information from piles of data present across various functional units of a firm and helping it to define effective business strategies. Most of these activities were mentioned in our preceding discussions. While knowledge management is a process that is critical to a firm's value addition, outsourcing help can be sought for the tedious parts of the process.

Off shoring research and development in pharmaceuticals and biotechnology holds great potential for KPO. So is the case for financial research. KPO is driven by the depth of knowledge, research capabilities and low costs of knowledge manpower. While India meets these requirements, it has several other competitors like China, Russia, Ireland, Czech Republic and Israel.

Table 28.2 mentions some of the horizontal services that can be outsourced.

TABLE 28.2 Some of the Horizontal Services That Can Be Outsourced

Sales And Marketing Management	*Human Resources*	*Transactions Processing*	*Finance And Accounting*	*Financial Research*	*Engineering, Design, R&D*	*Legal Consultation*
• Customer Selection • Customer Acquisition (Saies calls, Telemarketing • Customer Care and Relationship Management (Complaints, 24/7 help)	• Employee Payrolls • Employee Benefits Administration • Leaves and Other Personnel Records •Recruitment • Training	• Cheques Processing • Credit Card Transactions Processing • Loans Transactions Processing • Claims Handling	• Accounts Payables • Accounts Receivables • Cash-flow-Management • Financial Reporting • Managing IPOs • Auditing	• Financial Analysis • Financial Modelling	• Contract Research • ODM (original design manufacturing • Engineering outsourcing	• Routine Commercial Legal matters • Compliance with Regulations in Different States and Nations • Patent Reviews and Patent Infringement cases • Due Diligence Reports

Vertical Services

Services outsourced may be classified by the kind of industry that is outsourcing them. This is a 'vertical' classification of the outsourcing services and hence these are also called as 'verticals'. Each genre of industry has its special service operations issues, which are handled by specialist suppliers. They offer 'solutions' to the parent company's service problems.

While all industries have processes and activities that can be outsourced, certain genre of industries—particularly some of the service industries—have a preponderance of processes and activities that should be and can be outsourced.

Airlines

Airlines have been one of the early users of the BPO concept. Many of their front-end and back-end operations have been outsourced. Usage of call centres for booking and reservations, usage of outsourcing for cargo handling, intra-airport transport, outsourcing of catering have been common.

Since the last few years, aircraft maintenance is also being outsourced by several airlines. JetBlue and America West send their aircraft for regular maintenance at the repair hub in El Salvador in Central America. Northwest airlines send their aircraft to Singapore and Hong Kong. It is reported that now China is fast becoming a destination for outsourcing of aircraft maintenance. United Airlines is sending its aircraft to China for maintenance. China, Dubai (UAE), Korea and Singapore are making enormous investments in maintenance facilities in order to attract such aircraft maintenance work. The main reason for such outsourcing is savings in costs for the airlines that are facing immense competition leading to a pressure to constantly cut down airfares while the costs of fuel are mounting. While an American mechanic gets US $ 38 per hour on an average, an El Salvadorian mechanic gets wages of only US $ 300 to 600 per month. Offshoring of airlines maintenance to low-wage countries like China or El Salvador is, therefore, an attractive option.

Airline maintenance is a US $ 45 billion per annum industry today. This figure will grow rapidly as the air traffic grows. A whopping 70 per cent of the maintenance work in this industry is being outsourced. Within the USA there is much opposition, as an estimated 100,000 maintenance jobs alone are lost due to offshoring. Just one airline—Northwest—has 10,000 maintenance personnel. A point of concern is regarding aircraft safety—whether the safety standards would be diluted. For instance, unlike in the US, the mechanics in El Salvador are not FAA (Federal Aviation Authority) certified. Only their supervisors are. It is argued that even FAA monitoring of the maintenance gets watered down when such work is offshored. Many a time the work is double outsourced i.e. the company to who it is outsourced, further outsources it to another firm. Another fear is regarding security—security against terrorists when the maintenance work is offshored. Despite these concerns, the offshoring from this industry is growing as it makes much business sense in this highly competitive industry.

Healthcare

Drugs development process in the pharmaceutical industries presents a huge outsourcing option, as was mentioned earlier. Assessing drugs safety, clinical data management, trials on drug efficacy, documenting reports on clinical trials are some of the areas in which outsourcing is taking place from the pharma majors to the lower cost developing countries such as India.

Medical Transcription is another area where Indian service providers have been active. This deals with conversion of voice files dictated by medical professionals into electronic data files in

a prescribed format. There is much mandatory paperwork in patient observation and findings, operative notes, progress notes, discharge summaries, etc. Documentation overload in some of the developed countries is one of the main reasons for this outsourcing.

Medical billing and claims administration are other activities that are outsourced. Health insurance claims are a complex process, and some Indian firms have been handling such outsourced work.

Radiology—teleradiology in particular—has been emerging as another process that is being outsourced from the developed nations to low-cost destinations. This includes MRI examinations, ultrasound examinations, CT (computer tomography), PET (positron emission tomography), and studies related to nuclear medicine. In case of emergencies, some of the radiological reports can be produced in less than 20 minutes turn-around time.

In all the above, secrecy, privacy and data protection are the main concerns that go against offshoring.

Banking and Financial Services

There are very many back-office operations in banking and financial services industry that can be outsourced. All the items mentioned under 'transactions processing' earlier are relevant here. Processes that can be outsourced include cheques processing, credit card transactions processing, loans transactions processing, claims handling, securities processing, mortgage processing, and fund accounting.

Rule-based repetitive activities that are required to be done hundreds or thousands of times could be good candidates for outsourcing. Also, many activities could be such that they could be processed overseas via the telecommunications network; hence, offshoring is not a problem in such cases.

Insurance

Outsourcing from this industry is picking up during the recent years. Claims administration, policy servicing, closed book administration and new business servicing are some of the processes that can be outsourced The outsourcing/offshoring market in this industry can be huge.

Retail

In retail industry also much outsourcing is possible in the processes of merchandising, store planning and store support. Planogrammy, space planning, floor planning, retail price management, workforce planning and scheduling, forecasting and replenishment, inventory management, and IT helpdesk are some of the activities that could be outsourced. Potentially, retail industry could be a huge market in terms of outsourcing in the future.

Telecom, media and entertainment

Customer relationship management (CRM), end-to-end billing operations support and network management sendees could be the processes that could be outsourced. Media and entertainment is a fast growing and highly competitive industry worldwide. In order to remain competitive, media and entertainment firms would have to outsource many of their non-core processes.

Some of the vertical services that can be outsourced are summarised in Table 28.3 below.

Table 28.3 Some of the Vertical Services that can be Outsourced

Airlines	*Healthcare*	*Banking And Financial Services*	*Insurance*	*Retail*	*Media And Entertainment*
• Reservations • Cargo handling • Catering • Internal transport • Aircraft maintenance • Cleaning and janitorial services	• Assessing drug efficacy • Assessing drug safety • Clinical data management • Medical transcription • Medical billing and claims administration • Tele-radiology	• Cheques processing • Credit card transactions processing • Loans and mortgages processing • Securities processing • Claims handling	• Claims administration • Policy servicing • Closed book administration • New book servicing	• Planogrammy • Floor planning • Merchandising • Visual merchandising • Retail cost and price management • Workforce scheduling • Inventory management • IT help-desk	• Customer relationship management • Billing • Network management

Special Issues in Services Outsourcing

The merits and demerits of outsourcing, in general, have already been mentioned at the begin¬ning of this chapter as also in other narratives. There are some special merits and concerns in services outsourcing, offshoring in particular, which may be revisited.

Merits

- *Costs of Logistics and Storage is Negligible* An interesting aspect to services outsourcing is that unlike the manufacturing industry, the costs of logistics (transport of services between the supplier and parent firms) and storage are almost negligible. The main costs are that of the wages for the staff manning the services. The telecom technology revolution across the world has made much of the services outsourcing possible, almost nullifying the "transaction distance" between firms physically located across continents.
- *Highly Qualified and Motivated Manpower Available in Low-cost Countries* Cost savings and enhanced efficiencies obtained are the basic reasons that started this services outsourcing revolution worldwide. By offshoring services to countries like India, the American and European companies gain not only huge cost advantages— savings of 50 to 80 per cent, but also get a manpower that is highly educated (engineering graduates and post-graduates in IT, PhDs in bio-sciences in pharmaceutical BPOs, graduates and post-graduates in other disciplines in call centres and other IT-enabled services—who

are willing to be called 'Nick', 'Bob' or 'Tom', etc if need be and willing to do late night shifts to suit the customer timings) and proud to work in these jobs. Whereas, most IT professionals in the western countries are averse to the tasks of application maintenance and support. They like to be at the cutting edge. Therefore, by outsourcing, these western companies not only gain cost benefits but also a better quality of work output as highly educated, willing and motivated personnel will be working on the process/activity offshored.

Concerns

But there are concerns for the parent companies and parent countries.

- *Loss of Jobs* As mentioned at the beginning of this chapter, offshoring i.e. outsourcing overseas has meant a loss of jobs in the parent country. Services industry employs much manpower and therefore outsourcing or offshoring of some service processes would mean a loss of those jobs to the local people. Labour in the western countries has been protesting against offshoring of services. Offshoring has become one of the politically sensitive issues in some of these countries.

  There are other concerns, which are relevant when there is some measure of loss of control over a process or activity.
- *Safety* Banking and financial transactions of the customers are confidential. The concern is regarding a chance—however small—of such private information being stolen and misused. Similar concerns are present in the case of healthcare and insurance industries. If such processes are offshored to distant countries, the fear factor increases. Distance is also in terms of the cultural distance. The fear is more when the 'cultural distance' is more.
  Safety of intellectual property is another concern. This concern is more when the services are outsourced to countries where the Intellectual Property Protection regime is lax, which is the case in most developing countries. For companies that offshore the R&D services, e.g. pharmaceutical companies, the concern would be regarding the safety of the research output—discovery of a new or improved drug falling into the hands of the competitors.
- *Security* With the increase of terrorist activity, there is always a fear as to how such unscrupulous elements might take advantage of the offshoring. When aircraft maintenance services are outsourced or when sensitive drugs research information is being shared between the parent and outsource firms, people may get concerned regarding the security issue.

  There is an issue, which is relatively minor to the above concerns. But it is particularly relevant in offshoring of services. It is that of "local knowledge".
- *Local Knowledge* Take the case of handling life insurance claims. It requires not only knowledge of the products and services, but needs an insight into how the customers have purchased the products and what they expect in terms of the service in different circumstances. These are, indeed, quite intricate, sensitive cultural concerns. So, when one speaks of 'domain knowledge', it is not only about the procedures and rules, but also about the background of it all and the cultural context.
- *Language, accent and minor cultural problems* There are other minor issues like it was said about the UK directory enquiry services outsourced to India. The call centre personnel initially lacked the knowledge of the local place names, shop names, abbreviations,

where these places are located, etc. The customer service suffers on account of that. Of course, this initial problem can be solved with a good bit of focused training. The syntax and accent of the English language is different in USA, UK and Australia. It can be much different from the native English and hence requires linguistic training of the employee hopeful of joining the international duties of the call centre. This is not a major problem. Several language-training schools have now sprung up across many Indian cities and towns. These schools train the new BPO employees and employment-hopefuls in the requisite language skills.

QUESTIONS FOR DISCUSSION

1. Can every purchase be called as 'outsourcing'? Discuss.
2. "Outsourcing is more relevant to a manufacturing industry than to a service industry." Do you agree with this statement? Discuss your response.
3. Explain the concept of 'contract manufacturing'.
4. Explain the concept of 'transformational outsourcing'.
5. How can outsourcing help a start-up company? Discuss.
6. When should a firm outsource? Explain.
7. Is there a difference between a BPO and a KPO? Discuss.
8. "Many of the activities of the HR function of an organisation can be outsourced." Do you agree with this statement? Explain your response.
9. How could the 'demand management' aspects of a firm's operations be outsourced? Explain.
10. Why can India be a good place for 'contract research'? Explain.
11. Design and R&D are generally vital functions in an organisation. Can these be outsourced? Under what circumstances? Discuss.
12. What are the special concerns while outsourcing for the following industries? (a) Banking (b) Healthcare (c) Media (d) Airlines
13. Explain the phenomenon of 'offshoring' in the context of 'global supply chains'.
14. With the rapid growth of outsourcing, what are the challenges before World Trade Organisation (WTO)? Discuss.

ASSIGNMENT QUESTION

1. Study any BPO of your choice and observe its peculiar operational problems. Recommend improvements in its operations.

SECTION V

SPATIAL DECISIONS IN PRODUCTION AND OPERATIONS MANAGEMENT

Chapter 29 Plant Layout
Chapter 30 Cellular Manufacturing
Chapter 31 Location of Facilities

Space—its size, location and arrangement—is an important aspect of Production/Operations management. In reaching the customers, in accessing raw materials and/or key category of personnel, the size and the location of the operations facility is a vital decision. Proximity is an important dimension. While there could be 'virtual proximity' in today's electronic world, physical proximity to the customer and/or to the supply base is still very important. One may have a software solutions company in Gurgaon in India, but a regional office or two in the customer's country is essential. One cannot afford to let one's customer have even a shade of doubt regarding the company's accessibility. It is an important dimension of service quality. Similarly, a wrong decision of a production facility has its own negativities. Companies that have suffered due to a wrong location decision are plenty. Physical space many a time translates to the mental space of the customer. Market presence and/or a presence close to the supplies of vital/critical inputs is an absolute necessity for the survival of a company.

The spatial arrangements inside a company (its operations/production facility) are equally important towards facilitating the fulfillment of the customer's needs. With the risk of repetition one may say that a facility has to facilitate meeting the customer requirements and other goals of the firm such as improved returns

on the investment and enhanced efficiencies. Easy and uninterrupted flows of materials and/or people are necessary for reduced times to manufacture a product or provide a service. Interruptions may also mean more inventories and a wasteful blocking of much needed capital. While maintaining the velocity of the flows, it is also necessary to be able to offer multiple products or multi-pronged service to the customer. Moreover, the bunch of products/services to be offered tomorrow may not be the same as the bunch of products being offered today.

Performing a varying multiplicity of operations while retaining the smoothness of flows is a task cut out these days for manufacturing and service-providing firms.

Management specialists have come out with answers for such problems. Facilities layout has been a widely studied subject. The very same machines, same equipment, same employees and the same quality of material can produce very different results in terms of the productivity—usage of time, capital, material and human resource—when the physical layout for the equipment and people is different. Henry Ford showed that an arrangement of the production equipments that was radically different—from what was known until then—could enhance the production per day by five times. Few decades after that discovery, production/operations specialists applied a hybrid system—a marriage between the old Functional Layout and Ford's Line Layout—offering benefits of both the systems. Spatial arrangement could also have its impact on the 'quality' of the produce in addition to the quantity. It could also contribute to the human relations with in the factory/operations complex. 'Clean up your house. It would help clean up your life' is an old saying. One of the (Japanese) 5-Ss is about a similar principle. Spatial decisions could have a wide range of impact on the performance of the operations system.

29 Plant Layout

In this chapter, we shall deal with the arrangement of work areas and equipment. We shall discuss the relative allocation of adequate spaces at the appropriate places for work equipment, for working men, materials, other supporting activities and also customers—if they are present (as it happens in the service industries such as patients in hospitals, guests in a hotel). The basic theme behind the arrangement of work areas is to produce the product economically, to provide the service effectively, and to provide a safe and good physical environment for the users that is, the workers and/or the customers.

Facilities or plant layout is related to a number of aspects of production and operations management. This, we shall bring out, while discussing as to what results a good plant layout should produce.

FEATURES

Ease of Working, Maximum Safety, and Minimum Health Hazards for People Working in/Using the Facility

In production plants this will go a long way in increasing worker satisfaction and, therefore, labour productivity. Plant layout has much to do with productivity techniques such as work study, job evaluation, incentives and ergonomics. One cannot speak of these productivity related techniques/concepts without relating them to the design of the physical working environment, that is, plant layout. In fact, physical plant layout is one component of the integrated picture for labour productivity improvement, and has to fit properly in relation to the other components of the picture.

This is emphasised here because facilities layout theories in their quest for mathematical optimisation tend to overlook the human aspects and treat the subject as one dealing purely with the arrangement of physical spaces. As mentioned earlier, user-orientation is an important consideration in management decision-making; and ultimately, the arrangement of the work areas is for the users of the work areas.

With the rapid rise of the service industry, this feature of facilities layout-assumes a lot of importance these days.

Minimum Handling of Materials

A good plant layout takes into consideration the various flows of materials inside the facility thus minimising the handling of materials.

The choice of the material handling equipment and the systems of storage of materials, have a lot to do with the way the plant facilities are laid out. The decision as to whether one should employ an overhead crane or fort-lift trucks depends much upon how the different departments in the plant are located spatially with respect to each other. Conversely, the choice of whether the material is to be stored in the production areas or in the stores determines the physical plant layout. So, the decisions of movement and storage of materials and that of plant or facilities layout have mutual feedbacks. A good physical plant layout should produce economies in the storage and movement of materials.

Minimum Damage and Spoilage of Materials

If adequate consideration regarding the handling and storage of materials is given, it automatically minimises damage and spoilage of materials.

Reduced Congestion of Materials, Machinery and Men

A good physical layout should eliminate confusion in the plant. By doing so, it not only makes the life of the supervisor easier but also contributes towards overall improvements in the productivity of the shop.

A *good plant layout means a good spatial system*. This should make production scheduling and control easier and should consequently reduce the delays in production and increase utilisation of the available plant capacity. In the unnecessary search for materials, in the difficult handling of materials due to the unnecessary zig-zag movement of materials, and due to the general confusion and wrong information regarding their availability, many production hours have been lost in practice; many unnecessary change-overs of production have occurred. All these can be avoided by a systematic arrangement of the non-living and living entities that comprise a production plant.

Flexibility with Regard to Changing Production Conditions

A good layout, that is a good spatial system, should be one that is adaptable or flexible enough to take care of probable future changes in the volume of production, in the range of products manufactured, and changes in the methods/processes of production.

BASIC PRINCIPLES

The basic principles of plant layout are, therefore, as follows:

(a) The total movement of materials should be minimum. For this, one has to consider the movement distances between different work areas and the number of times such movements occur per unit period of time.

(b) The arrangement of the work area should have as much congruence as possible with the flow of materials within the plant (from the stage of raw materials to the stage of

finished goods). By 'flow' we do not mean a particular straightline direction, we mean the different stages through which the material passes before it becomes a finished product. The stages at which value is added to the product and the sequence of the work areas should correspond with each other, as much as possible. In effect, there should be no back-tracking and very little interruption in the flow of the product from the raw material stage to the finished product.

(c) The layout should ensure adequate safety and healthy working conditions for the employees.

(d) A good layout should take into consideration all the three dimensions of space available. In addition to the floor space, the vertical space available should also be taken into account while designing the work areas.

(e) The layout should be adaptable or flexible enough so as to allow for probable changes in the future as all systems should anticipate changes in the future.

A good system is one which can produce good results even with some changes in the system conditions. It should be malleable enough to change itself to some extent in line with the changes in the working conditions.

(f) A good layout has to satisfy, therefore, the availability of space, the size and work area requirements of machinery and other utilities, the flow direction, type and number of

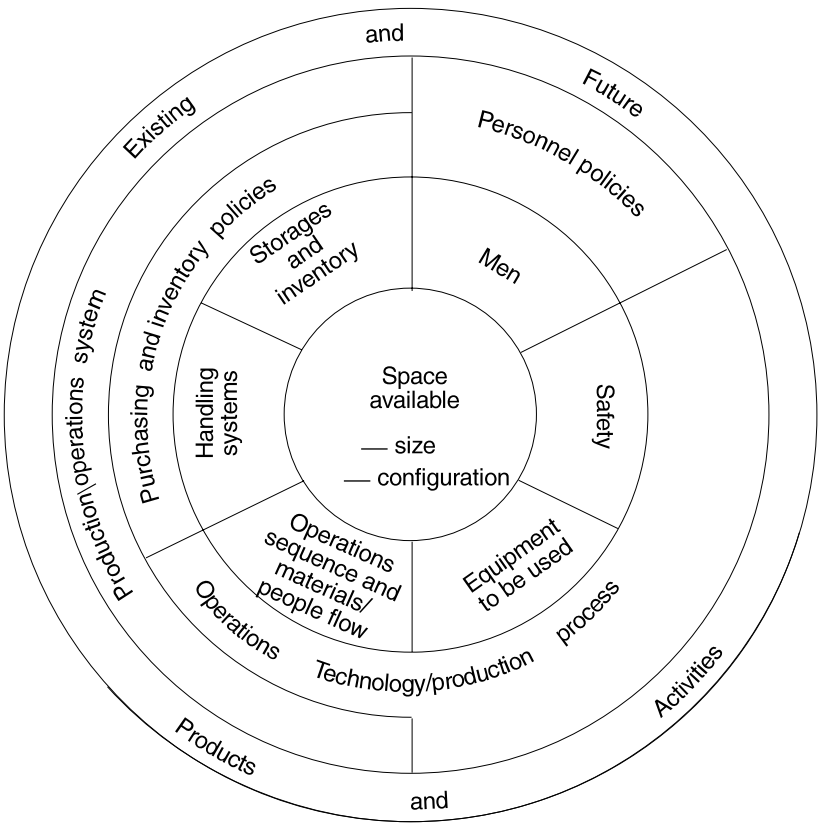


Figure 29.1 Factors Influencing Layout

movements of the material, workers, and also the future anticipated changes. The principle is one of integrating all these aspects. While satisfying the flow of materials, one may not be able to satisfy the space availability. While satisfying both these, one may not be able to satisfy the users of the system—the people. And while satisfying all these, one may not be able to satisfy the future whose requirements might be somewhat different from the present. The most important aspect is to keep the overall picture in mind (see Fig. 29.1).

COSTS

The costs associated with a decision on plant layout are:

1. Cost of movement of materials from one work area to another.
2. Cost of space.
3. Cost of production delays, if any, which are the indirect costs.
4. Cost of spoilage of materials.
5. Cost of labour dissatisfaction and health risks.
6. Cost of changes required, if the operational conditions change in the future. This is a long-term cost.
7. Cost of customer dissatisfaction due to poor service (quality, delivery, flexibility, responsiveness, cost) which may be due to poor layout.

A good layout should minimize all these costs put together.

Although all these factors are important; many of them are not amenable to mathematical analysis. Most of the available mathematical models deal only with the minimization of the costs of movement of the materials within a given total space and given the space requirements of individual work areas. This has been mentioned here because the different models which are presented in a later section of this chapter are not meant to provide the final answer to the layout problem; rather, it should be understood that the various other factors have also to be incorporated while designing the final layout.

BASIC TYPES OF LAYOUT

There are three different kinds of basic layouts, depending upon the method of production:

Process Layout or Layout by Function

This is typical of the job-shop type of production where the equipment performing similar operations is grouped together. For instance, grinding machines could be grouped together to form a work area, milling machines could be grouped together, drilling machines could be grouped together, etc. Such a layout is particularly useful where the volume of manufacture is low and the variety of jobs is great (in a job-shop every customer order is unique). Here, the layout should provide tremendous flexibil-

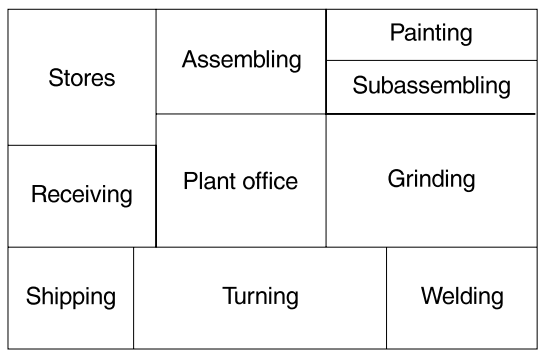


Figure 29.2 Process Layout

ity in the sequence of operations because, the sequence of operation for one job is different from that of another job. For this reason, in all job-shop types of production, work areas are grouped together as shown in Fig. 29.2.

Why is a process layout suited to a job-shop type production? Job-shop type production is characterised by a large variety of jobs, which are distinct from each other. If the machines performing similar operations are grouped together, the idle times of machines and operators can be better controlled and better time-shared thereby increasing machine and labour utilisation.

Product Layout or Line Production

The equipment here is laid out according to the sequence in which it is used for making the product. Product layout is usually suitable for assembling operations, for example in the automobile industry. Since a machine is assigned for each operation, the number of equipments in a Product layout is much more as compared to the Process layout. Therefore, the utilisation of the equipment has to be sufficiently high to justify the higher level of capital investment necessary in a Product layout. This means, the volume of production should be large and the variety of products should be low so that there is very little time lost in setting up the machinery. However, if two types of products are to be made, it may call for two separate layouts. Doing multiple jobs on the same equipment with the same men to save time is usually not the characteristic of a Product layout. Each Line layout caters only to one product.

The principles of minimum distance moved (each operation adjacent to the previous operation) and of congruence of flow of materials and sequence of equipments, are very well satisfied in a Line layout. But, this can only be true when there is only one standard product to be made, day in and day out. If there is another type of product to be made, then the present line-up of equipment may not correspond with the 'flow' of this new product, resulting in high costs due to excessive material movement and excessive idle-times of machinery and manpower.

So, when continuous production is possible due to high volume of production over a long run of time of a standard product with the assurance of a continuous supply of raw material, Product layout is preferred. When the production is of job-shop type, each product being unique in terms of the number and type of operations to be performed, and the setting of the machinery required, thus involving a high degree of change with low production volume, Process layout is preferred. The major requirement in a job-shop type production is *flexibility*:

(a) product-design, and therefore *machine-setting flexibility*;
(b) flexibility of types of processes operating or in other words, *routing flexibility*;
(c) flexibility regarding the number of similar items manufactured, i.e. *volume flexibility*.

Fixed Position Layout

In this layout, the material remains in a fixed position, but the machinery, tools, workmen, etc. are brought to the material.

Such a layout may be preferred when the equipment and the machinery is small in number and size, and where the workmen are highly skilled to perform the various small jobs on the product. For instance, such a layout is sometimes used in the manufacture of automotive batteries where 20–30 battery cases are fixed in position and the workman keeps moving from one battery to another, each time fixing certain components such as the electrodes, the chemicals, etc. into the main skeleton of the battery.

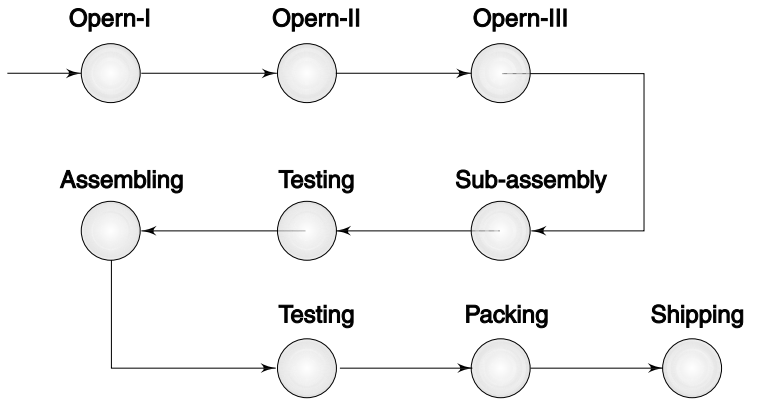


Figure 29.3 Product Layout

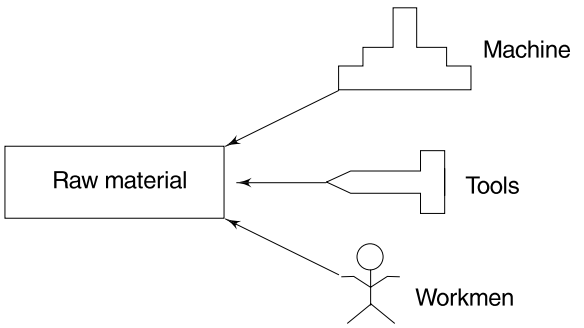


Figure 29.4 Layout by Fixed Position

The layouts by product and by fixed position are shown in Figs 29.3 and 29.4 respectively.

MERITS AND DEMERITS

The merits and demerits of Product and Process layouts are given in Table 29.1.

Table 29.1 Merits and Demerits of Product and Process Layouts

Product Layout		Process Layout	
Possible Advantages	*Possible Disadvantages*	*Possible Advantages*	*Possible Disadvantages*
1. Low total flow time of the product from the input stage to the output stage (i.e. higher rates of output) due to: (a) Continuous flow without intermediate stoppages and storages;	1. None or very little variety possible 2. Less flexibility to changes, particularly to other than minor changes 3. Entire line or significant portions of the line may come to a grinding	1. Very high degree of variety in products is possible 2. Flexibility and adaptability to changes is high 3. Machine breakdowns do not cause crippling	1. Higher flow times of products due to: (a) Intermittent flows of the material; and (b) More numerous machine set-ups 2. Production planning and control is more

Contd.)

(b) Repetitive, small fragmented jobs learnt to prefection by the concerned workers; and (c) Minimum set-ups of machines 2. Production planning and control is simple; less paper work 3. Inspection required is less 4. Lower degrees of skills in the manpower may suffice 5. Raw materials and other inputs can be planned better, even to the extent of 'Just in time', resulting in lower inventories 6. Lower work-in-process inventories needed 7. Lower material handleing costs 8. By 'balancing' the line, labour utilisation can be high	half if any equipment in the line breaks down, resulting in high stoppage costs 4. Larger maintenance crew needed 5. Very low job variety and therefore lower job satisfaction and higher boredom for the workers 6. More coordination required by supervisors 7. Duplication of machines and equipments may be necessary resulting in higher capital investment 8. More space may be required	production stoppages 4. Requires small-maintenance crew 5. Good level of variety, skills requirement and therefore higher job satisfaction 6. Coordination and supervision is simpler as the processes are similar and the staff is skilled	complex; much paper work is necessary 3. Worker skills need to be high in order to complete all components of the job 4. Higher inventories of basic raw materials may be necessary due to much uncertainty of demand 5. Higher work-in-process inventories due to necessary intermediate storages, if the machine and labour utilisation is to be at a satisfactory level and if the flow times of the products are to be at acceptable levels 6. More handling of materials

OPTIMISATION IN A PRODUCT/LINE LAYOUT

The product or line layout is relatively easy to plan as the layout is according to the flow of the product as it takes shape from the raw material state to the finished good state. The equipment and the work areas are laid out according to the sequence of the operations involved in converting the raw material to the finished product. The problem in the Line layout may not be that of how to sequence or relatively position the work areas, but rather to group the work elements in such a way that there is very little idle time at any of the grouped work centres. The problem in Line layout is therefore one of balancing the flow line of work (and also of the material) in such a way as to minimise the idle time at the different work centers (alternatively called 'work stations'). This is technically termed as Assembly Line Balancing and is discussed at length in Chapter 33. This procedure automatically minimises the relevant costs associated with Line layout.

OPTIMISATION IN A PROCESS LAYOUT

The problem in Process layout is one of arranging the different work areas in such a way that the inter-area material movement costs are kept to a minimum. Of course, one has to take into account, simultaneously, the total plant area available and any constraints on the individual area requirements or position requirements of the work centres. A mathematical treatment for this problem is available; but one ought to note that the mathematical optimising models take into consideration only the cost of material handling. It is assumed, at best, that the other relevant costs of layout will also be reduced on account of this optimising procedure. The material handling costs between two work areas (departments) is the product of the distance between the two work areas

and the number of loads that are handled between the two departments during a unit period of time. The sum of these products, for all the combinations of departments, should be minimum for an optimal plant layout. This can be expressed as follows:

$$\text{Minimise } \sum_{ij} d_{ij} \times L_{ij}$$

where d_{ij} is the distance between departments i and j, and L_{ij} is the number of loads per unit time moved (handled) between departments i and j.

The starting point in such a mathematical optimisation procedure for the Process layout is therefore, the gathering of the data on the number of loads per unit time moved between different combinations of the work areas. This data is called 'load summary' and is presented in matrix fashion in the following example.

Example A polyclinic has a number of departments such as General Medicine, Pathology, ENT, etc. The load summary given in Table 29.2 shows the number of patients moving from one department to another during a day.

Table 29.2 Number of Patients Moving from One Department to Another

	Pathology	*X-ray*	*ENT*	*Ortho-paedics*	*Obstetrics and Gynaecology*	*Paedia-trics*	*General Medicine*
Pathology	–	100	10	25	50	100	60
X-ray		–	30	20	0	20	10
E.N.T.			–	0	10	20	30
Orthopaedics				–	0	10	10
Obstetrics and Gynaecology					–	50	40
Paediatrics						–	100
General Medicine							–

Use of Schematic Diagrams

The departments are initially laid out as shown in Fig. 29.5. Note that the departments are shown as points or tiny rectangles on a grid. Due to physical constraints the location numbers 3 and 4 are not free for occupation of any department. Also note that in this simplified grid representation of the layout, the actual floor areas of the departments have not been taken into account (or alternatively, the areas are assumed to be equal). Moreover, that the adjacent departments are joined by solid straight lines, whereas the non-adjacent departments are connected by means of dotted lines depicting the movement of patients between different departments. The departments could be adjacent horizontally or vertically, or diagonally. The adjacent departments are separated by a distance of one unit (grid unit) and the non-adjacent departments are separated by multiples of such unit distances. For instance, the distance between Obsterics and Gynaeocology and General Medicine is two units. Similarly, the distance between Orthopaedics and ENT is also two units. The total movement of patients between the various combinations of the departments adds up to 895 patient-grid unit distances.

For example, between General Medicine and Obstetrics and Gynaecology there are $40 \times 2 = 80$ patient-grid unit distances.

This may not be the ideal layout; it is one we have started with. By a new relative location of the departments it is possible to reduce the total movement costs (expressed here as patient grid unit distance). By visual inspection, we may decide to exchange the positions of the departments as shown in Fig. 29.6.

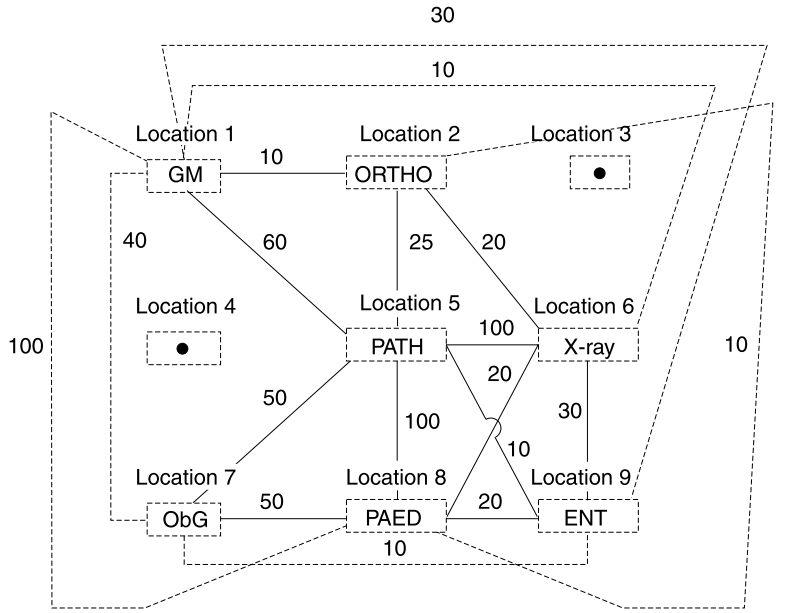


Figure 29.5 Schematic Diagram of the Existing Layout

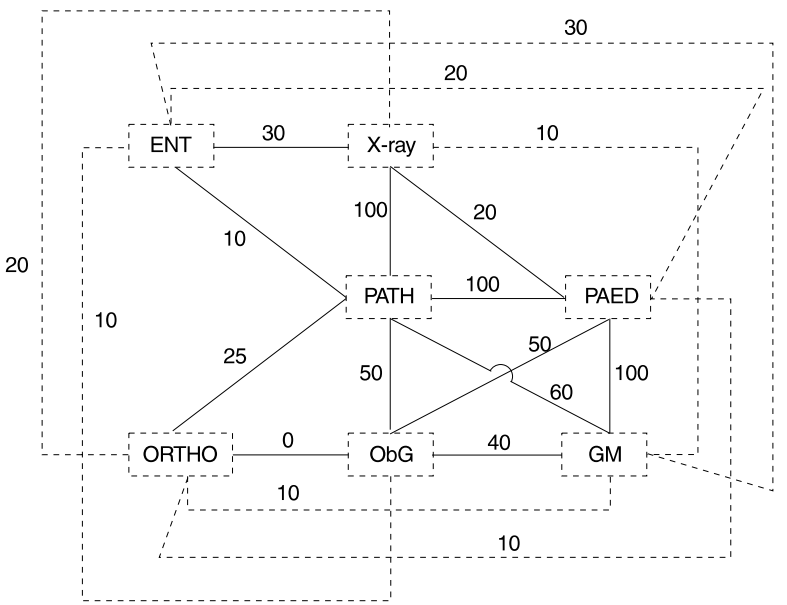


Figure 29.6 Modified Layout of Departments

For this modified layout the total cost adds up to 805 units. This is not necessarily the optimum solution. Various other exchanges of positions between different departments should also be considered.

This may lead to a figure smaller than the total of 805. While doing such a visual inspection to decide as to which departments are to be exchanged, one should keep in mind the number of loads carried between two different departments and the distance between them. The example given here is only for illustrative purposes.

Use of Templates

The above procedure can be complicated a little more by incorporating the consideration of the actual work area requirements of the different departments and the total configuration of the layout. The problem can still be solved by a visual procedure, but now one has to use templates to show the work areas. These templates can be moved about and the 'total costs' may be determined for various combinations.

A major drawback of the above mentioned visual procedures is that they are very tedious when the number of departments is large. Even with five departments there are 5! = 120 arrangements possible. The problem is quite formidable in the actual plant situation where there are a large number of departments.

CRAFT: COMPUTER PROGRAM TO SOLVE PROCESS LAYOUT PROBLEMS

The above difficulty can now be alleviated due to the availability of computer software packages such as the Computerised Relative Allocation of Facilities Technique (CRAFT). The basic technique of optimisation in CRAFT is similar to what we did visually: exchanges of positions between different departments. The computer program, therefore, requires input data such as:

1. Load Summary.
2. The existing layout and the distances between different locations.
3. The floor area requirements of the different departments.

   In addition to this, the computer program introduces two more aspects:
4. The possibility of the differences in the costs of material handling between two different pairs of departments, expressed as rupees per load per unit distance.

   The per load per unit distance cost of material handling between departments 1 and 2 may be quite different from the cost per load per unit distance between departments 1 and 3. For instance, in our earlier example (visual inspection) we had considered the per load per unit distance costs to be the same for all the combinations of departments. This may not be true in practice, because the type of material being handled between one pair of departments may be different from the other pair of departments, and therefore the material handling equipment needed for such movement within the pair of departments may be different from one pair to another. Naturally, the material handling costs between different pairs of departments will also be different. Such an interdepartmental cost-matrix should be provided as input data.
5. CRAFT also takes into account the non-moveability of certain departments in practice. For example, the receiving section may have to be located near the railway tracks if a large

volume of raw materials is received by rail. Such positional constraints should also be part of the input data.

The ultimate aim of the CRAFT program is to minimise the material handling costs for the entire plant.

Elements

A CRAFT program basically has the following elements:

1. It reads the load summary (the number of loads carried between pairs of departments), the costs per unit load per unit distance for the handling of materials between various pairs of departments, the existing layout of departments, the area requirements and the dimensions of the departments, and constraints on the positioning of the departments.
2. It computes the centres of the departments and computes the various inter-departmental distances. The inter-departmental distances are not diagonal ever, but only horizontal and vertical.
3. On the basis of the above it computes the total material handling costs per unit period for the layout.
4. It makes paired and/or three-way exchanges between the different departmental locations so as to produce a valid and improved layout pattern. The improvement is in terms of reducing the total material handling costs. While making these exchanges, due regard to the area and physical dimension requirements of the individual department is paid.
5. The computer prints out the scaled layout pattern and the corresponding cost.

Subroutines of CRAFT

For doing this, the CRAFT program employs various subroutines which are described below:*

AJA: The computer program exchanges only those departments which are of the same size or which are adjacent. This subroutine checks through the input data to find such eligible departments.

CKPAR: Checks the cost and volume-of-flow input, and computes the product of the load summary and the cost per load per unit distance matrices; it checks computations for zeros along the diagonal.

CENTER: Computes the centres of all the departments.

CDIST: Computes the distance (horizontal and vertical, not diagonal), between the centres found by the previous subroutine CENTER.

CKISP: Checks initial layout, indexes the layout for easy reference in location, and supervises the initial computation of centres, distances, adjacencies, etc.

ANACTL: A supervisory subroutine for two and three-way exchanges. It calls ANAN and ANAT intermittently, as they are required.

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*(a) G.C., Armour, & E.S., Buffa 'A Heuristic Alogrithm and Computer Simulation Approach to the Relative Location of Facilities,' *Management Science*, Vol. 9. No. 1, Jan. 1963, pp 294–309

(b) E.S., Buffa and T.E., Vollaman 'Allocation of Facilities with CRAFT', *Harvard Business Review*, 42(2), March-April 1964.

(c) For a copy of the CRAFT Program, contact the IBM Share Library System, Ask for Program Order No. SDA 3391.

ANAN: A supervisory routine for two-way exchanges; computes the cost reduction that can be achieved by the exchange of a department with other eligible departments.

ANAT: A supervisory routine for three-way exchanges.

FUNCTION COST: Computes the total transportation costs of alternative layout patterns. This used by other routines such as ANAN.

EXCH: Supervises the actual exchange of two departments. Equal size departments are easily exchanged. The unequal size departments are exchanged by calling other carving subroutines MESSR and/or MESSQ. For this part, the program puts the unequal size departments, which are to be exchanged, in a temporary matrix. After the carving out and the exchanges, the departments are positioned into the permanent matrix by means of another subroutine PICKUP.

SETUP: Facilitates the other carving subroutine MESSR and MESSQ by analysing the relative orientation of the departments to be exchanged and rotating the larger department for carving-out the smaller department out of it.

MESSR: A carving subroutine for the exchange of departments of unequal size. It carves out smaller departments out of the larger departments by taking vertical and/or horizontal slices. The subroutine SETUP is used for rotating the larger department for orientation to carve the smaller department out of it .

MESSQ: A carving subroutine useful for the exchange of departments of unequal size. This differs from MESSR, for it takes squares out of the department being carved (as against the vertical and/or horizontal slicing done by MESSR).

PICKUP: Picks up the exchanged departments from the temporary matrix and drops them back into the permanent matrix. It should be noted that the unequal size departments were placed in the temporary matrix for carving out smaller departments out of larger departments.

EXCT: Supervises the exchange of department A and department C across department B.

PERIM: Measures the common border between two departments which have been carved out of the larger department. This helps in limiting the spatial dispersion of departments.

CEXC: Puts the new departments resulting form MESSR and/or MESSQ back into the regular index and checks each new department for a valid shape, and computes their common border.

VALID: Checks the validity of the configuration of each department, for the initial as well as subsequently resulting modified layout patterns.

POSTM: Used for the post-mortem debugging, so that any error situation in the programme is detected and rectified.

FUNCTION IALPHA: Converts the numeric code to the letter code for printouts.

OUTISP: Facilitates the printing out of the results of the program: the layout with departments properly outlined, the cost, and other information is printed out.

A computer output—a layout of various departments, after a CRAFT analysis is shown in Fig. 29.7.

The basic procedure involved in CRAFT is depicted in Fig. 29.8.

Some of the other computer programs for layout are CORELAP (Computerised Relationship Layout Planning), ALDEP (Automated Layout Desing Planning) and RMA Comp 1 (Richard

The McGraw·Hill Companies

Mather Associates). These programmes basically consider the need of any two work areas to be near each other (see Fig. 29.9).

I.I.M.—Computer Centre—Bangalore

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LOCATION PATTERN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	A	A	A	A	B	B	B	B	B	B	F	F	F	F	F
2	A			A	B					B	F				F
3	A	A	A	A	B	B	B	B	B	B	F				F
4	I	I	I	I	G	G	G	G	D	D	F				F
5	I			I	G	G	G	G	D	D	F	F	F	F	F
6	I			I	H	H	H	H	D	D	D	D	D	D	D
7	I	I	I	I	C	C	C	C	C	D					D
8	E	E	E	E	J	J	J	J	D	D					D
9	E			E	J	J		J	D						D
10	E	E	E	E	E	J	J	J	D	D	D	D	D	D	D

Figure 29.7 CRAFT Representation of the Layout (A, B, C, . . . , J are the Respective Departments)

The reader may argue that if the visual inspection method is cumbersome, one might use other analytical methods for the solution of the layout problem. But such analytical methods are not available. Some heuristics methods are available, but these also involve tedious calculations and iterations. For this reason, a computer program such as CRAFT, provides an easier answer to the layout problem.

Even with the availability of the computer program, one must be cautioned that it takes into account only a few aspects of the layout problem. Aspects, such as, (i) providing for future expansion and other future considerations, and (ii) human relations and human psychology, are not explicitly taken into account by the computer procedure. These are important aspects. The layout problem is not just one of minimising the material handling costs as in CRAFT. Therefore, the so called 'optimal solution' needs to be checked for practicability and for incorporating the other considerations as mentioned just before. The output of CRAFT or other programs need not be the final layout of the facilities.

We should also note that in practice the entire plant need not be laid out by one method such as Line layout or Process layout. In fact, a practical layout is a combination of the different layouts depending upon the material flow. The principles of good Line layout and good Process layout should be applied to the relevant parts of the total plant layout.

Use of Miniature 3-D Models

As physical equipments do not just occupy areas, they occupy volumes, a consideration of all three dimensions is important. This 3-D aspect is particularly true of chemical plants, where the various pipelines and other accessories cris-cross over different floors of the buildings housing them. In such cases, a three-dimensional physical model, a miniature version of the real plant is very useful for analysis. In recent years, there has been an attempt to incorporate this consideration in the computer programme.

Application in Service Industries

A majority of service situations are of the process layout kind, mainly because services call for a more customised approach than in traditional manufacturing. CRAFT, CORELAP, ALDEP and such other computerised process layout techniques are as useful in designing a service facility as in designing a production plant. Some service facility situations may also call for a line layout.

All the aspects discussed earlier for a production plant layout are equally important for any service facility. A good facilities layout should facilitate customer satisfaction. There should be economy of movement of materials and people (workers and customers), reduced confusion, greater safety, improved convenience and comfort, and greater adaptability to changing conditions.

However, several service facilities in India seem to betray an appreciation of the basic management principles for facilities layout. There are major important hospitals where patients on stretchers are moved through narrow, dark, crowded and criss-crossing gangways and up and down several floors in elevators. The location of the operation theatres, surgical wards, passages for the movement of in-patients, out-patients, nursing and other medical staff, the illumination

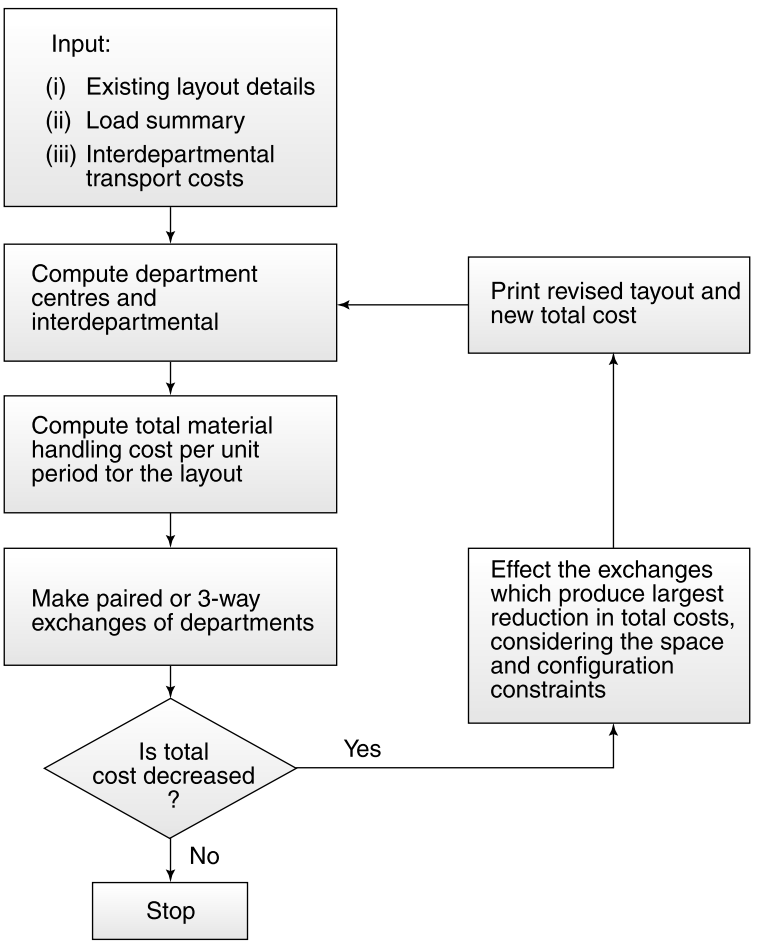


Figure 29.8 Essentials of CRAFT Method

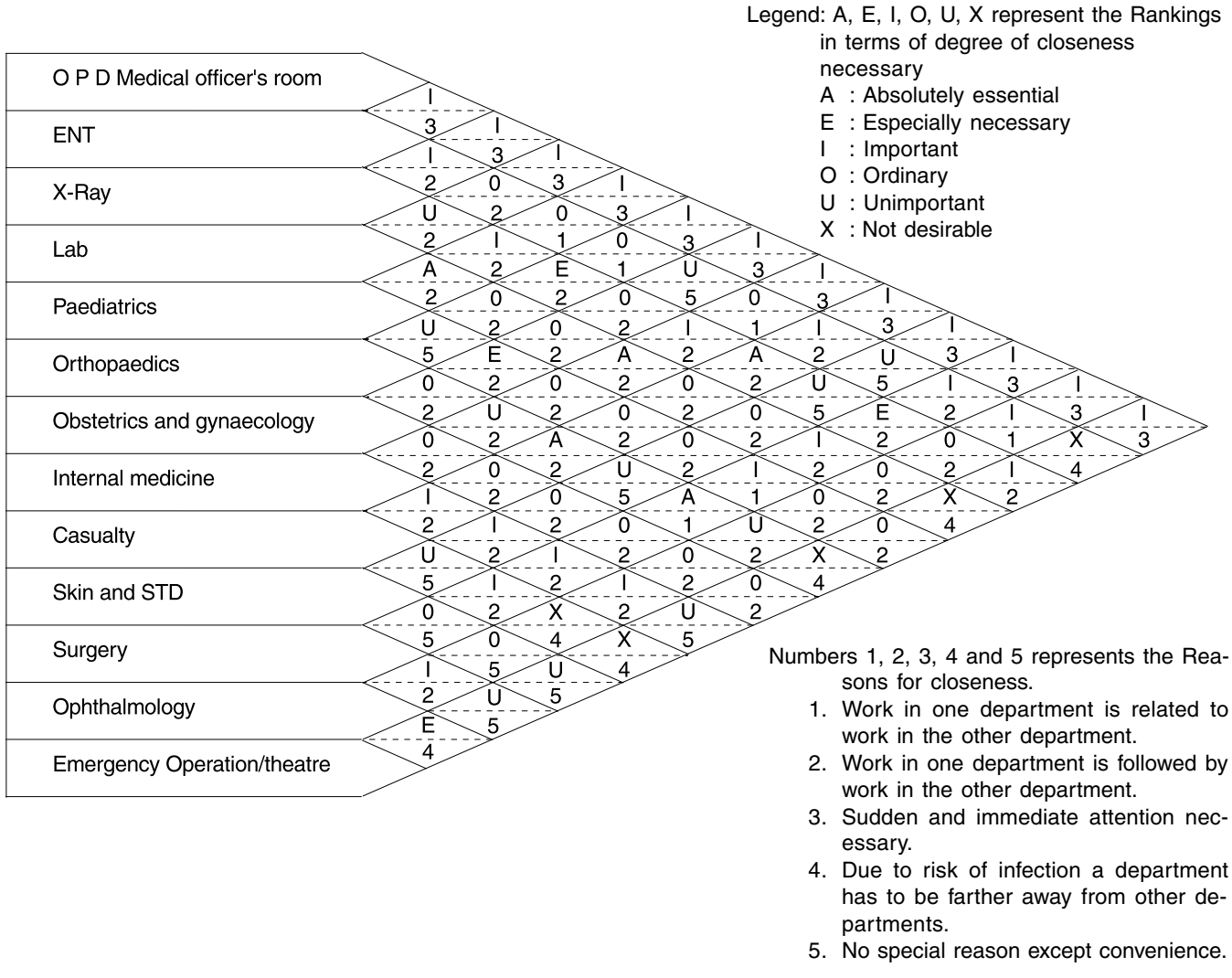


Figure 29.9 Nearness Diagram (for a Hospital Outpatient Block

and ventilation of rooms and other spaces and various other aspects need a rational approach as suggested in this chapter. Hospital architecture, if given a proper attention, would substantially improve patient care and comfort, and the productivity of the hospital. Same is true, to some extent, of our outdoor service facilities such as petrol bunks and service stations with almost unapproachable paths, and of hospitality industries such as hotels whose layouts need much improvement. Many a time these suffer from conjestion at undesirable places, lack of customer sensitivity and a lack of provision of flexibility for future operations. Our schools, even the so-called elite schools, leave a lot to be desired in laying out their classrooms, stairways, drinking water faucets and other facilities. One may say that customer satisfaction is generally given a go by, if one looks at the discomfort caused to the children sitting in dark, badly ventilated, cramped class-rooms with bad acoustics. The problem does not really seem to be that of a lack of resources but that of a good appreciation and application of the management principles in facilities layout.

SOLVED PROBLEMS

Sathyamuni, the factory manager of Shanti Industries, is considering an interchange of departments 3 and 6 in the present layout. The present layout and the interdepartmental materials handling frequencies are furnished in Fig. 29.10 (Note : All the departments are of the same size and configuration) and in the following matrix, respectively.

1	3	5
2	4	6

Fig. 29.10 Present Layout

Weekly Frequencies of Interdepartmental Materials Handling

From \ *To*	*1*	*2*	*3*	*4*	*5*	*6*
1		0	90	160	50	0
2			70	0	100	130
3				20	0	0
4					180	10
5						40

The per unit length interdepartmental costs of materials handling are equal. What is the effect of the interchange of the departments 3 and 6 in the layout ?

Answer

The distance matrix for the present layout can be given as follows (considering only the departments that share a border as adjacent departments).
Distance Matrix (for the Initial Layout)

From \ *To*	*1*	*2*	*3*	*4*	*5*	*6*
1		1	1	2	2	3
2			2	1	3	2
3				1	1	2

Contd...

From \ To	1	2	3	4	5	6
4					2	1
5						1
6						

The total cost–matrix can be easily calculated combining the interdepartmental materials handling frequencies and the distance matrices.

Total Cost Matrix (for the Initial Layout)

From \ To	1	2	3	4	5	6	Total
1		0	90	320	100	0	510
2			140	0	300	260	700
3				20	0	0	20
4					360	10	370
5						40	40
6						Total	1640

If the departments 3 and 6 are interchanged, the layout would become as shown in Fig. 29.11 The distance matrix for the modified layout would then be:

1	6	5
2	4	3

Fig. 29.11 Modified Layout

Distance Matrix (for the Modified Layout)

From \ To	1	2	3	4	5	6
1		1	3	2	2	1
2			2	1	3	2
3				1	1	2
4					2	1
5						1
6						

By combining the above distance matrix with the interdepartmental materials handling frequencies, we get the following Total Cost Matrix

Total Cost Matrix (for the Modified Layout)

From \ To	1	2	3	4	5	6	Total
1		0	270	320	100	0	690
2			140	0	300	260	700
3				20	0	0	20
4					360	10	370
5						40	40
6						Total	1820

Thus, the interchange of departments 3 and 6 increases the total materials handling cost. Therefore this interchange may not be a desirable modification, unless there are other more pressing reasons for the interchange.

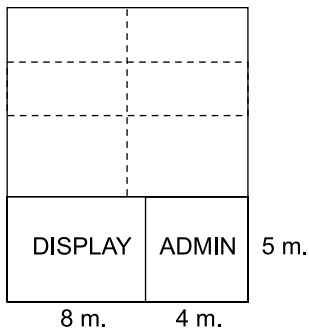
2. Abala Ashram of Ahmedabad raises its funds partly by making ladies' handbags and knitwear in their modest premises. The areas needed for and the various relationships between the activities are given in the relationship chart below. The total area available for all these activities is 15 m × 12 m.

Sl. No.	*Activity Name*	*Area (sq.m.)*								
1	Store	30								
2	Cut	10	E							
3	Sew	30	U	A						
4	Knit	20	E	U	U					
5	Paste	20	O	E	U	X				
6	Line	10	O	I	I	U	I			
7	Display	40	E	U	U	A	U	U		
8	Admin.	20	A	U	U	E	U	U	E	
			1	2	3	4	5	6	7	8

Design a layout of the activity areas if it is stipulated that the Display and Administrative areas should be at the peripheries of the layout so as to allow easy access to the customers and patrons of the Ashram.

Answer

Let the approximate divisions be made for the eight activity areas within the rectangular 15 m × 12 m total space given to us. Also, assign the last two (peripheral) rectangular spaces to the activities Display and Administrative. This is shown in the figure below.

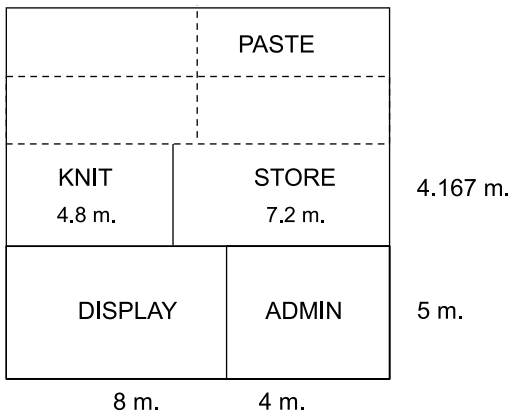


Now, consider the 'A' relationships. Activities 1 and 8 have 'A' type relationship and have to be located near each other. Thus, we place activity Store next to Admin.

Another pair of activities 2 and 3 also have 'A' relationship between them. So, they have to be next to each other. We can do this in a number of ways in the remaining spaces.

In order to determine which one way to choose, we can wait and consider another critical relationship of 'X' between activities 4 (knit) and 5(paste). Hence 4 and 5 have to be kept far from each other. We can do this as shown in the following diagram. While allotting

the spaces we can also keep the areas required in consideration. For instance, 'store' has an area of 30 sq.m. and 'knit' has 20 sq.m. Hence, 'store' will have space of 7.2 m. × 4.167m. and 'knit' will have 4.8 m. × 4.167 m. The boundaries for each allotted activity are thus indicated.



Activities 'sew' and 'cut' have "A" relationship and can be next to each other in two different ways. In order to choose, we check another relationship. Since 'cut' and 'paste' have the next best "E" relationship, these are to be placed next to each other. Thus, the three activities are arranged as is shown in the following diagram.

Note that the area requirements (sq.m.) have also been shown in the diagram. For instance, sew and cut together need 40 sq.m. and hence, can be accommodated in 12 m. × 3.333 m. area. Sew has an area of 9 m. × 3.333 m. and 'cut' has 3 m. × 3.333 m.

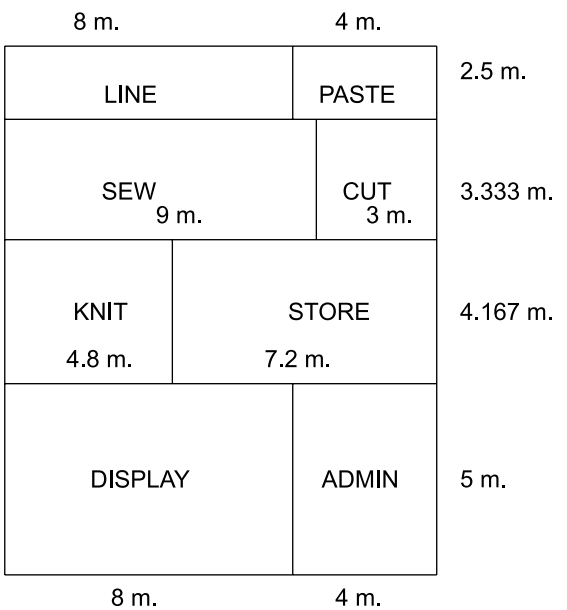


Fig. 29.12 Final Layout of the Activities.

Hence, now 'paste' and 'line' have areas of 8 m. × 2.5 m. and 4 m. × 2.5 m. A final check has to be given to check whether any relationships are not being met in the layout. The layout seems fine. It meets some relationships a little more than what is required ('sew' and 'knit', for example). But, that is admissible. The following diagram is the final layout of the activities.

3. A corporate hospital has an exclusive wing for Executive Health Check-up. The package of check-up consists of general medical check-up, blood and urine tests, eye check-up, cardio-related ECG and treadmill tests and a final counselling by the doctor. This wing has 2 doctors and 4 paramedical (i.e. support) staff. In conducting cardio tests like ECG and treadmill, in addition to the paramedics carrying out tests, one doctor is essential to be present. A work study lady has measured the jobs in the wing and has come up with the following standard times.

Work Elements	**Time, minutes**
(A) Registration of the patient	5
(B) Taking patient's medical history, height and weight	2
(C) Taking patient's temperature and blood pressure	6
(D) Collecting patient's blood sample	5
(E) Collecting patient's urine sample	4
(F) Carrying out blood examination in the laboratory for one sample	25
(G) Carrying out urine examination in the laboratory for one sample	25
(H) Putting drops in patient's eye	2
(I) Patient waits for eye dilatation	30
(J) ECG	12
(K) Treadmill test	15
(L) Eye examination by doctor after the eye dilatation of the patient	8
(M) Examination of the blood and urine test results by doctor	5
(N) General medical examination by doctor	12
(O) Final counselling of the patient by the doctor	15

For this wing, the hospital has employed 2 doctors (each of whom can look after all examinations and tests) and 4 paramedics (who can do all paramedical and registration tasks).

(a) Design a layout so as to minimise the time in the hospital by a patient. Registration will have to be the first activity, taking medical history, height-weight and blood pressure will have to be the next and final counselling has to be the last activity. Pathological examination (blood and urine tests), eye checkup, cardio checkup (ECG plus treadmill), and general medical examination can be conducted in any order.

(b) How many patients can be examined per day between 09:00 a.m. and 05:00 p.m.? How should the hospital arrange the patient appointments? Note that the doctors and staff will not work beyond 5:30 p.m. i.e. ½ hour after the official closing time for the patients.

(c) What is the minimum time spent in the hospital by any patient?

(d) If one more doctor is provided, will it reduce the time in the hospital for the patient? Will adding a paramedical staff improve the matters for the patient?

(e) The doctors and paramedics cost Rs. 4000 and Rs. 1500 per day. Health check-up charge for a patient is Rs. 2000. Is it economically viable for the hospital?

Answer

(a) The examination of the blood and urine samples in the laboratory by the paramedic (F and G) and then by the doctor (M) is an internal activity and can be done parallel to the patient's other activities.

The ophthalmic check-up consists of several activities of putting drops (H), waiting for dilatation of the eyes (I) and examination of eyes (after dilatation) by the doctor (L). These all have to be done in that order and no other activity can be taken up in between. Total time for this segment = (2 + 30 + 8) = 40 minutes.

ECG (J) and treadmill (K) is another segment comprising (12 + 15) = 27 minutes.

Registration (A), basic measurements (B) and blood pressure (C) are mandatory preliminary activities comprising (5 + 2 + 6) = 13 minutes.

One possibility of the flow of the patient and layout of facilities can be as follows. Doctors always work with the patient, excepting at activity M. The paramedics' work is also shown in parallel.

A, B, C ….13 ↓

D, E and N….21 ↓ ↓ Lab work (F, G. M)…25 + 5 or 50 +5

Ophthalmic (H, I, L) ....40 ↓

Cardio (J. K).....27 ↓

Final Counselling (O)....15 ↓

(b) Treating this as an assembly line, the bottleneck is at ophthalmic tests (40 mins.) and this determines the speed or flow of patients through this facility. The maximum number that can be processed in 8 hours or 480 minutes is not really (480 / 40) = 12. It is 2 less, i.e. only 10, as a patient registered at 3:40 p.m.has to go beyond 5:00 p.m by (116 – 80) = 36 minutes; this goes beyond working hours of 5:30 p.m. for all staff. So, the last appointment will be at 3:00 p.m. The patients may be given prior appointments at 40 minutes' intervals. This is crucial.

(c) However, a patient spends (13 + 21 + 40 + 27 + 15) = 116 minutes in the hospital.

If D (collecting patient's blood sample) can be done while the patient is waiting for dilatation, he saves 5 minutes. Then, he will spend 111 minutes. But, patients may not approve of this action.

(d) One paramedic can do (A + B + C + D + E + H) together = (5 + 2 + 6 + 5 + 4 +2) = 24 mins.

For every 40 minute patient cycle:

Two more are required for lab tests F and G each = 25 minutes each.

One is needed in Cardio (J + K) = 27

Hence, 4 paramedics are sufficient. Each has enough free time for tea or quick lunch. There is no need to add more.

A doctor is needed for activities J, K, L, M, N and O.

The two doctors may do activities (J, K and L) = 27 + 8 = 35 minutes and (M, N, and O) = 5 + 12 + 15 = 32 minutes, respectively.

Thus 2 doctors are sufficient. Adding one more doctor will not reduce the time spent by the patient inside the hospital. However, it may release additional free time for doctors, particularly for quick lunch or tea.

It may be reemphasised that patients must be given prior appointments at 40 minutes' interval between them.

2 doctors cost Rs. 4000 × 2 =Rs. 8000 and 4 paramedics cost Rs. 1500 × 4 = 6000 per day adding to Rs. 14000 in these wages per day. 10 patients will yield revenue of Rs. 20000 per day. While the cost of medical and paramedical staff may be recovered, there may be other expenses like the costs of infrastructure and medical supplies.

4. PQR Manufacturing Works makes the following products.

Product	*Monthly Volume of Production, Units*
P	140
Q	50
R	175
S	115
T	75
U	100
V	90

There are six departments *A, B, C, D, E* and *F* in the plant, each performing a single type of operation. Before the final product is ready for consumption/use it has to go through a number of different departments as :

Product	*Sequence*
P	A C D E F
Q	B D E
R	A D F C
S	F B D E
T	D A B E
U	A D E F
V	A C D E F

The area requirements of the various departments are :

A	1000 m^2
B	2500 m^2
C	1500 m^2
D	2000 m^2
E	2000 m^2
F	1000 m^2

The total available space is 100 m × 100 m. Suggest a suitable arrangement of the departments.

Answer

The baisc input to this process layout porblem is the load summary. The latter can be obtained by combining the product sequences given with the monthly production vol-

ume. For example the frequency of transport between departments *A* and *C* is found as follows.

The flow $A \rightarrow C$ occurs for products *P* and *V*. Product *P* is produced in the volume of 140 units and product *V* in 90 units. Thus, the flow $A \rightarrow C$ can be considered to be (140 + 90) = 230 units per month.

Based on similar considerations the following load summary matrix is arrived at :

Load Summary

A	*B*	*C*	*D*	*E*	*F*
A	75 (75)	140 + 90 (230)	175 + 75 + 100 (350)	0	0
B		0	50+ 115 (165)	75 (75)	115 (115)
C			140 + 90 (230)	0	175 (175)
D				140 + 50 + 115+100 + 90 (495)	175 (175)
E					140 + 100 + 90 (330)
F					

We have clubbed together the to-and-fro movements between any pair of departments. For instance, all the movements *A*-*D* and *D*-*A* are put together in the above load summary (175 is for *A*-*D*, 75 is for *D*-*A* and 100 is for *A*-*D*, giving a total of 350).

Based on the load summary, we can rank the closeness requirements of any pair of departments as :

Pairs of Depts.	*Load Frequency*	*Rank*
D and E	495	1
D and A	350	2
E and F	330	3
D and C	230	4
A and C	230	4
C and F	175	6
D and F	175	6
B and D	165	8
B and A	75	9
B and E	75	9

(Note : Rank 1 means it is highly preferable to keep this pair of departments close together. As the ranks increase, it shows less and less preference for closeness.)

Based on the rankings given above, the departments can be arranged on a grid, as per Fig. 29.13. (The flows between the departments are also shown).

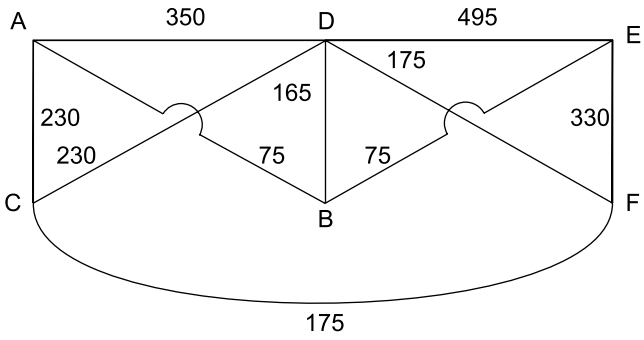


Fig. 29.13 Layout on the Grid

In Fig. 29.13 we notice that there is one flow between non-adjacent departments. This non-adjacent flow is between the departments *C* and *F* and is of a significant magnitude of 175 units. We shall try to improve the layout by reducing this flow. As a first step we exchange the places of the departments *B* and *F* on the grid. The resultant layout and the flows are shown in Fig. 29.14.

This is an improvement over the earlier layout because the non-adjacent flows are now 75 (an improvement by 100 units). We also see that no further improvement is possible.

The layout on the grid is now transformed into actual areas by putting the department squares on the grid, as in Fig. 29.15.

The departments are to be arranged in the available total space of 100 × 100 m. Keeping the individual department areas intact, the arrangement can be as shown in Fig. 29.16. (Note that the departments are kept as squarish/rectangular as possible).

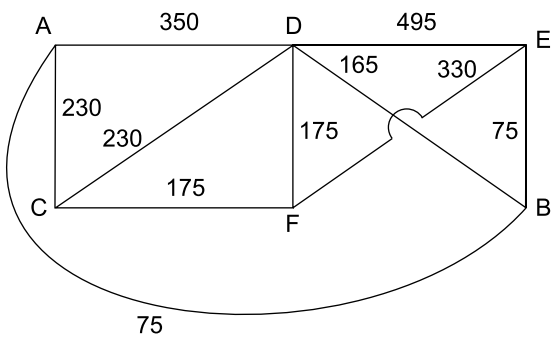


Fig. 29.14 Improved Layout on the Grid

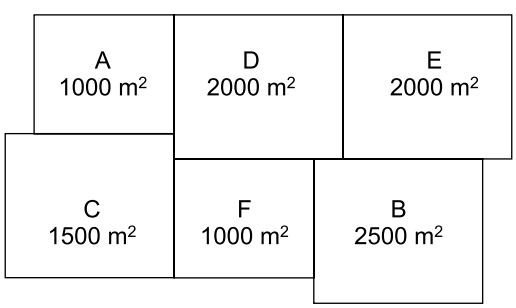
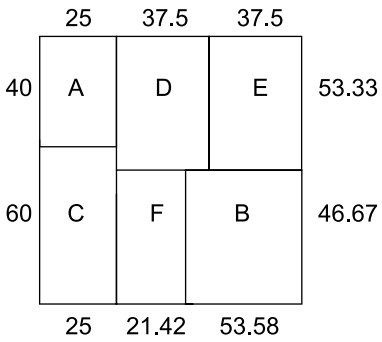


Fig. 29.15 Block Diagram



Note : All dimensions are in metres

Fig. 29.16 Final Layout

It should be noted that in the grid format the departments *F* and *E* are adjacent and departments *A* and *F* are non-adjacent. But, in the layout-to-scale *F* and *E* appear perhaps as adjacent or non-adjacent as the pair of departments *A* and *F*. Now, the layout-to-scale may be evaluated not in the grid units but in actual inter departmental distances (which could be the rectilinear distances between the centroids of the departments).

While improvements are always possible, we can leave the layout as given and hope to obtain fair results in terms of the materials handling costs.

QUESTIONS FOR DISCUSSION

1. How does a good plant layout help to improve productivity?
2. Can the plant layout principles be applied to forming a layout of an office? What criteria would you use in designing such a layout?
3. What is the effect of technology on physical layout? Discuss for manufacturing and service service situations.
4. What are the merits and limitations of CRAFT? What modifications do you suggest?
5. How would you use a Nearness Diagram for the layout design? How is it different from the Load Summary in its concept and its use?
6. Relate Ergonomics with plant layout.
7. Where would one make use of the concept of Group Technology?
8. What is a Flexible Manufacturing System? How is it related to the layout of physical facilities?
9. Does a production scheduling system have any bearing on the plant layout decision? If yes, how?
10. PQR Manufacturing Works makes the following products:

Product	*Monthly Volume of Production, Units*
P	*140*
Q	*50*
R	*175*
S	*115*

Product	*Monthly Volume of Production, Units*
T	*75*
U	*100*
V	90

There are six departments A, B, C, D, E and F in the plant. Each department performs a single type of operation. Before it is made, each product has to go through a number of different departments.

Product	*Sequence*
P	A C D E F
Q	B DE
R	A D F C
S	F B D E
T	D A B E
U	A D E F
V	A C D E F

The area requirements of the various departments are:

A	1000 m^2
B	2500 m^2
C	1500 m^2
D	2000 m^2
E	2000 m^2
F	1000 m^2

Suggest a suitable arrangement of the departments.

11. Nagda Agri-Products is planning to set up a regional warehouse in north-eastern Maharashtra. M/s Shivajirao & Co., M/s. Patil Farms, M/s. Aras & Brothers, and M/s. Jambhekar & Co. are its main clients in that area. The business volume with the above four is roughly in the ratio of 5:4:3:2. The distances of the clients from Lakshmipur, a town in that area are:

Shivajirao	50 km North
Patil	100 km North-East
Aras	75 km South-West
Jambhekar	45 km East

Where, with respect to Lakshmipur, should M/s. Nagda locate their planned warehouse?

ASSIGNMENT QUESTION

1. Study and suggest improvements in the layout of facilities in your educational institution (or your office/work–place). Present a report.

APPENDIX

MULTI-OBJECTIVE APPROACH TO FACILITIES LAYOUT PROBLEM

The chapter mainly considered a purely quantitative approach to the problem of facilities layout, minimising the materials handling cost derived explicitly by taking into account the inter-departmental flows, interdepartmental distances, etc. Another approach, which considers qualitative aspects in the main, such as the Nearness Diagram and CORELAP or ALDEP program, was also mentioned. In this qualitative approach, some quantitative aspects are generally introduced by giving preassigned numerical values to the Nearness rankings such as, $A = 6$, $E = 5$, $I = 4$, $O = 3$, $U = 2$ and $X = 1$.

Both the approaches have their merits and demerits. While the former approach has the merits of quantitative purity, the latter approach engages in gross approximations while trying to incorporate qualitative aspects. Whereas, the latter approach considers the necessity of two departments such as Opthalmology and Casualty to be far apart, due to the risk of infection, and for the same reason Operation Theatre and Ophthalmology to be close enough. Such thinking is conspicuously absent from the former approach which concerns itself primarily with the material/men flows, distances and therefore costs. This approach would not consider in its calculations a reason for closeness such as 'sudden and immediate attention necessary' as given in Fig. 29.9. Qualitative considerations have to be indirectly included, if at all, by altering the cost matrix which is not very satisfactory.

Rosenblatt* suggested combining both the approaches by a multi-objective function.

First Approach Objective

Minimise material handling cost,

i.e. Minimise $$Z_x = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{n} \sum_{l=1}^{n} a_{ijkl} X_{ij} X_{kl}$$

subject to: $$\sum_{i=1}^{n} X_{ij} = 1 \quad j = 1, 2, \ldots, n$$

$$\sum_{j=1}^{n} X_{ij} = 1 \quad i = 1, 2, \ldots, n$$

where $X_{ij} = \{ 1$ if dept. i is assigned to location j; 0 if otherwise

$$a_{ijkl} = \begin{cases} f_{ik}\, d_{jl} & \text{if } i \neq k \text{ or } j \neq l \\ f_{ii}\, d_{jj} + c_{ij} & \text{if } i = k \text{ or } j = l \end{cases}$$

c_{ij} = cost per unit time associated with assigning department i to location j;

d_{jl} = distance from location j to location l;

f_{ik} = work flow from department i to department k.

* M.J. Rosenblatt, 'The facilities layout problem; a multi-goal approach', *International Journal of Production Research*. 17, 1979, pp. 323–331.

Second Approach Objective

Maximise the closeness rating,

i.e. Maximise $$Z_y = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} w_{ijkl}\, X_{ij}\, X_{kl}$$

subject to: $$\sum_{i=1}^{n} X_{ij} = 1 \quad j = 1, 2, \ldots, n$$

$$\sum_{j=1}^{n} X_{ij} = 1 \quad i = 1, 2, \ldots, n$$

$$X_{ij} = 0 \quad \text{or} \quad 1 \quad \forall\, i, j$$

where $$w_{ijkl} = \begin{cases} r_{ik} \text{ if location } j \text{ and } l \text{ are neighbours (i.e. have common boundaries)} \\ 0 \text{ otherwise} \end{cases}$$

$$r_{ik} = \begin{cases} \text{closeness rating desirability of departments } i \text{ and } k \\ (A = 6, E = 5, I = 4, O = 3, U = 2, \text{and } X = 1) \end{cases}$$

These two objective functions are combined to form the following multiple-objective function:

Minimise $$Z = \alpha_2 Z_x - \alpha_1 Z_y$$

where a_2 and a_1 are weights assigned to total material handling cost and total closeness-rating score, respectively. (Note: $\alpha_1 + \alpha_2 = 1$ and $\alpha_1, \alpha_2 \geq 0$)

Fortenberry and Cox* combined the two objectives differently and have reported improvement over the earlier model. Their approach is given below:

Minimise $$Z = \sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n}\sum_{l=1}^{n} a_{ijkl}\, b_{ijkl}\, X_{ij}\, X_{kl}$$

subject to: $$\sum_{i=1}^{n} X_{ij} = 1 \quad j = 1, 2, \ldots, n$$

$$\sum_{j=1}^{n} X_{ij} = 1 \quad i = 1, 2, \ldots, \text{n}$$

where $$X_{ij} = \begin{cases} 1 \text{ if department } i \text{ is assigned to location } j \\ 0 \text{ otherwise} \end{cases}$$

$$a_{\text{ijkl}} = f_{ik}\, d_{jl}$$

d_{jl} = distance from location j to location l

f_{ik} = work flow from department i to department k

$b_{ijkl} = r_{ik}$

$$r_{ik} = \begin{cases} \text{closeness rating desirability of departments } i \text{ and } k \\ (A = 5, E = 4, I = 3, O = 2, U = 1\ X = -1) \end{cases}$$

Note: These pre-assigned values are different from those given by Rosenblatt.

* J.C. Fortenberry and J.F. Cox. 'Multiple criteria approach to facilities layout problem', *International Journal of Production Research*. 23(4), July-Aug. 1985, pp 773–82.

30 Cellular Manufacturing

Chapter 29 discussed the process layout and the product layout. It was seen that the product layout was more suited to mass production of goods while the process layout suited more to a job-shop type of production situation. Each of these layout types has its own advantages and disadvantages. Briefly stating, the main advantage of a product layout is that of ease (and therefore, economies) in flow of the material that is being processed, while the main advantage of the process layout is that it is flexible—allowing for a variety of products to be manufactured in small batches. In small-batch manufacturing (Fig. 30.1) which is typical of so many engineering industries, there is a tremendous potential for cutting down the production time of items.

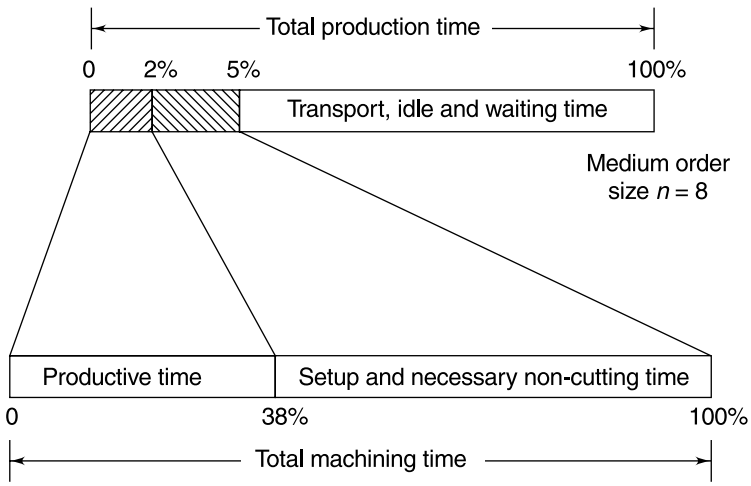


Figure 30.1 Analysis of Total Machining Time and Flow-through Time in Conventional Manufacture

Source: G.K. Hutchinson, "Flexibility is the Key to Economic Feasibility of Automating Small Batch Manufacturing", *Industrial Engineering*, Vol. 16, No. 6, June 1984, pp 77–86.

DEMERITS OF PROCESS AND PRODUCT LAYOUTS

The Problems of 'Flow' in a Process Layout

The flexibility of the small batch manufacture using a process layout is limited to the variety of the items produced. The flexibility is not with regard to time. As was seen in the earlier chapter that in a process layout, equipments performing similar operations are placed together in an area of the shop-floor. Lathes may be in one area while the milling machines may be in another, and the grinding machines in yet another work area. In manufacturing a component, it may need to go through all or some of these work areas, frequently more than once. Every time a machine may have to be set a new resulting in losses of time in terms of setup times and, more importantly, large 'wait times' of the items waiting for their turn at the machine/work centre due to the varying skewed workload at these work centres. That is, not infrequently, several parts land up at around the same time at a particular work centre, in their zigzag and varying and therefore unpredictable journey through the factory. This results in huge wait times for these semi-finished parts.

A delay in one operation, may compound the delay in another operation required for the particular component on its route to completion. Since these components may be required for an assembly at the end, the assembling may be delayed for want of a particular component.

A machine in a process layout faces:

(a) randomness or variability of the design of parts coming to it for production necessitating fresh setup each time, and

(b) randomness of the arrival of the parts at the machine due to randomness in the route each part traverses.

These two aspects of randomness compound each other increasing the randomness further.

The sum and substance of all this is that the throughput times are long and uncertain, the customer bearing the brunt of all these delays. Some factories keep extra machines in the work centres or keep extra inventory of the finished goods, in order to take care of this problem. Thus, there may be much inventory sitting in the factory—both the work-in-process kind and the finished goods kind, in addition to possibly excess machines sitting idly much of the time. Process layout caters to 'intermittent flow' type of production (another name for job-shop production); and, precisely the problem with this layout and production system is that of flow.

The Human Relations Problems in a Process Layout

Since the persons with same/similar skills are deployed together in a work centre (resulting in different work centres having people with dissimilar skills), it may lead to:

(a) a lack of appreciation of the work of other work centres,

(b) a lack of the need for cohesion within a work centre,

(c) diversion of focus from the final product and/or the company's goal, and

(d) an inflexible mechanistic organisational structure requiring a management intervention all too often to resolve conflict situations between work-centres and between people belonging to the same work centre.

The negative effect of such a lack of communication and of a lack of a sense of cohesion is acutely felt in the not-so-infrequent a situation when a particular high-priority rush order has to be expedited through the various work centres. There is more often than not a resistance to the order

cutting through the already set sequencing procedures and 'hierarchies'. There is conflict between the work centres. The company's goal is rarely in the picture and there is a need for frequent intervention by the management. This further divides the management from the (non-management) employees. Moreover, the management gets preoccupied with fire-fighting of this kind and would therefore be more inwardly focused than having an outward focus and understanding the customer and the external market in general. Thus, the company's management ends up neglecting its main job. The functional layout (another name for process layout) ends up being dysfunctional on these counts.

Of course, just because we have mentioned the demerits of the process layout, it does not lose its merits viz. making large variety possible, honing up skills of the workers as they repeatedly carry out the same operation, and giving them a better job satisfaction. (Refer to Table 29.1)

Problems in Line Layout or Product Layout

Line layout is great for flow, has excellent throughput times, eliminates the inter-departmental conflict (because it is one joint line, however branched it may be) and has almost nil work-in-process inventories. But, it is too big for making any quick changes—in the product and in the process. It is inflexible on that count. One only wishes that it was small or short.

CELLULAR MANUFACTURING AS A SOLUTION TO THE CONVENTIONAL LAYOUT PROBLEMS

Cellular manufacturing, also known as Group Technology, is an approach whereby production can be done in small batches while taking advantage of the flow characteristics of the product or line layout. Components that may appear to be dissimilar but which require similar manufacturing processes and/or similar setups of the machine are grouped together and go through a particular group of such machines which may be dissimilar. Thus, instead of functional work centres we have these groups of machines or short lines. For instance, we may have a turning machine, a drilling machine and a polishing equipment put together in a group, using which a group of components can be manufactured. However, not all components of a components' group need to go through all the machines in the corresponding group or short line of machines. This concept is called Group Technology. Each of these short lines or groups of machines is also called as a 'cell'. A cell, thus, consists of a group of machines and a 'family' of related components being produced on these machines. Since the manufacturing plant would now consist of several cells, manufacturing using such Group Technology is also called Cellular Manufacturing.

Group technology exploits the similarities and relationships* between the large population of components. It thereby could, reduce transport between successive machines, reduce setup on a machine and cut down the artificial uncertainty of the flows. The effect would be a reduction in the time and cost of manufacture.

Cells can be formed to manufacture different variety (within a range) of components. The entire variety requirement of the factory in the short term and a foreseeable intermediate term can be met by having a limited number of such lines or cells. In effect, we have all the variety needed, and at the same time we have simulated line production too. We thus have the flexibility of variety as well

*Relationships could be that of the sequence of flow through the machines. It could be that between the final product, the subassemblies and the components.

as reduced flow times. A small number of people functions as a cohesive group and accomplishes a common whole task. So, there is a lot more job satisfaction. Unlike large assembly lines, there is no boredom here and very little in-process inventory is needed within a cell.

A diagrammatic representation of cells is given in Fig. 30.2.

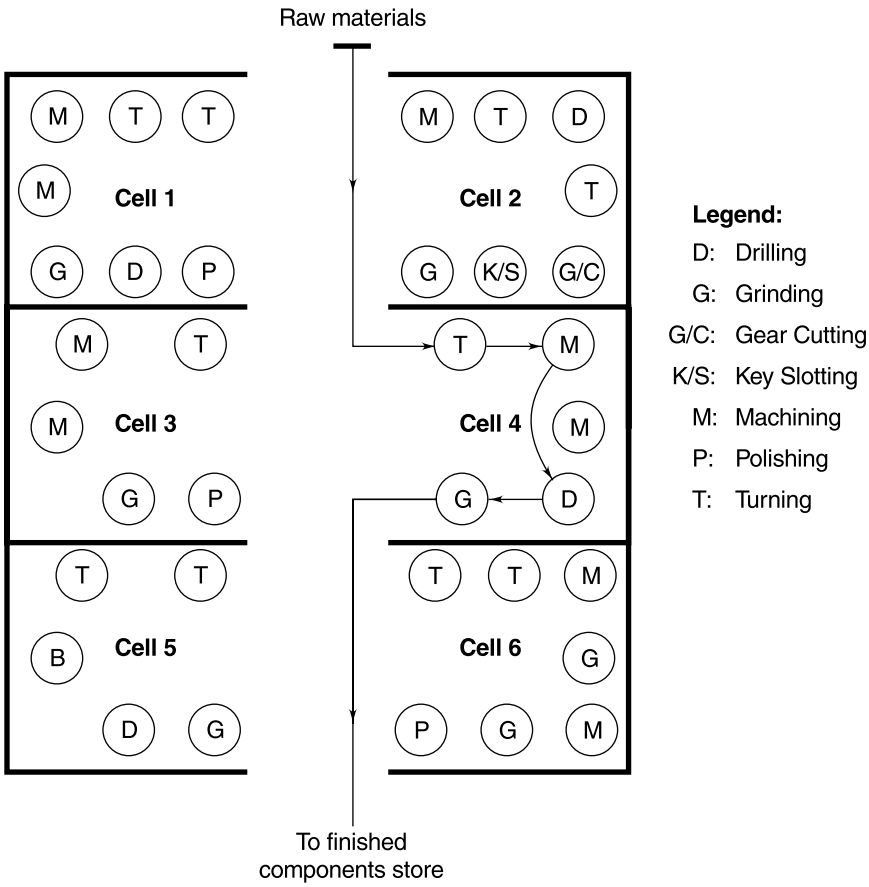


Figure 30.2 Cellular Manufacturing

Management can empower the cell to function as an independent unit with independent maintenance and internal quality functions. The management has to, however, ensure that the 'group' goals are in line with the company goals.

BENEFITS OF CELLULAR MANUFACTURING

What happens with such grouping? We already saw some of the advantages. Here is a more comprehensive list.

1. Compared to the earlier process layout, there are very few halts. Hence flow times are reduced considerably.

2. Unnecessary fresh setups or modifications to setups are eliminated. This saves process times significantly.
3. 'Very few halts' translates to a drastic reduction in inventories of work-in-process.
4. However, all the required variety can be produced. Group technology does not compromise on the variety of items.
5. Even a sudden rush order can be produced without causing much problem.
6. Employees feel empowered.
7. Employees in the cells derive much job satisfaction.
8. Cells satisfy several other psychological needs of its members: a sense of belonging, self-esteem and security. This, in turn, reduces absenteeism, labour turnover and labour unrest.
9. An employee of a cell is free to do any operation within the cell, provided he has developed that skill. Multi-skilling is commonly observed in cellular manufacturing. So, there is job enlargement for the employee.
10. Since the employee is familiar with a known range of components that come to a cell, the employee tends to make less errors; this can improve the quality of the items.
11. Quality can also improve because of reduced handling of the items, because multiple operations get done in a single cell.
12. Since cells mean a modular approach to organising production, it is easier to manage/direct/re-orient/repair a cell than either a huge elephantine flow line or the amorphous process layout.
13. In times of crisis, such as sudden demand changes or labour unrest, the crisis can be contained because of the modular nature of production.
14. Production control methods could be simpler; there could be even visual methods of production control in some cases. Because, the product (being worked upon) goes quickly through the system.

HOW ARE 'CELLS' FORMED?

A basic question in cellular manufacturing is the determination of part families and machine cells. This issue is known as cell formation problem.

Mitrofanov's Grouping for a Single Machine

Before this question is answered it may be mentioned that the idea of a cell originated from the concept of a 'single machine' as initially developed by Mitrofanov of Russia in the 1960s. He suggested grouping of similar components for production on a single machine. This would eliminate setups or drastically reduce setup times, thus considerably reducing total time to manufacture. Thus, his idea was 'grouping for a single machine'. This would also save on all the transport, waiting and idle times.

If the entire lot of components can be produced on one single machine, then Mitrofanov's arrangement is fine. However, if this is not the case, the subsequent operations will get clogged by the increased output from this machine. Hence, enhancing productivity of merely a single machine may be counter-productive. This suggests that there should be an extension of the concept of a 'single machine' by having secondary operation machines *around* the primary operation machine.

Together they should be able to produce the range of components coming to them. There is under-utilisation of the secondary operation machines in this scheme of things, but that needs to be tolerated in view of fulfillment of other criteria. This kind of arrangement has given rise to the concept of a cell and cellular manufacturing.

The basic idea is that a 'component family' is to be processed in a 'cell' comprising the primary and secondary machines. A component family or group is a collection of components which are similar for the purposes of manufacture. The components' family formation can be approached by several methods.

A Simple and Visual Method of Cell Design

After a broad classification such as rotational parts and non-rotational parts, further classification may be done as per the material that the component is made of, component size and its detailed shape. The priorities in classifying may be in the order indicated.

- Rotational or non-rotational
- Material
- Size
- Shape

This is shown in Fig. 30.3.

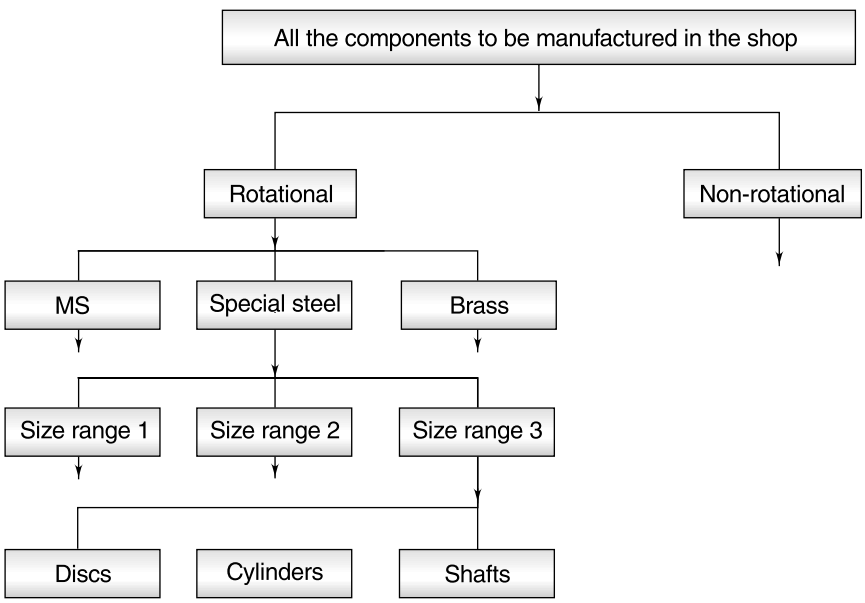


Figure 30.3 A Simple and Visual Method of Cell Design

Method Using the Concept of a 'Composite Component'

For a family of parts, a composite component can be envisaged which has all the necessary features of the members of the family. The composite component could well be a hypothetical one (usually it is) but is very useful in developing tooling layouts on machines. While such a concept can be

easily applied on the primary machine in a cell, considering the secondary operation machines is rather complex, particularly when the total number of components is large. A 'family of parts' and a 'composite component' are shown in Fig. 30.4.

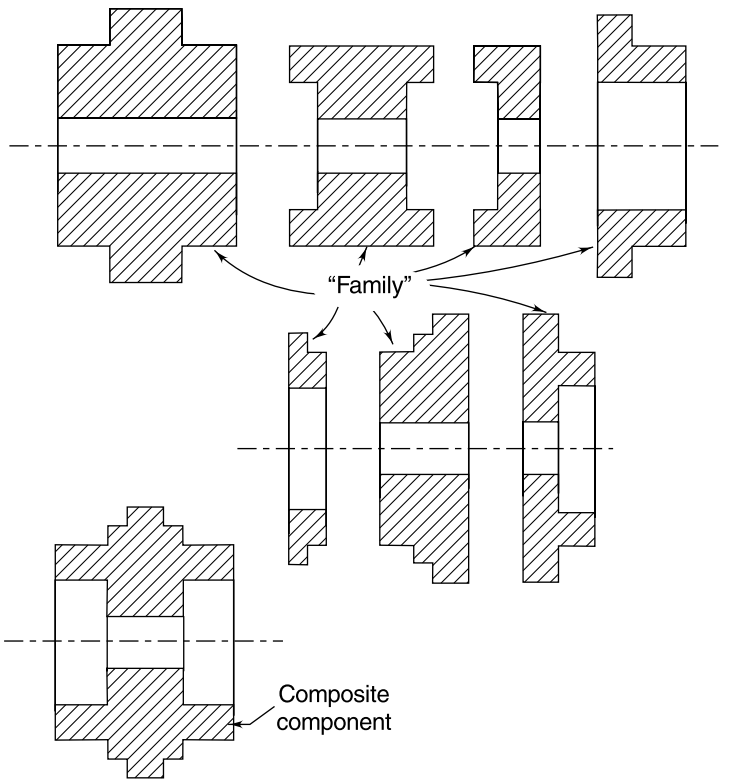


Figure 30.4 Family of Parts and a Composite Component

The production machine tool is set up to machine the composite component. Thereby, in effect, the entire range of parts can be machined with small adjustments. This greatly reduces the setup times for the different parts. It artificially creates a large batch of items to be manufactured on the machine setup. Instead of a large batch of 'same' items to manufacture in a product layout, now we have a large batch consisting of 'similar' parts. A large volume is thus artificially created, conferring the advantages of mass production.

'Family' Formation by Classification and Codification

When the number of parts is quite large, it may be advisable to have such code numbers for the parts that will help identify similar parts. Thus, looking at the code numbers, it should be possible to form families of parts for cellular manufacture. Opitz codification system, developed in Germany, is one such useful system for Group Technology. Opitz system is as follows:

1st digit: Type (rotational or non-rotational) and shape (e.g. length to diameter ratio)

2nd digit: External shape and external shape elements
3rd digit: Internal shape and internal shape elements
4th digit: External plane surface machining
5th digit: Auxiliary hole and gear teeth
6th digit: Diameter or edge length
7th digit: Type of material used to make the component
8th digit: Initial shape of the material
9th digit: Accuracy to which the component is manufactured

In addition to being helpful in forming cells for a group of components, such codification will help in forming a design information system and in standardisation.Opitz classification with the first five digits is shown in Fig. 30.5.

The main issue in Group Technology is that of identifying, from a large population of components, of the 'families' needing similar manufacturing operations on very similar setups. The classification and codification system adopted for the components should be of immense value in sorting out 'families' from the large population of components.

Towards this purpose, one need not necessarily follow the Opitz system. One could have one's own classification and codification system if it serves the purpose. In fact, a firm can derive the benefits of Group Technology using its existing system of codification. It is not the 'choice' but the 'use' of the codification system that is important.

The other point to note is that the classification and codification system uses the physical description of the component more than the manufacturing processes to be performed to produce that component. While the physical attributes are helpful in guiding towards the suitable manufacturing processes, it is not the same as developing a classification based mainly upon manufacturing considerations. In firms where data on manufacturing aspects of the components is available, one would rather directly use the manufacturing process data for 'grouping' and arriving at the 'families'.

Cell Formation Using Production Flow Analysis

The theme of a production flow analysis is to arrive at a grouping and layout of the groups such that the inter-cell flows are minimised. The flows can be analysed based on the information contained in the route cards for the parts and assemblies produced on the given shop-floor. Groups or families of the parts are arrived at based upon similar routes in terms of the machines used. This method was first suggested by Professor J.L. Burbridge.

Certain processes such as heat treatment, electroplating, gear-cutting, welding, casting and forging may need separate locations and control. These incompatible processes will be left out of this analysis.

The technique uses only the data on the plant, machines, tooling and processing methods that are currently being used. The technique basically consists of dividing the entire shop / factory into groups so as to achieve a more orderly layout, resulting in improved flow of work. The aim behind this technique is more macro than considering the design features or shape of the components. In fact this technique of grouping does not consider the design and/or shape aspects. Its focus is not the component but the work flow. It groups the machines for better flow and then on that basis considers which component should be made in which cell. A component gets manufactured in one cell alone. So, those components which have to go through similar route of processes are grouped together and not necessarily those requiring similar tooling setup. Same or similar flows constitute a cell. This is basically a material flow simplification technique.

1st Digit: Component class		
0	Rotational components	L/D ≤ 0.5
1		0.5 < L/D < 3
2		L/D ≥ 3

2nd Digit: External shape, external shape elements		
0	Smooth, no shape elements	
1	Stepped to one end or smooth	No shape elements
2		With screwthread
3		With functional groove
4	Stepped to both ends (multiple increases)	No shape elements
5		With screwthread
6		With functional groove
7	Functional taper	
8	Operating thread	
9	Others (> 10 functional diameters)	

3rd Digit: Internal shape, internal shape elements		
0	Without through bore blind hole	
1	Smooth or stepped to one end	No shape elements
2		With screwthread
3		With functional groove
4	Stepped to both ends (multiple increases)	No shape elements
5		With screwthread
6		With functional groove
7	Functional taper	
8	Operating thread	
9	Others (> 10 functional diameters)	

4th Digit: Plane surface machining	
0	No surface machining
1	External plane surface and/or surface curved in one direction
2	External plane surfaces related to one another by graduation around a circle
3	External groove and/or slot
4	External spline and/or polygon
5	External plane surface and/or slot and/or groove, spline
6	Internal plane surface and/or groove
7	Internal spline and/or polygon
8	External and internal splines and/or slot and/or groove
9	Others

5th Digit: Auxiliary hole(s) and gear teeth		
0	No gear teeth	No auxiliary hole(s)
1		Axial holes(s) not related by a drilling pattern
2		Axial holes related by a drilling pattern
3		Radial hole(s) not related by a drilling pattern
4		Holes axial and/or radial and/or in other directions not related
5		Holes axial and/or radial and/in other directions related by drilling pattern
6	With gear teeth	Spur gear teeth
7		Bevel gear teeth
8		Other gear teeth
9		Others

Figure 30.5 Example of Opitz System of Codification for a Short Rotational Component

The procedure is to construct a Production Flow Analysis chart. This consists of plotting operation numbers (each operation would have been given a number) against the corresponding pack numbers. A 'pack' is a group of components using similar processes (regardless of the sequence within these processes). Various 'packs' are given different numbers to facilitate graphical analysis. Such a chart is shown in Fig. 30.6.

This chart can now be used for grouping packs along with their respective processes into cells. While doing this, it is ensured that a component is completely produced in one cell only (barring the independent operations like heat treatment or electroplating).

Points to be Noted about Cell Formation by Production Flow Analysis

- Machine workloads must be checked after the initial grouping to ensure that the machines are not overloaded.

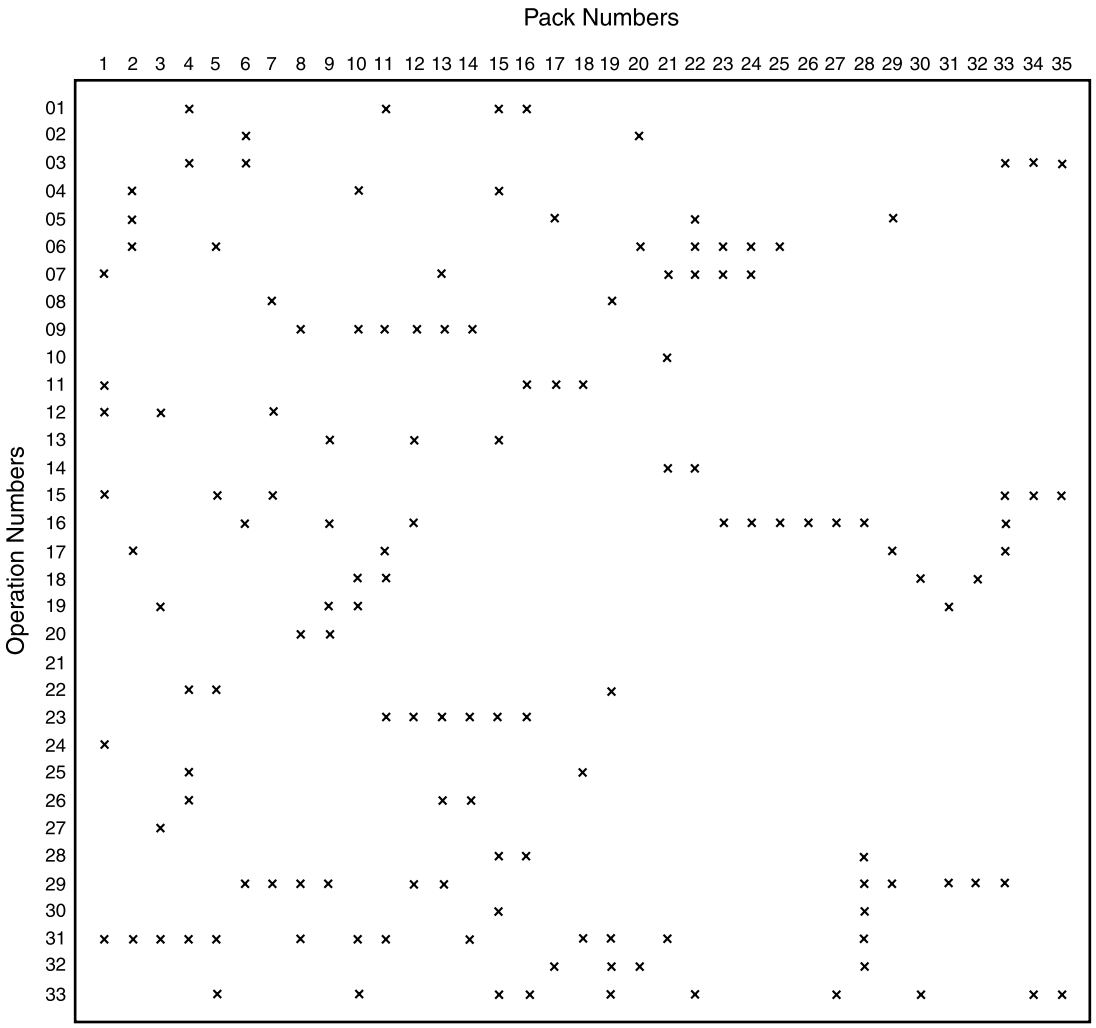


Figure 30.6 Production Flow Analysis Chart

- One should take into consideration the variables within a machine type—some machines may be old and some may be new with different process capabilities and different types of tooling.
- Within a cell, it is unlikely that all component would follow the same sequence of machines. Therefore, a table may be prepared showing the frequency of each sequence number (i.e. carried out 1st, 2nd or 3rd, etc) for each machine in the cell. Based on this information, a layout may be prepared to minimise the component travel within the cell. Such a table is depicted in Fig. 30.7.

Machine number	Sequence number						
	1	2	3	4	5	6	7
M1	4				4		
M2		29	2				
M3	1		3	5		10	9
M4	34	5					
M5			7	1	10		
M6			20		2		
M7		1	2	11			

Figure 30.7 Frequency Table for Designing Layout within a Cell

Points to be Noted, in General, Regarding Cell Formation

There are a few issues to note in forming cells, whatever may be the method used for grouping

The Issue of the 'Cell size' (i.e. the Number of Machines/People)

- A cell should have a 'sociable' number of employees in it. This is generally between 6 and 12. The allocation of the machines to the cell should be made taking this factor into consideration.
- The deployment of employees to the cell should be democratic. They should be comfortable working with each other.
- The size of the cell should be such that a visible control of the cell is possible.

The Issue of 'Cell Independency'

- A component should be made, as far as possible, completely in one cell. Care should be exercised in cell design such that the operations sequences do not spill over to other cells. A cell should, thus, be independent. There are, of course, certain incompatible processes such as heat treatment, electroplating, etc. which are left out of the formation of the cells.

The Issue of Cell Flexibility

- There should be internal routing flexibility (ability to process parts on alternate machines inside a cell).
- A cell should be able to accommodate new parts.

Issue of 'Completeness'

- All the components/parts flowing through the production system in the plant should be analysed. No component should be left out of the analysis and grouping.
- Group technology should be implemented fully. Partial implementation may not do justice to the objective.

Various Approaches to Cell Formation

The various approaches to cell formation can be summarised as shown in Fig. 30.8. (Only some of these approaches have been discussed in this chapter.)

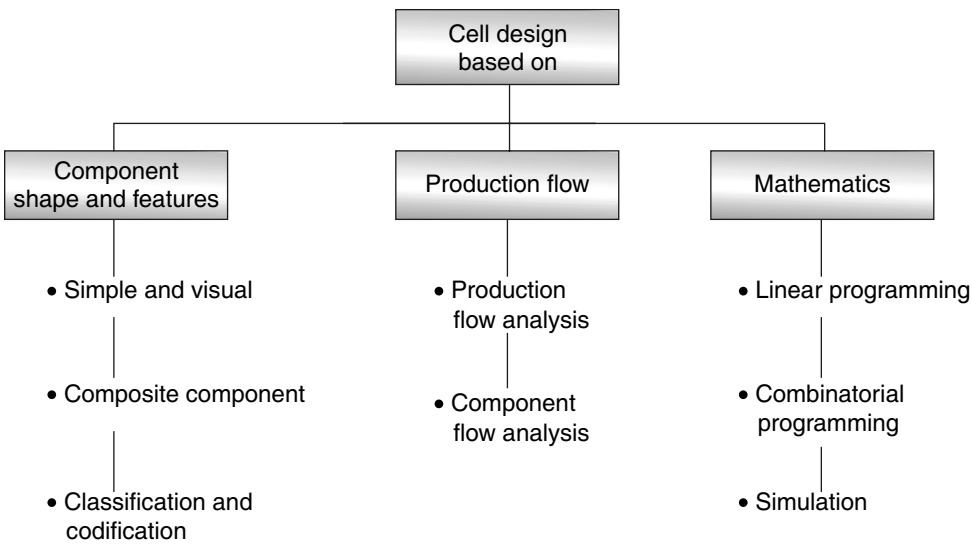


Figure 30.8 Approaches to Cell Formation

LIMITATIONS OF CELLULAR MANUFACTURING

Group Technology is a great concept. But all good concepts do have their own limitations and need proper care in their application, for results to be realised in practice. Improper implementation and/or half-hearted attempts may usually backfire. The concepts have to be applied with a great deal of thought prior to their application. The assumptions behind the theory have to be properly assessed. A good homework needs to be done before the application and a wholehearted implementation needs to follow. Thus, the limitations of cellular manufacturing may be as follows:

1. Setup times or change-over times may not always be significantly reduced just because the components in the 'family' bear apparent similarity. Some of the literature* on Group Technology reports that a major proportion of the features of a group of components must be virtually identical for the reduction in the setup times to take place.
2. Similarly, the assumptions regarding raw material and work-in-process inventories need to be checked during the design of the cells. In a process layout, the machines share a common pool of inventories; whereas in an ill-designed cellular system, machines may require their own individual stocks of materials.
3. Improper cell formation, whether based on component shapes/features or on production flow analysis, would turn out be inefficient in terms of time, investment and humanistic aspects. Load balancing, utilisation of non-key machines and the placement of bottleneck machines are issues that need to be addressed during cell formation.
4. Inadequacies in employee education, training and involvement could come in the way of proper implementation.

Cellular Manufacturing—the *avatar* of Group Technology in manufacturing—has concerned only to the internal 'spatial' arrangements. That is, it has been focusing on only one dimension of the production/operations system. It has not been systemic in nature. To that extent, the application has been limited in its scope. Therefore, the results may not be radical in their extent. Newer management technologies such as Just-in-Time system have used the concept behind Group Technology—that of bringing in the properties of a line layout in batch production—in addition to several other concepts and measures which take care of other issues in the management of production and product delivery. The results have been quite positive, remarkably so.

A BROADER CONCEPT OF GROUP TECHNOLOGY

In a broader context, Group Technology is an attempt to achieve improved control by looking for commonalities i.e. looking for avenues for standardisation and achieving better rationalisation and harmonisation through the same. Basically, 'cells' are nuclei for control. These concepts of 'rationalisation of activities', 'harmonisation of flows' and 'nuclei of control' can also be used in several situations other than manufacturing. Administrative offices and banks, for instance, could have such 'nuclei' for enhanced delegation of responsibility and control. In fact, the 'teller' system used in the banks is one such example of a nucleus formation by combining several small jobs into one job. The idea is akin to a composite element being made on a single machine. This is similar to a receptionist at a hotel who does a number of tasks, including registration, check-in and check-out, cash collection and refunds (if any), answering queries of customers, providing them with varied information related to the hotel and regarding the city ('Is there a restaurant in the town nearby where I can get good sea-food?', 'What mode of transport should I take to go to Haji Ali's dargah?') and environs including sightseeing trips, arranging for the same, answering and taking appropriate action on complaints of the customers. In several offices, the related activities are grouped and placed physically together (near each other) for better efficiency that could be possible due to a better/quicker flow of information and papers through the system.

*Waghodekar, P.H. and S. Sahu in *Facility Layout and Group Technology—A Short Term Course for Working Professionals*, Indian Society for Technical Education—Continuing Education Project, sponsored by Ministry of Human Resources Development, Government of India, 1992, (Chapter 3).

In general, it could be said that many problems/tasks could be 'similar'. By grouping such similar problems/tasks, a single solution to the problem or a single point of control for the tasks could be found. This saves on time and effort. Group Technology could be viewed in this broader perspective.* It appears, the benefits that Group Technology could offer to the discipline of management have yet to be fully exploited.

QUESTIONS FOR DISCUSSION

1. How could Cellular Manufacturing be of strategic value to an organisation? Discuss.
2. Would the formation in cells lead to a duplication of machines and, therefore, a larger investment in machines? Discuss.
3. What are the disadvantages of a Line Layout that one should avoid in Cellular Manufacturing? How would one do that? Explain.
4. What human relations problems, if any, would you expect in a cellular manufacturing situation? Explain.
5. How is management control different in a Cellular Manufacturing situation as opposed to the traditional situation of a process and/or a line layout? Discuss.
6. In addition to the grouping of machines and/or components, what other aspects need be considered while designing a cell? Explain.
7. Is Cellular Manufacturing because of its departure from a process layout, inimical to new product design? Group technology is an attempt to discover uniformity in diversity. Whereas a new product design is about offering to the customers something out of the ordinary. Discuss.
8. Refer to the modular concept in Product Design. How is the concept of modularity important in Cellular Manufacturing? Discuss.
9. How could a cell design problem be expressed in a Linear Programming format? What is the objective? What are the variables? What are the constraints? Explain.
10. Refer to Just-in-Time (JIT) manufacturing system which is presented in Section VI. What could be the Group Technology applications, if any, in JIT? Discuss.
11. How do 'spatial' relationships such as the Facilities Layout influence other relationships within and outside the organisation? Discuss.
12. 'Group Technology as applied to a production/operations system is a human relations technology.' Would you agree with this statement? Discuss.
13. Reflect on various areas in which Group Technology could be used productively. Mention those areas. Discuss.
14. Find about systems of classification and codification other than the Optiz system mentioned briefly in this chapter. Find about their application in Group Technology for manufacturing.
15. Would the principles of Cellular Manufacturing be useful in a large hospital? Explain your answer in detail.
16. Does grouping take away some of the flexibility from manufacturing? Does grouping of machines and people in cells introduce more rigidity into the operations system? Discuss.

*Solaja, V. and S.M. Urosevic, 'Optimization of Group Technology lines by methods developed in the Institute for Machine Tools and Tooling (IAMA) in Belgrade' in 'Group Technology' Edited by Burbridge, J.L., Proceedings of International Seminar, September 1969, ICATVT, Turin, Italy, pp. 157–76.

31 Location of Facilities

NATURE OF LOCATION DECISION

Facilities location deals with questions such as: 'Where should our main operations be based? Should it be Maharashtra, Karnataka or Tamil Nadu? If Karnataka is most desirable, should it be at Bangalore or Mysore? If Tamil Nadu is a close second to Karnataka, should the operations facility be located at Hosur which is in Tamil Nadu but is only 40 kilometers from Bangalore?' Once such a decision is taken, say Mysore, then the organisation has to live for a long time with the prospects and problems regarding the raw materials, supplies, labour and all other resources and also markets that Mysore would present. Once the manufacturing plant has been erected, it is a long-term commitment on the capacity created: Capacity not only in terms of the machinery and equipment but also in terms of arrangement and development of raw materials resources, labour skills, market and distribution channels and the adjustments with the environment. Location of facilities for operations is, thus, a long-term capacity decision which involves a long-term commitment about the geographically static factors that affect a business organisation. Some changes and adjustments in capacity—qualitatively and quantitatively—at the location are always possible; however in most of the cases, it is not easy to change the location of the operations base once it has been established. For service organisations, location decision is as important—if not more important—as that for the manufacturing organisations.

LOCATION DECISION: AN INTEGRAL PART OF ORGANISATIONAL STRATEGIES

The planning for 'where' to locate the operations facilities should start from 'what' are organisation's objectives, priorities, goals and the strategies required to achieve the same in the general socio-economic-techno-business-legal environment currently available and expected to be available in the long-term future. Unless the objectives and priorities of an organisation are clear i.e. the general direction is clear, effective functional or composite strategies cannot be designed. And, it is these strategies of which the location decision is a product. (See Fig. 31.1)

As shown in Fig. 31.1 the various strategies feed into one another. For instance, a marketing strategy (customer profile, products, markets, volumes, price structures) suggests a necessary technology strategy (technology, process, methods, sophistication, machinery and resources); while a technology strategy requires a particular marketing strategy to make the former viable. Similarly, a strategy considering resources—material as well as manpower (quantity, quality, users, availability—short and long term) will suggest suitable technological strategies; and a technological strategy would require a certain resources strategy (regional availability, procurement and development). Financial strategy feeds into all of these; and the reverse is also true. Plant or facilities location is a product of all these strategic considerations. Volumes, technology, resources and organisational and social costs amount to an operations strategy. Location of facilities is, therefore, an integral part of the operations strategy of an organisation.

Choice of Region and Site It may be noted that the consideration of **(i)** an organisation's strategies, **(ii)** its already existing operating facilities if any, **(iii)** the managerial control considerations in handling these multiple facilities, **(iv)** the region-specific environmental considerations—economic and business environment (users, suppliers, competitors), legal and governmental regulatory and developmental environment, social environment and natural geographical environment and the effect of locating operating facilities on the same and vice versa, **(v)** along with a broad consideration of value added and the transportation costs would help in deciding on the *region* for locating the facility. The exact location of the site within the region chosen would depend on a detailed examination and comparison of the various resources (and conveniences) and their costs for a number of possible alternative sites.

SITUATIONS THAT INFLUENCE LOCATION DECISION

The location decision can be for two different situations:

1. Location choice for the first time.
2. Location choice for an already established organisation with one or more facilities existing.

Both the cases involve the kind of strategic considerations described earlier. However, the first case may be the simpler of the two; whereas the second case involves fitting of a new operational facility in the mosaic of the already existing facilities, an operational strategy that may have to seriously consider the legacy of the past—traditions, values, systems, customer profile, customer and societal perceptions, geographical and time-phased plans drawn earlier, etc., and also the multiplicity of the existing realities and future possibilities. So, perhaps, the second case may be a little more complex. However, it is also possible that the unknowns may be more in the decision made for the first time. In any case, it needs to be understood that the two cases are different. For a company having a small presence in Middle East, it may make more sense to locate an additional facility in the same region of the world in order to strengthen the presence and bring in more focus. A high-tech hospital chain for the metropolitan up-market may be better of by adding the next hospital facility in a similar metropolitan market segment.

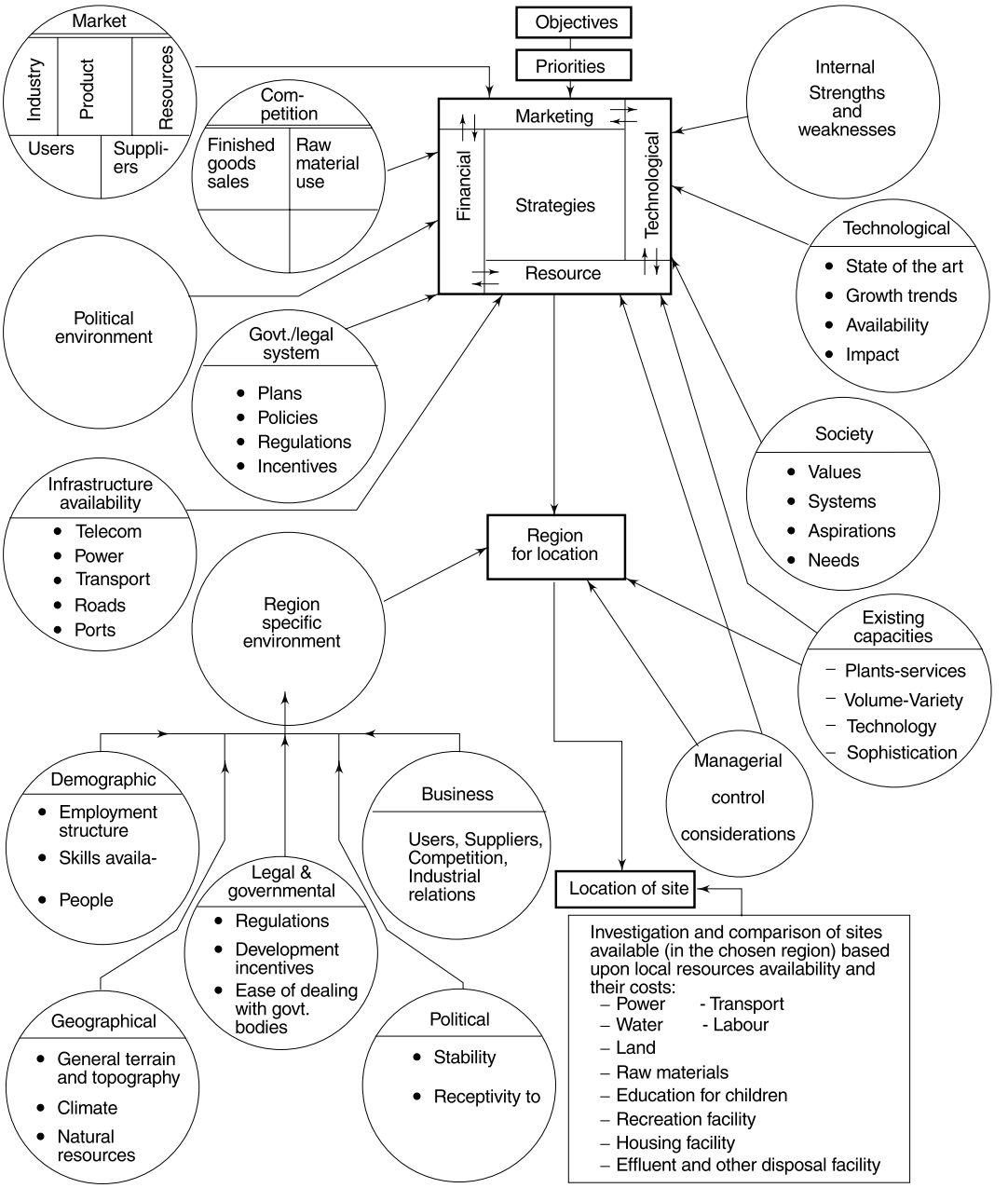


Figure 31.1 Decision-Making in the Location of Facilities

NOTE: In Fig. 31.1 factors influencing are those that are available in the present and in the long-term future.

CASE OF THE ALREADY ESTABLISHED ORGANISATION

A new manufacturing plant has to fit into a mutli-plant operations strategy. The different operations strategies could be:

1. Plants Manufacturing Distinct Products or Product Lines However, each plant services the entire market area for the organisation. This strategy is necessary where the needs of technological and resource inputs are specialised or distinctively different for the different products/product-lines. For instance, a high quality precision product-line should preferably *not* be located along with other product-line requiring little emphasis on precision. It may not be proper to have too many contradictions such as sophisticated and old equipment, highly skilled and semi-skilled personnel, delicate processes and those that could permit rough handling, all under one roof and one set of managers. Such a setting leads to much confusion regarding the required emphasis and the management policies. Product specialisation may be necessary in a highly competitive market; it may also be necessary in order to fully exploit the special resource potential of a particular geographical area. Instances of product specialisation could be many: A watch manufacturing unit and a machine tools unit; a textile unit and a sophisticated organic chemicals unit; an injectable pharmaceuticals unit and a consumer products unit; etc. All these pairs have to be distinctively different—in technological sophistication, in process, and in the relative stress on certain aspects of management. The more decentralised these pairs are in terms of the management and in terms of their physical location, the better would be the planning and control and the utilisation of the resources.

2. Manufacturing Plants each Supplying to a Specific Market Area Here, each plant manufactures almost all of the company's products. This type of strategy is useful where market proximity consideration dominates the resources and technology considerations. This strategy requires a great deal of coordination from the corporate office. An extreme example of this strategy is that of soft-drinks bottling plants. The Associated Cement Companies Ltd. have 17 cement factories spread over Rajasthan, Gujarat, Maharashtra, Madhya Pradesh, Haryana, Andhra Pradesh, Karnataka, Tamil Nadu, Himachal Pradesh and Bihar. Fertilizer Corporation of India Ltd. has plants at Durgapur, Gorakhpur, Nangal, Namrup, Sindri, Trombay, Barauni, Korba and Haldia.

3. Manufacturing Plants Divided According to the Product/Product Line being Manufactured; and these Special-Product Plants Located in Various Market Areas This type of a combination strategy may be possible for a large organisation.

4. Plants Divided on the Basis of the Processes or Stages in Manufacturing Each production process or stage of manufacturing may require distinctively different equipment capabilities, labour skills, technologies, and managerial policies and emphasis. Since the products of one plant feed into the other plant, this strategy requires much centralised coordination of the manufacturing activities from the corporate office who are expected to understand the various technological and resources nuances of all the plants. Sometimes such a strategy is used because of the defence/national security considerations. For instance, the Ordnance Factories in India.

The McGraw·Hill Companies

5. Plants Emphasizing Flexibility in Adapting to Constantly Changing Product Needs This requires much coordination between plants to meet the changing needs and at the same time ensure efficient use of the facilities and resources.

The new plant or branch-facility has to fit into the organisation's existing strategy, mainly because the latter has been the product of deep thinking about the long-term prospects and problems, and strengths and weaknesses for the organisation as a whole.

Frequent changes in the long-term strategy, in order to either alleviate temporary problems or improve the efficiency temporarily, are not healthy for the organisation. Rather, such temporary palliatives may give rise to more complications in the future. In any facility location problem the central question is: "Is this a location at which the company can remain competitive for a long time?" rather than "Is it cheaper to do business here?"*

It may also be noted that for an established organisation in order to add on to the capacity, there can be ways other than opening up new operations facilities:

(a) Expansion of the facilities at the existing site/sites;
(b) Relocation of the facilities (closing down the existing ones).

The procedure (a) is acceptable until it does not violate the basic business and managerial outlines, i.e., philosophies, purposes, strategies and capabilities. For instance, expansion should not compromise on quality, delivery, or customer service. If it does, it is an indication that the diseconomies of scale such as incompatibilities, loosening of the management control and inflexibilities have crept into the system. It is then appropriate to look for a new location for the expanded portion of the activity. Procedure (b) is a drastic step which can be called as 'Uprooting and Transplanting'. Unless there are very compelling reasons, relocation is not done. The reasons are almost never of increasing plant size but those of either bringing radical changes in technology, resource availability or other destabilisation. There have been instances in the past of some large firms shifting their plants and headquarters from Calcutta to Hyderabad and Bangalore.

Whatever has been said here is equally applicable to service organisations. For instance, there could be (1) different service facilities providing distinctly different 'service products', (2) separate service facilities for various market areas, (3) a combination of (1) and (2), and (4) service facilities divided on the basis of processes or stages involved in the service operations. Of course, it is needless to mention that the objectives, priorities and strategies for service organisations may differ from those for hardcore manufacturing organisations.

LOCATION CHOICE FOR THE FIRST TIME

In this case, there is no prevailing strategy to which one needs to confirm. However, the organizational strategies have to be first decided upon before embarking upon the choice of the location of the operating facility/facilities. The importance of the long-term strategies cannot be over emphasised. Cost economies are always important but not at the cost of long-term business/organisational objectives.

Identification of Region As mentioned earlier, the organisational objectives along with the various long-term considerations about marketing, technology, internal organisational strengths and weaknesses, region-specific resources and business environment, legal-governmental environ-

* R.W. Schmenner, 'Look Beyond the Obvious in Plant Location', *Harvard Business Review*, Vol. 57, No. 1, 1979, pp. 126–32.

ment, social environment and geographical environment suggest a suitable region for locating the operations facility.

CHOICE OF A SITE WITHIN A REGION

Once the suitable region is identified, the next step is that of choosing the best site from an available set. Choice of a site is less dependent on the organisation's long-term strategies. It is more a question of evaluating alternative sites for their tangible and intangible costs if the operations were located there. Cost economies now figure prominently at this final stage of facilities-location problem.

Even in the earlier stage of Region-identification, costs were important, but *not* explicitly, because they were the long-term costs. (Perhaps, transportation costs would have been one category of costs which might have been of explicit interest.)

The difference between 'factors for strategic consideration', and 'costs' (tangible and intangible) needs to be pointed out to the reader. While the former have mutual feedbacks, the latter may be considered to be more or less independent of each other. The 'costs' are therefore additive, perhaps with different weightages to different items of cost if necessary.

Therefore, the problem of location of a site, within the region already decided upon, can be approached with cost-oriented non-interactive models/procedures as given below.

Dimensional Analysis

If all the costs were tangible and quantifiable in rupee value, the comparison and selection of a site is very easy. The least cost site is selected. However, in most cases, there are many 'intangible costs'- which may be better expressed in relative terms than in absolute terms. For instance, educational facilities for children or the lack of it at a site is difficult to quantify in absolute terms. However, the relative merits/demerits of two alternative sites can be compared more easily. One site may be said to have a facility twice as good as the other site. Since both tangible and intangible costs need to be considered for the selection of a site, a procedure of comparing relative merits of alternative sites suggests itself.

Bridgeman's* Dimensional Analysis consists in computing these relative merits (or cost ratios) for each of the cost items, giving each of the ratios an appropriate weightage by means of the power (index) to which it is raised, and multiplying these weighted ratios in order to come up with a comprehensive figure on the relative merit of the two alternative sites. That is, if

C_1^M, C_2^M, C_3^M … C_z^M are the different costs associated with a site M on the 'z' different cost items.

C_1^N, C_2^N, C_3^N, … C_Z^N are the different costs associated with a site N, and

W_1, W_2, W_3 … W_Z are the weightages given to these cost items, then the relative merit of site M and site N is given by:

$$\left(\frac{C_1^M}{C_1^N}\right)^{W_1} \times \left(\frac{C_2^M}{C_2^N}\right)^{W_2} \times \left(\frac{C_3^M}{C_3^N}\right)^{W_3} \times \cdots \left(\frac{C_z^M}{C_z^N}\right)^{W_z}$$

If this is > 1, it means site N is superior; and vice versa.

For instance, if the following tangible and intangible costs were considered: (See Table 31.1.)

* P.W. Bridgeman, *Dimensional Analysis*, Yale University Press, New Haven, Conn., USA, 1963.

Table 31.1 Dimensional Analysis

Costs / Site	Labour	Power	Educational Facilities for Children (Score)*	Recreational Facilities (Score)*
M	Rs 1,50,000	Rs 40,00,000	2	2
N	Rs 1,00,000	Rs 25,00,000	6	4
Weightage	1	1	2	2

*Note: The 'scores' range from 1 to 10 for the best to the worst conditions.

Then, the relative cost of site *M* to site *N* is:

$$\left(\frac{1,50,000}{1,00,000}\right)^1 \times \left(\frac{40,00,000}{25,00,000}\right)^1 \times \left(\frac{2}{6}\right)^2 \times \left(\frac{2}{4}\right)^2 = 0.0666$$

Thus site *M* is much preferable to site *N*. Although the tangible costs for site *M* are higher than those for site *N*, the effect of the intangibles is seen to be overwhelming. In practice, such things do happen. There are many reasons other than the quantifiable costs which go into the choice between alternative sites. However, when such choice is important from the national or social point of view, then the choice of the intangibles and the weightages attached to them assumes a critical importance. For instance, in the case of NALCO Srinivasan et al. have questioned the locations: bauxite mine at Panchpatmali, alumina factory at Damanjodi, and the smelter and captive thermal unit at Talcher. "Is it cheaper to transport alumina by rail than to transmit power by transmission line? If the project was based on the 1480 MW of Hydel power being produced in Koraput district, then both the captive thermal set and the captive railway line would be rendered unnecessary with very significant savings in energy cost and in transportation cost."*

Brown and Gibson Model for Site Location**

This model is more elaborate and considers three classes of site location factors:

(i) Critical … e.g. water for a refinery
(ii) Objective … e.g. labour costs, raw material costs
(iii) Subjective … e.g. recreational facilities, union activities

For 'each site '*i*' a location measure, LM_i, is defined

$$LM_i = CFM_i \times [D \times OFM_i + (1 - D) \times SFM_i]$$

where CFM_i = critical factor measure for site *i* ($CFM_i = 0$ or 1)

OFM_i = objective factor measure for site *i* ($0 \le OFM_i \le 1$ and $\sum_i OFM_i = 1$)

* K. Srinivasan *et al.*, 'The Orissa Aluminium Complex-points towards a Debate', *Economic and Political Weekly*, Dec. 5, 1981, pp. 2005–14.

** P.A. Brown and D.F. Gibson, 'A Quantified Model for Facility Site Selection-Application to a Multiplant Location Problem', *AIIE Transactions*, Vol. 4, No. 1, March 1972, pp. 1–10.

SFM_i = subjective factor measure for site i
$(0 \le SFM_i \le 1$ and $\sum_i SFM_i = 1)$

D = Objective factor decision weight
$(0 \le D \le 1)$

Sites with higher location measures are preferred to sites with lower location measures.

A further elaboration of the various location factor measures is necessary:

$$CFM_i = \prod_j CFI_{ij}$$

where CFI_{ij} is the critical factor index for site i with respect to critical factor j (CFI_{ij} = 0 or 1).

In order to ensure compatibility between objective and subjective factor measures, objective factor costs are converted to dimensionless indices.

$$OFM_i = [OFC_i \times \sum (1/OFC_i)]^{-1}$$

where OFC_i is the *total* objective factor cost for site i.

The rationale behind the above equation is:

(a) site with minimum cost must have the maximum measure;

(b) the relationship of the total objective factors cost and the corresponding objective factor measure must be maintained; for instance, a site with half the objective factor cost is assigned twice the objective factor measure of the other site;

(c) the sum of objective factor measures for all sites must equal 1.

The subjective factor measure is given by:

$$SFM_i = \sum_k (SFW_k \times SW_{ik})$$

where SFW_k = weight of subjective factor k relative to all subjective factors (property weight)
SW_{ik} = weight of site i relative to all potential sites for subjective factor k (site weight)

These values of 'property weight' and 'site weight' are determined through Preference Theory. For example, for a particular business organisation the following may be the preferences:

Subjective Factor	*Comparison*						*Sum of Preferences*	*Property Weight*
	1	*2*	*3*	*4*	*5*	*6*		
Recreational facility	0	0	1				1	1/7 = 0.142
Transport availability	1			1	1		3	3/7 = 0.429
Union activities		1		1		1	3	3/7 = 0.429
Climate			0		0	0	0	0/7 = 0.000
Total							7	1.000

Similarly, for a subjective factor, say Recreational Facility, the comparison of different sites may be as follows:

Site	*Comparison*			*Sum of Preferences*	*Site Weight*
	1	*2*	*3*		
1	1	1		2	2/4 = 0.500
2	0		1	1	1/4 = 0.250
3		0	1	1	1/4 = 0.250
Total				4	1.000

Note that with 4 factors there are 6 comparisons, and that with 3 sites there are 3 comparisons to be made. The general formula for the number of comparisons needed is:

$$\frac{n!}{2(n-2)!}$$

where 'n' is the number of factors/sites.

D (in the location measure formula) is the relative importance of the objective factors to the subjective factors. The value of D depends upon the nature of business and the preferences of the management.

For a multiplant location, Brown and Gibson try to extend the above given analysis by doing Mathematical Programming with zero-one variables. The following terms are defined.

LM_{ij} = location measure for site i with facility of capacity j;

OFC_{ij} = objective factor cost for site i with facility of capacity j;

CAP_{ij} = capacity of facility at site i with capacity j;

Y_{ij} = decision variable for site i with capacity j (Y_{ij} = 0 or 1);

MRC = total minimum required capacity for all facilities constructed;

MAE = total maximum allowable expenditure for all facilities constructed;

i = 1, 2, 3, …, I; and

j = 1, 2, 3, … J.

Objective function is: Maximise $z = \sum_i \sum_j Y_{ij} \cdot LM_{ij}$

Subject to:

$$\sum_i \sum_j CAP_{ij} \cdot Y_{ij} \geq MRC$$

$$\sum_i \sum_j OFC_{ij} \cdot Y_{ij} \leq MAE$$

$$\sum_j Y_{ij} \leq 1 \text{ for each } i$$

There could be additional constraints for specific problems. For example, if a facility at site 'i' excludes a facility at site 'i'" and vice versa, then:

$$\sum_j Y_{i'j} + \sum_j Y_{ij} \leq 1$$

BACKWARD AREAS AND INDUSTRIAL POLICY

In the facilities location problem, whether multiplant or single plant, the industrial policies of the governments are very important inputs in the overall consideration. In India, the industrial development of backward areas for a balanced regional development of the country has always been emphasised. This has been attempted mainly through:

1. licensing policy;
2. location of public sector projects;
3. investment subsidy;
4. concessional finance;
5. concession on income-tax, import duty, etc.; and
6. setting up of industrial estates.

All the districts in the country have been classified into four categories:

A. No industry districts and 'special region' districts,
B. Moderately backward districts,
C. Least backward districts, and
D. Non-backward districts.

The *A*, *B* and *C* categories are eligible interalia for subsidy on investment in fixed assets in an industrial unit.

Taking cognizance of the importance of infrastructural facilities, Government of India provided for one-third of the total costs of the development of infrastructural facilities in the "no-industry" districts, the remaining two-thirds of the cost to be met by the concerned state government. Government of India also proposes to help the "no-industry" districts by establishing a 'nucleus' plant in each such district, which would lead to a number of ancillary units. The State Governments give various incentives to industries so that they may locate their plants in the backward areas.

Notwithstanding such helpful measures from the governments, the backward area development has not been very successful. More than half of the industrial licences issued during the gone to the backward areas in the developed states. Fourteen cities and towns accounted for 60 per cent of total employment in the industrial estates in the country. While Madras City accounted for 82 per cent of employment in industrial estates in Tamil Nadu, Bombay and Pune accounted for 65 per cent of employment in industrial estates in Maharashtra, and similarly the cities of Ahmedabad, Baroda and Surat accounted for 60 per cent in Gujarat. Regarding Investment Subsidy, only 15 per cent of the eligible districts accounted for 56 per cent of the subsidy amount. Moreover, most of these districts are situated close to large urban centres—such as Mysore and Dharmapuri near Bangalore, North Arcot near Madras and Medak near Hyderabad. In the case of the concessional finance provided by all-India financial institutions, only 22 of the 247 districts eligible for concessional finance received the total amount of concessional finance disbursed. It is worth noting that most of these districts were in the developed states.

Due to such performance of these governmental measures—which seem to have been counterproductive—the implementation of the backward area industrial policy hasmany a time come under severe criticism. For instance: 'The so-called emphasis on development of backward areas via incentives to entrepreneurs, has enabled the State to provide subsidies to industry that it was

not otherwise in a position to give. The policy for development of backward areas is no more than a red herring.'*

The above told is debatable. But, the point is that there are a number of factors which influence the plant location decision and all of these have not been considered in an integrated manner by the policy makers. The emphasis has been more an financial incentives. However, the amount of 'pull' generated by the large cities, already industrialised towns and other developed areas needs a deeper analysis by the decision-makers in order to come up with suitable measures to counter these factors exerting the pull in a direction opposite to that of the intended objective. The case of backward area development highlights the importance of the various issues—qualitative and quantitative, short-term and long-term, economic and behavioural—that influence the plant location decision. The line dividing 'political' issues and social-and-behavioural issues is not always clear. However, a consideration of the latter issues is essential for the policy makers as well as the entrepreneurs.

GLOBAL LOCATION

Globalisation has arrived. Trade and flows of capital are freer than earlier, despite a few hiccups once in a way. Multinational corporations are setting up their shops in India and Indian companies are extending their operations in other countries—there are India-based companies in USA, in Europe and in the eastern countries such as China.

Virtual Proximity

When should a firm think of setting up a manufacturing plant or service operations in a foreign country? With the advances in telecommunications technology, a firm can be in virtual proximity to its customers. For a software services firm much of its logistics is through the information/communication pathway, anyway. Many firms use the communications highway for conducting a large portion of their business transactions. This is not to deny the importance of logistics in business in the present day. Logistics is certainly an important factor in deciding on a location—whether in the home country or abroad. Markets have to be reached. Customers have to be contacted. Hence, a market presence in the country of the customers is quite necessary. However, 'logistics' in today's parlance may not be the conventional kind of logistics.

Virtual Factory

Many firms based in USA and UK—in the service sector and in the manufacturing sector—often outsource part of their business processes to foreign locations such as India. Thus, instead of one's own operations, a firm could use its business associates' operations facilities. In a way, the Indian BPO firm is that foreign-based company's 'virtual service factory'. So, a location could be (a) one's own and/or (b) one's business associate's. The location decision need not always necessarily pertain to own operations. Due to globalisation, these days the supply chains (for materials, information, and mental capacity) have spread to countries abroad.

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* Vinod Vyasulu and Amar Nath Pandey, 'Industrial Policy for Backward Areas', *Inter. Jour. Dev. Bank*, Vol. 4, No. 2, July 1986, pp. 21–31.

REASONS FOR A FOREIGN LOCATION

Reaching the Customer

One obvious reason for locating a facility abroad is that of capturing a share of the market expanding worldwide. The growth of the GDP of India and China at around a phenomenal 8 per cent is a big reason for the multinationals to have their manufacturing/operations facilities in these countries. Same is the reason for India-based companies to set up their operations in China. But what does 'capturing a good share of the market' got to do with location near that market? An important reason is that of providing service to the customer promptly and economically. Much of this may indeed be logistics-dependent. Therefore, 'cost and ease of logistics' is a reason for setting up manufacturing facilities abroad. By logistics we mean here the set of activities that closes the gap between production of goods/services and reaching of these intended goods/services to the customer to his satisfaction. Reaching the customer is thus the main objective. The tangible and intangible gains and costs depend upon the company defining for itself as to what that 'reaching' means. The tangible costs could be the logistics related costs; the intangible costs may be the risks of operating is a foreign country. The tangible gains are the immediate gains; the intangible gains are again, an outcome of what the company defines the concepts of 'reaching' and 'customer' for itself.

Other Tangible Reasons

The other tangible reasons could be as follows.

1. The host country may have/offer substantial tax advantages compared to the home country.
2. The costs of manufacturing and/or running operations may be substantially less in that foreign country. This may be due to
   —lower labour costs
   —lower raw material (inputs, in general) cost
   —better availability of the inputs (component materials, energy, water, ores, metals, key personnel)
3. The company may overcome the tariff barriers by setting up a manufacturing plant in a foreign country rather than exporting the items to that country.

Intangible Reasons

The intangible reasons for considering setting up an operations facility abroad could be as follows.

Customer-related Reasons

1. With an operations facility in the foreign country, the firm's customers may feel secure that the firm is more accessible. Accessibility is an important 'service quality' determinant.
2. The firm may be able to give a personal touch.
3. The firm may interact more intimately with its customers and may thus understand their requirements better.
4. It may also discover other potential customers in the foreign location.

Organisational Learning Related Reasons

1. The firm can learn advanced technology, if it is available in that country. For instance, it is possible that cutting-edge technologies can be learnt by having factory/operations in an industrially/technologically more advanced country. The firm can learn from advanced research laboratories/universities in that country. Such learning may help the entire product line of the company.
2. The firm can learn from its customers abroad. A physical location there may be essential towards this goal.
3. It can also learn from its competitors operating in that country. For this reason, it may have to be physically present where the action is.
4. The firm may also learn from its suppliers abroad. If the firm has a manufacturing plant there, it will have intensive interaction with the suppliers in that country from whom there may be much to learn in terms of modern and/or appropriate technology, modern management methods, and new trends in business worldwide.

Other Strategic Reasons

1. A capacity already built could be an effective deterrent for the entry of competitors in that market.
2. The firm, by being physically present in the host country, may gain some 'local boy' kind of psychological advantage. The firm is no more a 'foreign' company just sending its products across international borders. This may help the firm in 'lobbying' with the government of that country and with the business associations in that country.
3. The firm may avoid 'political risk' by having operations in multiple countries.
4. By being in the foreign country, the firm can build alternative sources of supply. The firm could, thus, reduce its supply risks.
5. The firm could hunt for human capital in different countries by having production/operations in those countries. Thus, the firm can gather the best of people from across the globe.
6. Foreign locations in addition to the domestic locations would lower the market risks for the firm. If one market goes slow, the other may be doing well—thus lowering the overall risk.
7. Wider exposure to different cultures, different customer tastes, different technology and different systems of management may make the firm better able to cope with change.
8. The firm can build its 'brand' internationally. This would help further expand its business overseas.

For many companies, the intangible benefits are far more important than the tangible ones. Lego, the Danish toy company did not move its manufacturing operations from Denmark, USA, Germany and Switzerland to low-cost countries like Taiwan, Thailand and China.* This company believed that the developed country locations would offer it many technological advantages—excellent research centers, sophisticated suppliers, highly skilled technicians—and would allow its factories to develop unique capabilities in plastics and in injection moulding. Possessing 'unique capabilities' in plastics seems to have been the company's strategy.

* Kasra Ferdows, 'Making the Most of Foreign Factories', *Harvard Business Review*, March–April 1997, pp. 73–88.

Globlisation, because of its accompanying intensified competition, has enhanced the role of strategy in the location decisions. Decision to locate a factory or operations facility abroad is a strategic decision for the company.

LOCATION OF FACILITIES FOR SERVICE BUSINESSES

Services can have (a) virtual and/or (b) fixed location. The issue of location of facilities comes up when the service facility has to have a fixed location. For instance, a hotel has to have a fixed location. Once it is set at that location, it cannot be relocated easily. There are services like the Internet services, E-business and telecommunication that can have virtual location. In fact, today many 'fixed location services' are getting virtualised. For example, the banking service is increasingly performed on the telephone (phone-banking) or Internet. With the spread of credit cards and debit card, money transactions are getting done in the virtual space.

Location of service facilities (for fixed location services as explained above) can have various strategic considerations. These are as follows.

1. Creating Entry Barriers

The presence of a service provider in a region could be an effective deterrent against the entry of new players or competitors into that region. In a manufacturing context, this purpose of creating entry barrier may be less served by locating a plant in a region, because geographical proximity to the customers may not be a vitally important necessity. Manufactured goods can always be transported to its customers, although at a cost, and the overall cost economics may not necessarily suggest that the plant be located near the customers of a region. However, for services that act on people's bodies, belongings and some services that act on minds proximity to the customers in very important necessity. If one services provider establishes a facility, it acts as a damper on other competing service providers in the same business.

Creating an Image that is Hard to Beat

By locating service facilities at multiple locations, a firm can establish a barrier to competitors. This barrier could be as much real as psychological. Multiple locations create a large and more lasting impression on the buyers of the service regarding the firm providing the service. It builds up an image that is difficult for probable competitors to counter and/or replace.

Grabbing Prime Locations

Also, a firm starts out first can acquire prime locations before the competition can hold any, thus shutting out opportunities for the competitors.

2. Generating Demand

There may be a potential demand for a particular service in a particular place or region. By placing a service facility in close proximity, this potential demand is converted into real demand. There could also be many new converts drawn to the particular service—consumers who can physically visit the facility, experience it, and decide to repeat the experience. A new facility allows consumers to try out new alternatives. Until the multiplexes came into existence, people in the metros of India were sceptical about their functioning and utility. Once they experienced a multiplex and all the services it could provide, they have started using the services frequently.

3. Demand Management

One of the problems that a service facility faces is that the customer demand may not be steady over the year (or week or day). There may be excessive demand during some periods, which the facility cannot handle, and in some other periods there may be a lack of demand leading to under-utilisation of the resources invested. Moreover, fluctuating demand gives rise to other problems regarding scheduling, employee management, managing suppliers and other business associates, and management of funds, materials and other resources among other issues leading to inefficiencies, wastes and reduced profitability.

Therefore, the service facility may be located at such a place where there is diverse set of market generators that would supply a steady demand regardless of the season, day of the week or any demographic and economic factors.

4. Saturating the Demand

By establishing service facilities at multiple locations, the firm can inundate and saturate the demand before anyone else can capture a share of it. That is the strategy used by many a convenience store i.e. place a facility at several locations convenient to the customers so that the entire region is covered, thus inhibiting the entry of new players.

5. Developing Focus

Some service firms believe in developing a 'focus' by having facilities at multiple sites delivering a standard narrowly defined service. The strategy is to (a) have the customer identify the firm with a specific specialised service; (b) make the firm specialised in delivering the narrow service so that it develops much expertise and efficiency in so doing ; (c) make further expansion easy and (d) shut out any competition in the market for that narrowly defined service by means of brand image development, higher quality and lower costs in addition to saturating the market .

6. Hedging Risk

Some firms locate the facilities at such variety of places that the economic or market risks are minimised. Which means if one facility is running at a loss due to lower demand at that place/region, another facility at a different location may be running at a good profit due to favourable demand position at that place/region.

LOCATION OF SOCIAL OR NON-PROFIT SERVICES

The issue of location of government-run and government-aided basic service facilities such as primary health-care centres and primary and secondary schools, differs from the issue of industrial plant location because the objectives in these two cases are different. While profit or revenue is one of the important considerations in the case of 'industries' location, the goal of purely service centres is to provide as equitable and to the extent possible service to a large section of people. In the case of emergency services such as ambulance, police and fire, a major objective is to deliver the service as quickly as possible.

Health Service Location

Abernathy and Hershey model for the planning of primary health centres (PHCs) is worth noting. The model recognizes that for some categories or strata of people, distance (of the PHC from their locality) is a stronger barrier to the utilisation of the health service than for other categories of people who are more mobile. Accordingly, the model defines the following:

L = no. of localities or blocks ($i = 1, 2, \ldots L$):
M = no. of categories or strata of people ($j = 1, 2, \ldots M$);
n_{ij} = no. of people of stratum 'j' in block 'i';
N = total population in the region

$$= \sum_{i=1}^{i=L} \sum_{j=1}^{j=M} n_{ij}$$

G = no. of PHCs ($k = 1, 2, \ldots G$);

Z_{i_1}, Z_{i_2} = coordinates of the centre of the block 'i';
X_k, Y_k = coordinates of the PHC 'k';
b_{ik} = actual distance between block 'i' and PHC 'k'

$$= |Z_{i_1} - X_k| + |Z_{i_2} - Y_k|$$

The model supposes that data is also available on:

v_j = expected no. of visits per time period by stratum 'j' people if a PHC is in the immediate vicinity of the individual,

and d_j = chararacteristic effect of distance on utilisation for the different strata of people ($j = 1, 2, \ldots M$).

The overall utilisation for the 'n_{ij}' individuals is defined as:

$$u_{ij} = n_{ij} \cdot v_j/(1 + d_j\, b_{ik})$$

(Note: Utilisation approaches $n_{ij} \cdot v_j$ as b_{ik} approaches zero).

When more than one PHCs exist (say G of them) then:

$$u_{ijk} = P_{ik} \cdot n_{ij} \cdot v_j/(1 + d_j \cdot b_i)$$

where $b_i = \min. b_{ik}$ $(k = 1, 2, \ldots G)$ and

P_{ik} = probability of the choice of PHC 'k' by people from block 'i'

$$= \left[\frac{1}{\sum_{k=1}^{k=G} b_i/b_{ik}} \right] \cdot (b_i/b_{ik})$$

The total utilisation (U) of primary health care service in a region is calculated:

$$U = \sum_{i=1}^{L} \sum_{j=1}^{M} \sum_{k=1}^{G} u_{ijk}$$

Statement of the facilities location problem: To determine the (X_k, Y_k) coordinates of 'G' PHCs ($k =$

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1, 2, … G) so as to maximise or minimise a specified criterion. The choice of the criterion depends upon the objective of the planners for the region. Several objectives are possible, for example:

1. Maximise utilisation, i.e. maximise the total utilisation of primary health care service in the region; in short, *max U*.
2. Minimise average distance per capita to the closest PHC, i.e.

$$\min \left[\frac{\sum_{i=1}^{L} n_i b_i}{N} \right]$$

3. Minimise distance per visit, i.e.

$$\min \sum_{i=1}^{L} \sum_{j=1}^{M} (u_{ij} \cdot b_i / U)$$

4. Minimise per cent degradation in utilisation, i.e.

$$\min \left(\frac{1}{N} \right) \sum_{i=1}^{L} \sum_{j=1}^{M} [n_{ij}(v_j - u_{ij})/v_j]$$

Criterion 1 would tend to place the PHCs closer to areas that have large numbers of people for whom distance is a stronger barrier to utilisation. Criterion 2 would place the PHCs in or near areas of large population density and tend to neglect the preferences of different strata of people. Criterion 3 will favour the strata of people for whom distance is not a major barrier.

The method used to assign facilities to location is through Hooke-Jeeves Search algorithm.

The number of PHCs can be varied and the performance on various criteria can be studied. Cost implications and marginal benefits can be compared for different alternatives on different criteria. Thus, a planner can have a scenario of alternatives to choose from.

School Location

School education planning has become very important in India due to (i) rapid increase in the total population (ii) continued lack of educational facilities for children in the rural areas. Indian Government is taking many steps to provide basic education to the rural children. For instance, during 1951-1980, 267366 primary schools, 73725 higher primary schools and 37291 high schools were opened. While the Central Government formulates and coordinates the national policy on education, the decisions about the locating of the schooling facilities are taken by the state governments and union territories. Location models can be very useful in the systematic planning of school facilities in order, 'to achieve a large measure of equalisation of educational opportunities, both in regard to access and achievement'.*

In order to verify the extent of usefulness of location models in school planning and examine the existing decision-making process, Tewari and Jena studied the district of Bellary in Karnataka.**

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* Government of India, *Sixth Five-Year Plan: 1980–85*, Planning Commission, Government of India, New Delhi, 1980.

** V.K. Tewari and S. Jena, 'High School Location Decision-making in Rural India and Location-Allocation Model', Draft Manuscript (July 1985) for Chapter 10 in Avijit Ghosh and Gerard Rushton (Editors), *Spatial Analysis and Location-Allocation Models*, forthcoming, Van Nostrand Reinhold, New York.

Location-allocation heuristics (Tietz and Bart 1968*) were used to find optimal locations with respect to the following criteria:

(i) To minimise the average travelled distance of the population to the nearest school facility; and
(ii) To maximise the population covered within a maximum service distance of 8 kilometres.

Twelve proposed school locations were examined to measure their efficiency vis-a-vis 12 'optimal' locations. The study observed that the proposed locations were 52% and 62% inefficient on the criteria of minimising average distance and that of maximising coverage, respectively. The average size of the villages proposed for new schools was found to be larger than the average size of the villages in an equal number of optimal locations found by using the location models. Also significantly, while for 4 sanctioned locations the minimum distance from nearest existing school was 5.5 kilometres, the same for the optimal locations was 10 kilometers or more. Thus, while the sanctioned locations violated the location criterion that no school should be opened within 8 kilometres of an existing school, the locational models gave solutions that did not violate this criterion.

Such application of the models has helped in the deeper probing of the existing decision-making process for any lacunae. For instance, some of the lacunae found are:

(i) The government administration invites proposals (for establishing a school) asking for various details; this calls for much local initiative and contributions. Therefore, the very purpose of the regional planning exercise becomes futile.
(ii) The facts gathered, about the locations proposed, are not always accurate.
(iii) Decisions on location are not based on any explicit objective function even though a large amount of data are collected.

Thus this case study, although restricted to one district only, demonstrates the utility of the location models in this vital sector, i.e. the education sector. It also points out some of the self-defeating aspects of the governmental process.

BEHAVIOURAL ASPECTS IN LOCATION PLANNING OF SERVICES

It may, however, be noted that there is an implicit assumption in using these models i.e., by changing the spatial organisation as suggested by the models, the behaviour of the people will be changed in ways that are desired and the people will accordingly respond. However, the reactions of people to spatial changes are in many cases, not controlled. This fact suggests that, while the available modelling procedures are very useful, a new line of research is needed in the facility location theory incorporating the behavioural aspects.**

Municipal Corporations and slum development boards have realised as to how difficult it is to relocate people to what is perceived by the government as an improvement in the living conditions of the slum-dwellers. Same is true of school locations and health centres.

Organizations in the private sector too have succeeded or failed because of the behavioural response from the customers and the employees to the location/relocation decision. The assumption that the setting up of a service facility will manifest the potential demand may not come true to theto the extent anticipated. The strategey of locating service facilities at multiple locations creating an unassailable image about the company in the minds of the customers may not succeed, instead resulting in multiple loss-making service facilities. Many of the service location strategies

* M.B. Tietz and P. Bart, 'Heuristic Methods for Estimating the Generalized Vertex Median of a Weighted Graph,' *Operations Research*, Vol. 16, pp. 955–61.

** Rushton Gerard, 'Use of Location-Allocation Models for Improving the Geographical Accessibility of Rural Services in Developing Countries,' *International Regional Science Review*, Vol. 9, No. 3, 1984, pp. 217–40.

rely heavily upon the psychology of the current and potential customers and competitiors. This behavioural aspect needs to be appreciated while planning locations.

SOLVED PROBLEMS

1. Mandar Morgaonkar is a final semester student of PGDBA in Siddhivinayak Management Institute in Prabhadevi, Mumbai. As a part of the curriculum, Mandar is doing a project for Kapadia Mills and helping them to make a decision on the location for their first showroom in Mumbai. After strategic considerations, Mandar is left with three locations to choose from. These are Fort, Vashi and Worli. Each location has its relative merits in terms of three key characteristics, viz. Accessibility to its desirable customer segment, Local attitudes towards business and Future expansion possibilities. Mandar considers the importance of the key characteristics to be A+, B- and B+ on a letter-grade scale similar to that in his PGDBA programme. He also assigns a letter-grade to each of the three locations for the three key characteristics and arrives at the following matrix.

	Fort	*Vashi*	*Worli*
Accessibility	A+	C+	A
Local attitudes	A	C	A+
Future expansion	D	A	B–

If A+, A, A–, B+, B, B–, C+, C, C– and D can be given numerical values from 10 to 1 respectively, which location would Mandar recommend?

Answer

$$M_i = \sum_{k} (FW_k \times W_{ik})$$

where FW_k = weight of subjective factor 'k' (property weight), e.g. 10 for accessibility; W_{ik} = weight of site 'i' for subjective factor 'k' (site weight), e.g. 4 for Vashi for accessibility; and M_i = Final measure for a site 'i'.

M_i, the final measure for Fort = (10×10) points for accessibility + (5×9) points for local attitudes + (7×1) points for future expansion = 100 + 45 + 7 = 152 total points. Similar computations are made for other potential sites. We obtain the following matrix.

	Fort	*Vashi*	*Worli*
Accessibility	$(10 \times 10) = 100$	$(10 \times 4) = 40$	$(10 \times 9) = 90$
Local attitudes	$(5 \times 9) = 45$	$(5 \times 3) = 15$	$(5 \times 10) = 50$
Future expansion	$(7 \times 1) = 7$	$(7 \times 9) = 63$	$(7 \times 5) = 35$
Total points	152	118	175

Worli scores highest number of points and it should be Mandar's recommended location for the showroom.

2. Bhavana Biologicals Limited is deciding on a location for the production of an enzyme. After a study of critical strategic issues, the choice has narrowed down to five possible places, viz. Ahmedabad, Bhubaneshwar, Nainital, Pune and Ranchi. For its planned operating capacity, Bhavana estimates the costs at the different locations. The estimates (in Rs. Lakh) on various categories are furnished below.

Costs	*Ahmedabad*	*Bhubaneshwar*	*Nainital*	*Pune*	*Ranchi*
Transport	5	7.5	6.7	8.25	8.5
Power	6.25	3.25	5.25	6	3.75
Land	7.5	5.25	6	3	4.5
Construction	19.5	16.5	18	10.5	15
Equipment	12.5	14	10	15	22.5
Taxes	10	8	12	9	20
Wages	4.5	5	7	4.5	4

As given below, these possible locations are also evaluated for important qualitative factors of Industrial Relations Climate, Skills Availability, Quality of Life available and Geographical Climate. All the four factors are considered equally important.

Location	*IR Climate*	*Skills Availability*	*Quality of Life*	*Geo. Climate*
Ahmedabad	Excellent	Fair	Good	Fair
Bhubaneshwar	Good	Good	Fair	Fair
Nainital	Fair	Excellent	Good	Excellent
Pune	Fair	Fair	Excellent	Excellent
Ranchi	Excellent	Good	Excellent	Excellent

Use Brown and Gibson's method and decide on the location. Take the objective factor and subjective factor decision weights as 0.7 and 0.3, respectively.

Answer

Step 1: Objective Factor Measure

Calculate the Objective Factor Measure, OFM_i, for each of the locations as shown in the table below.

Costs	*Ahmedabad*	*Bhubaneshwar*	*Nainital*	*Pune*	*Ranchi*
Transport	5	7.5	6.7	8.25	8.5
Power	6.25	3.25	5.25	6	3.75
Land	7.5	5.25	6	3	4.5
Construction	19.5	16.5	18	10.5	15
Equipment	12.5	14	10	15	22.5
Taxes	10	8	12	9	20
Wages	4.5	5	7	4.5	4

OFC_i	65.25	59.50	65	56.25	78.25
$1/ OFC_i$	0.01533	0.01681	0.01538	0.01778	0.01278
				Thus, $\Sigma 1/ OFC_i = 0.07808$	
$(OFC_i \times \Sigma 1/ OFC_i)$	5.09472	4.64576	5.0752	4.3920	6.10976
$OFM_i =$					
$(OFC_i \times \Sigma 1/ OFC_i)^{-1}$	0.1963	0.2153	0.1970	0.2277	0.1637

Step 2: Subjective Factor Measure

Also calculate the Subjective Factor Measure, SFM_i, for each of the locations. Towards this, the weight of a site (i.e. location) relative to all other sites for a subjective factor 'k', SW_{ik}, needs to be calculated. The calculations done after paired comparisons are shown below for each of the subjective factors.

Industrial Relations: (Paired comparisons for different locations)

Location															SW_{iIR}
A	1	1	1	1										4	4/12
B	0				1	1	0							2	2/12
N		0			0			1	0					1	1/12
P			0			0		1		0				1	1/12
R				1			1		1	1				4	1/12
										Total :				12	1.00

Skills Availability: (Paired comparisons for different locations)

Location															SW_{iSA}
A	0	0	1	0										1	1/12
B	1				0	1	1							3	3/12
N		1			1			1	1					4	4/12
P			1			0		0		0				1	1/12
R				1			1		0	1				3	3/12
										Total:				12	1.00

(Note: Locations A: Ahmedabad, B: Bhubaneshwar, N: Nainital, P: Pune and R: Ranchi.)

SW_{iIR}, SW_{iSA}, SW_{iQL} and SW_{iGC} refer to weight of a site '*i*' relative to all other sites for the subjective factors of Industrial Relations (*IR*), Skills Availability (*SA*), Quality of Life (*QL*) and Geographical Climate (*GC*), respectively.

Quality of life: (Paired comparisons for different locations)

Location															SW_{iQL}
A	1	1	0	0										2	2/12
B	0				0	0	0							0	0/12
N		1			1			0	0					2	2/12
P			1			1		1		1				4	4/12
R				1			1		1	1				4	4/12
										Total:				12	1.00

Geographic climate: (Paired comparisons for different locations)

Location														SW_{iGC}
A	1	0	0	0									1	1/14
B	1				0	0	0						1	1/14
N		1			1			1	1				4	4/14
P			1			1		1		1			4	4/14
R				1			1		1	1			4	4/14
											Total:		14	1.00

It is given that all the four subjective factors are equally important and hence have equal weight of 0.25. That can be expressed as: $SFW_k = 0.25$ for all '*k*'.
Now, the subjective factor measure for location 'i' is given by:

$$SFM_i = \sum_{k}(SFW_k \times SW_{ik})$$

So, SFM for Ahmedabad is:
$(0.25 \times 4/12) + (0.25 \times 1/12) + (0.25 \times 2/12) + (0.25 \times 1/14) = 0.1637$
SFM for Bhubaneshwar is:
$(0.25 \times 2/12) + (0.25 \times 3/12) + (0.25 \times 0/12) + (0.25 \times 1/14) = 0.1220$
SFM for Nainital is:
$(0.25 \times 1/12) + (0.25 \times 4/12) + (0.25 \times 2/12) + (0.25 \times 4/14) = 0.2173$
SFM for Pune is:
$(0.25 \times 1/12) + (0.25 \times 1/12) + (0.25 \times 4/12) + (0.25 \times 4/14) = 0.1964$
SFM for Ranchi is:
$(0.25 \times 4/12) + (0.25 \times 3/12) + (0.25 \times 4/12) + (0.25 \times 4/14) = 0.3006$
The final "Location Measures" for each of the five locations are computed from the individual OFM_i and SFM_i. Give the decision weights of 0.7 for OFM_i and 0.3 for SFM_i, respectively. These calculations are as follows :

$$LM_{Ahmedabad} = 0.7 \times (0.1963) + 0.3 \times (0.1637) = 0.1865$$

$$LM_{Bhubaneshwar} = 0.7 \times (0.2153) + 0.3 \times (0.1220) = 0.1873$$

$$LM_{Nainital} = 0.7 \times (0.1970) + 0.3 \times (0.2173) = 0.2031$$

$$LM_{Pune} = 0.7 \times (0.2277) + 0.3 \times (0.1964) = 0.2183$$

$$LM_{Ranchi} = 0.7 \times (0.1637) + 0.3 \times (0.3006) = 0.2048$$

The highest location measure is for Pune and therefore, Pune is the preferred location for the production facility.

3. Government of West Bengal has funds for setting up an industry producing fertilisers. Two locations are being strongly considered: (a) Kharagpur and (b) Purulia. The major differences between the two locations are (1) in the costs of transportation essential for shipping the goods to the rural and semi-urban market estimated at Rs. 36 crore and 18 crore, respectively for the two locations, and (2) cost of labour per unit of production estimated at Rs. 550 and Rs. 440, respectively. The state government is also keen that due to the setting up of the industry, the intangible economic cost to the local tribal population

and farmers be as low as possible. On this count, the intangible costs at Kharagpur and Purulia compare at a ratio of 5:4. Another important subjective factor is that of ecological cost and here Kharagpur and Purulia compare at 2:3 ratio. If the weights for the latter two factors are 1.5 and 2, using Dimensional Analysis which location between the two is to be preferred?

Answer

The following table presents the facts of the case.

	Costs			
Location	*Transport*	*Labour*	*Economic*	*Ecological*
Kharagpur	36	550	5	2
Purulia	18	440	4	3

Weights for Economic and Ecological factors are 1.5 and 2 respectively.
Using "dimensional analysis", the relative cost of locations at Kharagpur and Purulia is:

$$(36/18) \times (550/440) \times (5/4)^{1.5} \times (2/3)^2$$

$$= 2 \times 1.1 \times 1.3975 \times 0.4444 = 1.3664$$

Therefore, the fertiliser facility may be located at Purulia.

4. Government of Tamil Nadu is planning for a PHC (public health centre) for the villages of Andipatti, Bhamavur, Chendilpatti, Dandapakkam, Elsapet and Fatimpet. The PHC is to be located in one of these villages. The state government feels that the location of the PHC should be so decided that, for the group of villages, the per capita average distance to the PHC should be as small as possible. The distances between the villages by the approachable roads and also the populations are as given in the table below. A, B, C, D, E and F stand for Andipatti, Bhamavur, Chendilpatti, Dandapakkam, Elsapet and Fatimpet, respectively.

	Population	*Distance, Km.*					
Village		*A*	*B*	*C*	*D*	*E*	*F*
A	1500	0	7	6	3	5	3
B	500		0	3	6	2	6
C	3000			0	2	5	2
D	1500				0	4	2
E	2000					0	3
F	2500						0

At which village should the PHC be located? What is your comment on the criterion for choosing the location?

Answer

Let us express the population in thousands ('000). For instance, the population of A would then be expressed as 1.5 and that of B as 0.5, etc.
The criterion for the location of the PHC is:

Minimise the per capita average distance = $\sum_i (d_i \times p_i) / \sum_i p_i$

Since the denominator (sum of the populations of all the six villages) is a known constant, the criterion is to minimise $\Sigma(d_i \times p_i)$ which is the total man-km distance to the PHC. Hence, the given table of inter-village distances may be converted into inter-village man-km.

For example: The man-km between *A* and *B* for *A* is: $(7 \times 1.5) = 10.5$

Similarly, the man-km between *B* and *A* for *B* is: $(7 \times 0.5) = 3.5$

Village	*Population*	*Man-Km if PHC is at*					
		A	*B*	*C*	*D*	*E*	*F*
A	1.5	0	10.5	9	4.5	7.5	4.5
B	0.5	3.5	0	1.5	3	1	3
C	3	18	9	0	6	15	6
D	1.5	4.5	9	3	0	6	3
E	2.0	10	4	10	8	0	6
F	2.5	7.5	15	5	5	7.5	0
	Total:	43.5	47.5	28.5	26.5	29.5	22.5

From the above table it is seen that if PHC is placed at Fatimpet, the man-km will be the least. Hence, Fatimpet is the desired location for the PHC.

Fatimpet is farthest from Bhamavur (6 km). That is, in fact, the longest distance between any two villages. So, the population of Bhamavur will have to travel the long distance to get treated at the PHC. The reason is that Bhamavur has the smallest population and, therefore, has an inherent disadvantage in the man-km criterion. Such a criterion works against small hamlets.

QUESTIONS FOR DISCUSSION

1. Discuss the importance of facilities location decision in operations planning.
2. Why are some industries located near the source of raw materials, whereas some near the markets for their finished goods?
3. In locating additional nuclear power plant in India, what factors would you take into consideration? Explain.
4. In order to attract more industries to the industrially backward areas in India, what additional measures would you suggest other than the measures already being taken by the Central and State Governments?
5. What are the plus and minus points of India in attracting foreign investment? If Government of India were to desire for more foreign investment, what steps need to be taken?
6. How do the location problems for a manufacturing industry, a government hospital, a fire station, a new railway station and a higher primary schools differ from one another?
7. Compare the following two methods of site location:
   (i) Dimensional analysis
   (ii) Brown and Gibson method

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8. What are the limitations of the above two methods? Can these be used for locating Emergency-Service units?
9. How are social values important in location decisions? Explain for (a) manufacturing industry and (b) service facilities location.
10. What is the behavioural dimension in planning location for a manufacturing industry? A supermarket? A low-cost housing complex?
11. How does the 'technology component' influence the location decision?
12. Would Linear Programming be of any help in a site selection problem? Explain.
13. Collect data about and present a critique of the 'Navi Mumbai' (twin cities) project.
14. Jai Hind Industries is planning to set up a new plant. Following, is a table showing alternative locations and respective costs (in Rs.):

Cost \ Location →	1	2	3	4	5
Transport, per unit	1.00	1.50	1.35	1.65	1.70
Power, per unit	1.25	0.65	1.05	1.20	0.75
Land*	50 lakh	35 lakh	40 lakh	20 lakh	30 lakh
Buildings Construction*	130 lakh	110 lakh	120 lakh	90 lakh	100 lakh
Equipment (depreciation expense), per unit	2.50	2.80	2.00	3.00	4.50
Location taxes, etc.	10 lakh	8 lakh	12 lakh	9 lakh	20 lakh
Wages (average), per unit	0.90	1.00	1.40	0.90	0.80

* To be costed at 15% per annum.

If the volume of production is to be 5,00,000 units, what is the preferred location? If the volume is expanded to 7,00,000 units, would the decision change?

If the locations are rated for some factors as given below, would the earlier decisions change?

Location \ Factor →	Industrial relations Climate	Skills Availability	Quality of Life	Geographical Climate
1	Excellent	OK	Good	OK
2	Good	Good	OK	OK
3	OK	Excellent	Good	Excellent
4	OK	OK	Excellent	Excellent
5	Excellent	Good	Excellent	Excellent

How did you go about quantifying these factors? Can you use Brown and Gibson method for this location decision? Explain.

15. Agri-Products Company has two factories, one at Tiruchi and one at Meerut. There are four major warehouses to which the finished products are sent: at Guwahati, Nagpur, Ahmedabad and Chandigarh. The Company is thinking of locating an additional factory either at Indore or at Kanpur. If the following matrix gives the details of the shipping costs,

manufacturing capacities and warehouse requirements, how would you go about choosing between the two proposed locations, i.e. Indore and Kanpur. Suggest an approach.
Shipping costs Rs. per unit

Place	Guwahati	Nagpur	Ahmedabad	Chandigarh	Factory Capacity
Tiruchi	25	9	10	20	200
Meerut	10	8	6	5	400
Indore	15	2	3	10	200
Kanpur	10	5	7	5	200
Units required	100	150	300	250	

16. What infrastructure is important in deciding upon the location of an IT industry? What infrastructure is important in deciding upon the location of a Bio-tech (BT) industry? Discuss. As a CEO (Mayor) of a city that desires to attract IT and BT industry, what would be your vision? Describe.
17. Discuss the merits and demerits of Business Process Outsourcing (BPO) for the country that outsourced.
18. What may be the merits and demerits in Indian industries setting up operations facilities in USA? What may be the merits and demerits in setting up operations in P.R. of China? Do these merits and demerits differ for industries in different sectors such as engineering, pharmaceuticals and IT? If these differ, how do they differ?
19. If Silicon Valley of USA were to attract Indian capital and you were the Marketing Representative based in India for the Silicon Valley, what action plan would you suggest to Silicon Valley? Why? Discuss.

ASSIGNMENT QUESTION

1. Study a multinational corporation. Present your observations on its global locations and the merits and demerits of such arrangements. Present your suggestions with supporting arguments.

SECTION VI

Timing Decisions

Chapter 32 Production Planning and Control
Chapter 33 Aggregate Planning
Chapter 34 Scheduling
Chapter 35 Project Management—I
Chapter 36 Project Management—II
Chapter 37 Just-In-Time Production
Chapter 38 Lean Operations

An industry is a systematic economic activity. It produces physical products or services. Jobs have to be planned. Time schedules for these jobs, or for tasks within an assignment, are necessary. Without the schedules there would be chaos. This is easy to understand. The role of operations planning and scheduling is, therefore, clear. Since the time 'craft' became an 'industry' businessmen have understood the role of planning/scheduling production/operations. In fact, one may argue that those nations/peoples that consciously cared for time industrialised faster. Those nations that believed in a lax or relaxed concept of time, may have had crafts but these industrialised rather slowly. Thus, 'time' has been associated with industry.

However, the focus on time in the early half of the twentieth century—the century of worldwide industrialisation—had been about bringing order into the otherwise chaos. It was regarding making one's own life a little easier. There was this demand

function for the products that needed to be addressed to. In a job-shop environment, the already given promises had to be met. This involved some planning and a lot of short-term decisions or firefighting. Production had to be planned and then the deviations (which were normal) had to be controlled. Time was something that a market demanded or an individual customer asked for. Time was a constraint.

For a long time it was all simple and straight-jacketed. Production/operations had to have a long-range plan—a plan of activities for say 5 to 10 years. This plan had to be brought down to the manageable yearly, and then quarterly or monthly plans. This would help in broad allocation of facilities. This was the intermediate range plan or aggregate plan. Then, based on these plans, the weekly/daily work schedules had to be made—as to which particular machine and which person will work on which particular job. This planning was and is good. It is necessary to plan future work so that the demand and available capacity can be matched. Work has to be organised in terms of the long-term future (mostly forecasted) requirements on the production or operations facility, the intermediate term real loads on it and the actual production in the short-term. This line of thinking is valid even today. However, one needs to realise that this is only one dimension of time. It is a view that treats time as a *constraint* posed by the market. It is a quantitative view.

Somewhere around three decades ago, management thinkers started realising that the role of production could be much more than just producing a product. If the product was produced and delivered at the time when the customer needed it, it gave much satisfaction to the customer. Timeliness was realised as a much desired quality. This timeliness had to be from the customer's viewpoint. It was not enough if a firm delivered on promised time. As the promised time could be a compromise between 'when the customer really wants the item' and the capability of the firm's production system as to 'when it could make the item', if a firm could deliver actually at the time the customer needs it, it would amount to a delightful experience for the customer. Toyota Motor Company realised that promising the customer that her car will be available three months later and then delivering the car to her exactly after three months is one aspect of punctuality. However, if a customer could pick up a car any day she walks in to their showroom, it would amount to a whole new experience for the customer. Toyota Production System came into existence to provide this kind of service to customer. It was a service provided Just-in-Time. Therefore, time became a vital element of service quality.

What are the resources that a firm uses? Historically, men, machines and materials have formed the trinity of resources. (Of course, Money was an important resource, but it was made up of these three 'M's.) It is natural that companies should think as to 'how many' people to hire, 'how many' machines to have and 'how much' material needs to be procured. But, hidden behind all these questions was a vital question of 'when'. It was, for instance, realised that whatever quantity of materials one procures, if that quantity is used up in a short duration of time the costs of inventory-carrying are very low. Several significant costs were related to time in an inverse manner. If time was used efficiently and effectively, then the other resources got utilised proportionately more efficiently and effectively. Time was realised to be a mother resource.

It is, indeed, interesting that when it came to project management, time has always been perceived as an all-important criterion of success. Deadlines definitely had to be met. The three resources had to be made available accordingly, failing which projects got delayed. Project management has always been time-driven. PERT/CPM have been significantly in use in the industrialised

world since their genesis in the 1940s. Even in India—which had a largely government controlled industry—use of management techniques in projects started spreading in a major way during the 1980s. But the urgency exhibited in project management did not get transmitted to the usual production. The latter was considered as a daily activity. A project's availability (time of completion) was driven by the customer. In contrast, production was decided by the firm itself—customer was in the picture far away in the shadows.

Only when the global competition heated up with the far-eastern firms providing ready availability of products whenever the customer needed, did the firms all over the world wake up to this new paradigm of business. It was verily called 'time-based competition'. The line between managing projects and managing production started getting blurred. It was realised that everything is customer-driven. Customer service was/is the main focus of a business. A business is 'for' the customer and is 'because of' the customer. Mahatma Gandhi had made the same statement much earlier—during the 1930s. However, the industry was not in a position to benchmark the statement as it came from a person acting in a different domain—a freedom–fighter and a philosopher. Today, 'Lean Operations' emphasize that every operation has to be based on the premise of 'service to the customer'.

When a business is for and because of the customer, the customer needs to be served in several ways. It is now being realised that it is not enough if a company satisfies the requirements that a customer 'asks' for. A firm has to go one step ahead and anticipate the expectations. It not only has to satisfy the customer but also delight by providing several things as a surprise. A company has to think ahead of the customer's conscious thinking and demanding. Research and development, product design, and the production and delivery of these new items of service have to take place as early as possible. Time has ramifications beyond the service quality as the latter is normally understood. Time is the strength of a business.

32 Production Planning and Control

WHAT IS PRODUCTION PLANNING?

Planning and control are the two important components of the management process. Planning involves the consideration of all input variables to achieve defined output goals. Control involves the corrective actions taken when the actual output varies from the desired one by bringing the actual output in line with the planned output.

Production planning, in particular, would therefore consist mainly of the evaluation and determination of production-inputs such as labour (manpower), machinery and equipment, materials, and utilities to achieve the desired goals. The definition of the goals is also, of course, a part of the production planning process.

We may break down the planning process into various stages as follows:

(i) Defining objectives and setting priorities to attain these.
(ii) (a) Studying the environment external to the system being planned.
(b) Studying the internal environment of the system being planned.
(iii) Determining realisable targets (quantified as far as possible).
(iv) Gearing the inputs to achieve these targets.

PRODUCTION PLANNING AS AN INTEGRAL PART OF THE CORPORATE PLANNING PROCESS

Figure 32.1 depicts the planning process for a corporation. What is seen here is that production planning is an integral part of the total corporate planning effort. Although the former seems to be derived from the marketing plan, the targets are set at a higher level—a total corporate planning level. Moreover, the production plan has feedback links upwards, modifying the targets when necessary. In the entire dynamic corporate endeavour, production operation is a dynamic and important strategic link.

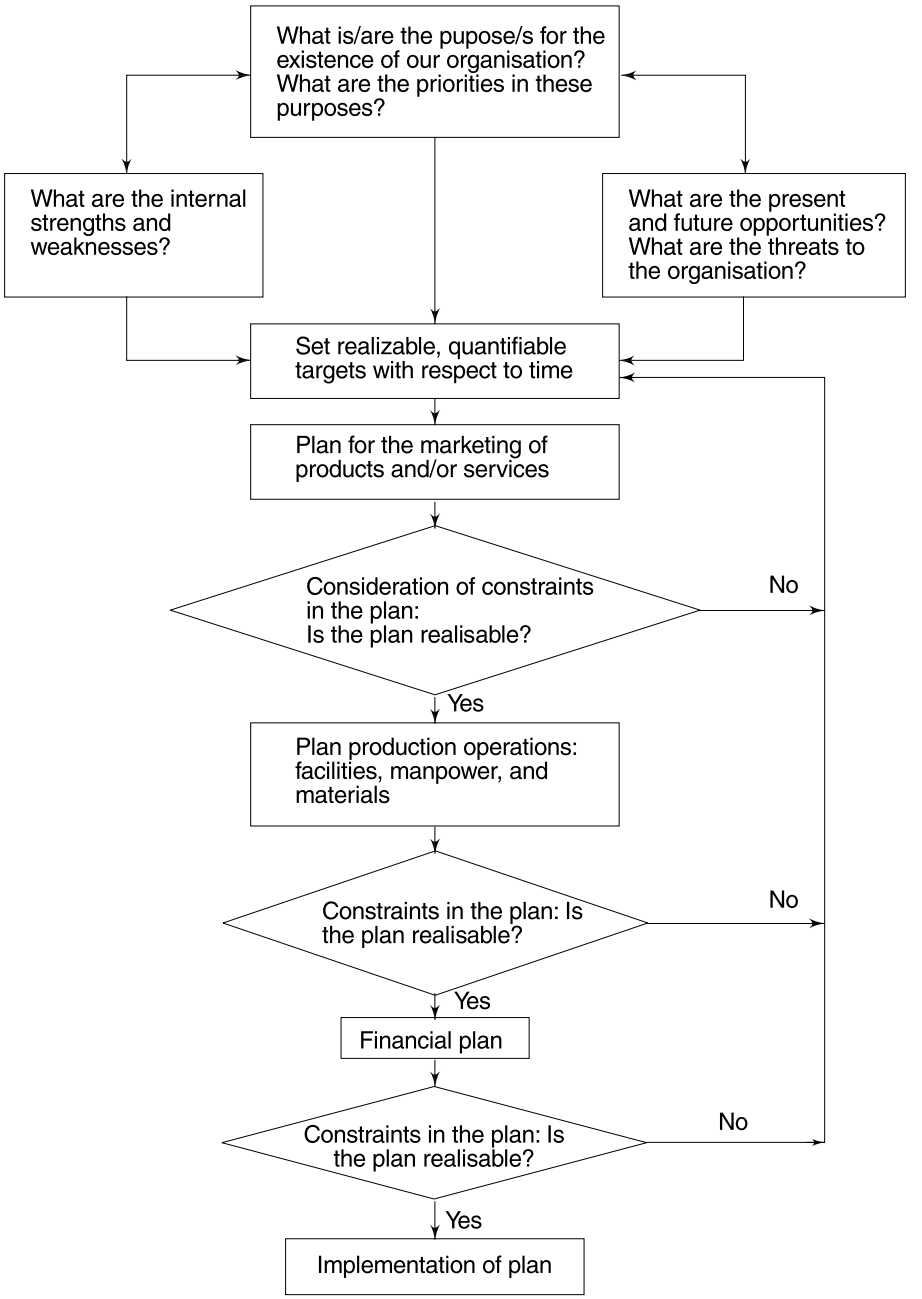


Figure 32.1 Corporate Planning Process

Importance of Time-Horizon

Plans have a time dimension and to the extent the time-span is limited, the scope of functional plans also remains limited with less interaction from other functional plans. The longer the time-span of the plan, the more integrative, organisation-wide the plan has to be. The wider time-horizon plans cover a wider organisational perspective.*

That is why very often the corporate planning process is synonymous with Long Range Planning.

As the time-horizon of the production plan widens, from a short-range plan (day-to-day scheduling), to an intermediate range (monthly, or quarterly or annual), to a long range plan (annual or five-yearly), the flexibility available—to change the variables and allow modifications when found necessary—also increases. The five-year range plan allows a company the flexibility of increasing the production capacity by purchasing new equipment, locating new plants, acquiring new technology, or recruiting adequate technical manpower.

This is not applicable for a one-year plan. Here, much of the flexibility in procuring new plants and machinery or acquiring the technology and know-how is lost. Coming to the weekly or daily plans, hardly any flexibility is left except to assign different jobs to the available machines and manpower. As the flexibility decreases the strategic or tactical options also decrease and the nature of planning itself assumes a different character. The planning problems for different time-horizons are therefore different and the solutions are also different.

Dovetailing of Plans

One important fact is that the short, medium and long-range plans have to dovetail into one another. Shorter-range plans are always made within the framework of the longer-range plans. Production planning as it is generally understood, is really the intermediate-range and short-range plan. The long-range production plan has lost its identity with the overall corporate planning process. That is why, production planning is said to follow from the marketing plan. Or, as is usually said, the production plan is the translation of the market demands into production orders. The market demands have to be matched with the production capacities (see Fig. 32.2):

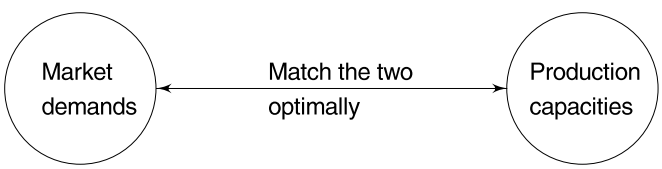


Figure 32.2 Production Planning

The keyword in Fig. 32.2 is 'optimally'. Market demands are either known or are forecasted, but we do know them, and the production capacities are also known. But how these two are matched will generate different cost structures and utility (e.g. time) structures. Optimisation of the cost or other utilities is the concern of production planning.

* What constitutes a 'long' time span as opposed to a 'short' time span depends a great deal on the life cycle characteristics of the product/outputs of and the inputs for the organisation.

The market demands (actual and forecasted) will not usually be level and steady over time. At different points of time the market will demand differently. It is, not always possible for the production department to follow the market fluctuations as and when they arise (or even if they are known in advance) and very often it is not 'optimal' (economical-costwise) to do so. Therefore, the production plan will many a time, look very different from the marketing or sales plan, although the total production figures will be more or less in agreement with the market requirements.

Suppose the demand in the market for a company's goods are forecasted as shown in Fig. 32.3. What should the production strategy be? Should the company respond completely to the market fluctuations? Or should it maintain a level production (producing more than needed sometime and less than needed at other times)? Or should it produce at one level for half the time and at another level in the other half of the time (Stepwise Plan, as shown in Fig. 32.3)?

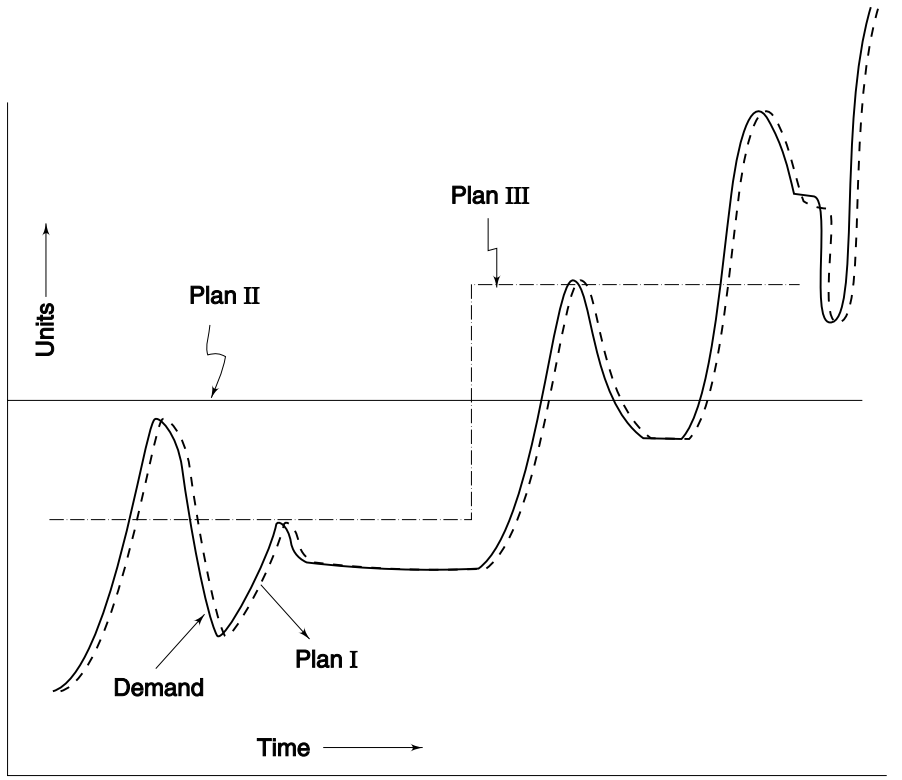


Figure 32.3 Forecast of Demand and Different Production Plans

These questions can be answered in light of the costs involved (such as the labour cost, inventory cost, etc.) and the constraints on the availability and deployment of the resources (see Fig. 32.4).

	Costs of Operational Changes	Inventory-related costs	Total
Plan I	5,50,000	15,000	5,65,000
Plan II	–	1,55,000	1,55,000
Plan III	60,000	75,000	1,35,000

Note Plan III is the best suited costwise.

Figure 32.4 Cost Comparison of Different Production Plans

Based on purely cost comparisons Plan III seems attractive. But if we place a high value on the delay to the customer, Plan I would probably be the best plan. The various alternative production plans are the intermediate-range production strategies available–which could be used to suit the corporation's needs in a competitive environment.

Need for Detailed Plans

The production strategy arrived at by the company will be the gross-level plan, which needs to be further translated into a detailed plan for individual products. The detailed plan must fit into the gross-level plan.

Once the targets for production are fixed, the weekly or daily schedules can be derived keeping in mind technological and other constraints. Production planning on a short-term basis (or a smaller "planning horizon") is often termed as Production Scheduling.

At a gross level, one must balance the gross demand into gross level availability of resources in machine-hours or man-hours, etc. At the detailed level one needs to balance the requirements of individual products with the availability of individual machines/equipments and labour of different skill categories.

For production planning, the operations research techniques such as Linear Programming, Queueing theory, PERT/CPM, assignment problem, etc. are quite useful.

WHAT IS PRODUCTION CONTROL?

Production Control is the updating and revising procedure where, according to the requirements of implementation, the labour assignments, the machine assignments, the job priorities, the line speeds, the production routes, etc. may be revised. It is basically a correcting mechanism which goes on throughout the implementation process of the already drawn up production plan and schedule.

In order to continually monitor the progress of implementation, many control techniques such as Gantt Charts, Line of Balance, PERT/CPM, etc. may be used. Essentially these are bar-charts, with the latter two showing some sequence relationship.

Extraordinary revisions of schedules would need an extra person to look after the changes and monitor and communicate decisions and information faster on the production line. Such a person, who is not uncommon in industries, is called an "expediter".

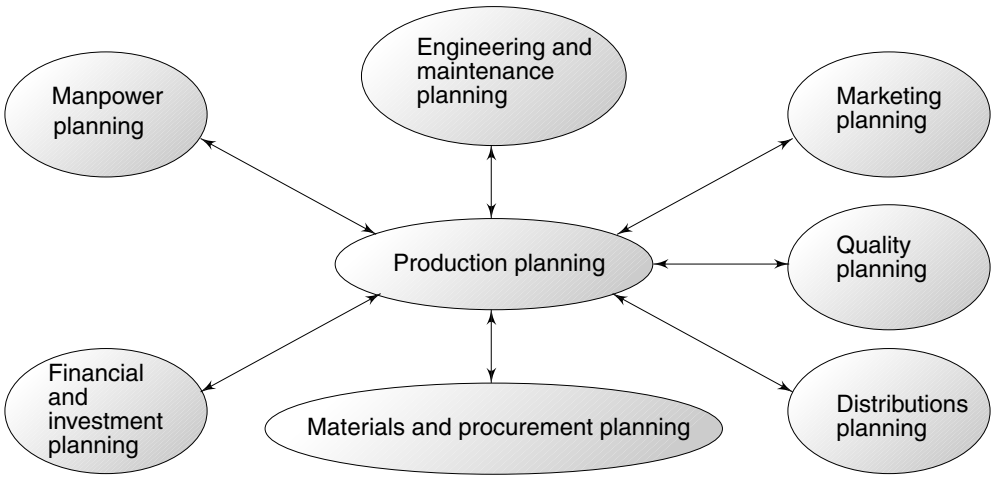
In order to control the production schedule as efficiently as possible, a procedure called Short Interval Scheduling is used in many western countries. This is nothing but scheduling production to a micro

level, thereby exercising tight control over the minute deviations from the already drawn-up production schedule.

INTEGRATIVE NATURE OF PRODUCTION PLANS

Production Planning and Control (PPC) therefore, is an effort to optimise the process of conversion of raw materials into finished products required in the market. Since various activities are involved in the conversion of raw materials into finished goods, PPC is and has to be an integrated function if the corporation has to derive maximum benefit out of planning. The procurement of raw materials, the quality control and inspection of raw materials, the inventory levels of in-process and finished goods, the production costs, the labour available, the machinery and equipment that is available, the warehousing capacity available, etc. all have their influence on the planning of production operations which convert the procured raw materials into finished goods. All the functions have inter-links; and the more such inter-links are considered in the planning process, the better will be the planning process.

For instance, sometimes production and maintenance are planned separately, leading to conflicts between the preventive maintenance needs and the production needs. Such conflicts can be avoided if the planning for maintenance is done in coordination with planning for production, allowing for sufficient number of days of shut-downs of different machineries while drawing up the production plan for the year. The more integrative the PPC, the better will be the planning decisions. Figure 32.5 shows various functional departments which influence planning for operations.



32.5 PPC and Related Functions

CENTRALISATION AND DECENTRALISATION

Although theoretically PPC is an integrated function, in many organisational set-ups, for various special organisational needs, and also because in certain organisations certain functions play a more important role than others in terms of profit contribution to the corporation, the PPC unit

may have a limited function, with other functions distributed to other departments such as materials management, manufacturing, etc.

At higher levels or longer time-horizons, plans have to be integrative. At lower levels or shorter time-horizons, benefits may be derived by the decentralisation of the planning process. The organisation of the totality of the PPC function, therefore, will vary in different organisations depending upon the different external and internal climates in which the organisations have to function. However, this fact neither refutes the necessity of congruency when formulating various functional goals, nor does it deny the integrative nature of the production planning process.

The chapters that follow will discuss the techniques and mechanics of PPC in detail.

QUESTIONS FOR DISCUSSION

1. What is the aim of production planning?
2. Wickham Skinner has written a book *Manufacturing—A Corporate Strategy*. How could manufacturing be used as a corporate strategy? Give examples.
3. Should cost be the primary criterion in operations planning? Explain.
4. To make PPC truly integrative, what prerequisites are necessary?
5. How could a good Management Information System contribute to PPC?
6. Discuss centralisation and decentralisation in the context of PPC.
7. How are production planning problems and solutions different for long range and shorter range? Discuss.
8. What is the importance of forecasts in PPC?
   For different operations planning needs how are different forecasting techniques suitable?
9. What impact could computerisation have on PPC?
10. Would operations planning and control in service industries be different from PPC in manufacturing industries? Discuss.



33

Production planning in the intermediate range of time is termed as 'aggregate planning'. It is thus called because the demand on facilities and available capacities is specified in aggregate quantities, e.g. aggregate quantities of thousands of litres of paint, or tonnes of fabrication work, or number of automobiles, etc. This means that the total demand (expected) is measured without regard to the product mix that makes up this figure.

WHAT IS AGGREGATE PLANNING

The aggregate plan is made within the broad frame work of the long-range plan. Usually, the planning horizon for such plans ranges from a month to a year. The physical plant and equipment capacity would be fixed over this planning horizon. Therefore, the sales orders have to be met by strategies like using overtime, hiring of extra staff (temporary) or layoff of such persons, carrying inventory or giving a subcontract. The intermediate planning time-horizon derives its 'intermediate' character due to the 'type' of decisions that need to be taken, given a certain framework of long-term decisions which have been taken. What the actual time span of such planning should be—six months or 24 months or less than six months—is dependent upon the business, technology and production system of the particular organisation.

The first step for such planning would be to make a sales forecast of demand for the intermediate range. And based on this sales forecast one has to develop the aggregate production strategy. A production aggregate plan can be developed by the following procedure:

Checking as to whether the total requirements for the forecast period are within the combined equipment and manpower capacity of the plant. If the forecasted sales requirements cannot be met by existing plant capacity including any additional capacity that can be installed within the intermediate planning period, the sales forecast may have to be scaled down to the maximum capacity that is available during the aggregate planning period.

Now the alternative production plans (aggregate) have to be made and the one that is most economical will be selected. We could have a production plan which closely follows peaks and val-

leys in the production requirements forecast or we could have a steady production rate equalling the average of these peaks and valleys. There could be other plans which could be combinations of these two plans.

STRATEGIES AND COSTS

In trying to meet the demand with the production capacity in the intermediate range we have the following different strategies at hand.

1. Overtime and undertime.
2. Hiring and layoff; working single or multiple shifts.
3. Carrying inventories to meet the peak demands.
4. Having backlog of orders.
5. Sub-contracting to other companies.
6. Turning down some sales demands.

Each of these strategies has a cost factor associated with it.

The marginal cost of overtime is not difficult to estimate, whereas, the costs of undertime are not that easy to determine. The hiring costs include the costs of selection, the costs of training and the cost of maintaining additional records. Moreover, there are costs associated with learning-on-the job of a newly hired employee. The costs of inventory include the capital cost for carrying the inventory, the cost of obsolescence, taxes and insurance, etc. The stockout costs are the costs due to lost sale or the loss of goodwill of the customer. These might be somewhat difficult to estimate. The cost of sub-contracting is the amount by which the sub-contracting cost is greater than the manufacturing cost at the higher level of production.

The combination, rather than a single strategy, will usually result in the most economical plan. A few mathematical methods are presented below which employ a combination of the different strategies mentioned above which will lead to minimum cost. The whole idea behind this exercise is to plan different amounts of overtime, hiring, inventory, backlogs of orders and sub-contracting such that the different levels of demand for different future periods are met most economically. The most common model used is that of linear programming.

Linear Programming Model

The production requirements specify the quantities of product to be made available in each of the several time periods in the future. The limits on production capacity can be expressed as the maximum quantities of product that can be produced in regular and overtime operation in each of the time intervals to be planned. When one has to increase production capacity within the regular time,one has to hire more labour, and vice-versa for decreasing the production capacity.

The total of opening inventory plus accumulated production planned must equal or exceed the accumulated expected demand at every point in the period in the planning horizon. The job will be to minimize the sum of the costs incurred over the aggregate planning horizon. In simple algebra, we can express the regular-time production limit (constraint) as follows:

$$P_1 \leq M_1$$

where P_1 is the scheduled regular-time production in period 1, and M_1 is the maximum regular-

time production that can be scheduled in period 1. Similarly, we can write for the second period:

$$P_2 \leq M_2$$

and for the third period: $P_3 \leq M_3$; and so on.

We can write similar inequalities for the 'overtime' strategy. Once again the capacity estimates must be made before hand. This time, they include the maximum overtime production that can be scheduled in each period. The overtime limits (constraint) for the first period can be written as:

$$T_1 \leq Y_1$$

where T_1 is the scheduled overtime in period 1, and

Y_1 is the previously estimated overtime production capacity in period 1.

Similarly for period 2 we can express: $T_2 \leq Y_2$

and for the third period: $T_3 \leq Y_3$; and so on.

Now we have a restriction that the total of opening inventory plus accumulated production planned must equal or exceed accumulated expected sales in each of these periods. This restriction (constraint) can be expressed for the first period as:

$$P_1 + T_1 \geq D_1$$

(assuming that the initial level of inventory is zero)

where D_1 is the aggregate demand for period 1. For period 2 we can express the constraint as:

$$P_1 + T_1 - D_1 + P_2 + T_2 \geq D_2$$

or

$$(P_1 + P_2) + (T_1 + T_2) \geq (D_1 + D_2)$$

which is expressed in short form as:

$$\sum_{i=1}^{n} P_i + \sum_{i=1}^{n} T_i \geq \sum_{i=1}^{n} D_i$$

where i stands for individual periods (1, 2, 3, …) in the aggregate planning horizon.

Next, we have limitations on the extent of production level changes. In the first period the increase in production level A_1 must be greater than or equal to the difference between scheduled production in period 1 and that in the preceding period which is expressed as:

$$A_1 \geq P_1 - P_0$$

The value of P_0 must be supplied to us. Since the period which precedes the planning model is often the current period, the estimation of P_0 does not pose a problem.

For the second period we have: $A_2 \geq P_2 - P_1$; and for the third period: $A_3 \geq P_3 - P_2$.

Similarly, we have constraints on reductions in production levels. If the production level reductions are represented by the letter R, then for the first period we can write:

$$R_1 \geq P_0 - P_1$$

which means, the reduction must be greater than or equal to the decrease in the production level between successive periods.

For period 2 similarly, we have $R_2 \geq P_1 - P_2$;

and for period 3 we have: $R_3 \geq P_2 - P_3$; and so on for other periods.

Now our objective is to minimise the sum of the costs incurred over the planning horizon. If we limit our planning horizon to only three periods, we can carry out the following analysis. A few other definitions for the following symbols are necessary here:

r = Regular-time production cost per unit
c = Inventory carrying charge per unit per period
h = Cost of increasing the production level by one unit of output (hiring)
f = Cost of reducing the production level by one unit of output (layoff)
v = Overtime production cost per unit

Now, we turn our attention to the objective of minimising the sum of the costs incurred over our three period planning horizon. In the first period the sum of costs is:

$$rP_1 + hA_1 + fR_1 + vT_1 + c(P_1 + T_1 - D_1)$$

For the second period the sum of costs is:

$$rP_2 + hA_2 + fR_2 + v\,T_2 + c[(P_1 + T_1 - D_1) + (P_2 + T_2 - D_2)]$$

and for the third period it is:

$$rP_3 + hA_3 + fR_3 + vT_3 + c[(P_1 + T_1 - D_1) + (P_2 + T_2 - D_2) + (P_3 + T_3 - D_3)]$$

The sum of the three equations can be written in a general notation, for our objective, as follows:

$$\text{Minimise costs} = r\sum_{i=1}^{3} P_i + h\sum_{i=1}^{3} A_i + f\sum_{i=1}^{3} R_i + v\sum_{i=1}^{3} Ti + c\left[\sum_{i=1}^{3}\sum_{j=1}^{i}\left(P_j + T_j - D_j\right)\right]$$

Thus, we have formulated the linear programming model for our planning process. Linear programming models can be solved manually if they are simple enough, or by means of computer packages if they are complex. By solving the linear programming model, we can get a period-wise allocation of our regular time capacities, and overtime capacities, in order to meet the sales forecast or the requirements forecast in the most economical fashion. Other more advanced linear programming models for production planning have been developed by some. In addition to the overtime, hiring and layoff, and inventory variables which we have just included, they include undertime and shortages as alternative means of absorbing the demand fluctuations.

Transportation Problem Method

Bowman* has indicated a Transportation Problem approach to aggregate planning. The model, considering a combination of only the three strategies of (i) regular time production, (ii) overtime production, and (iii) inventory, is presented in Fig. 33.1. It is for four periods of time.

where M_i = Maximum regular time production possible during period i
Y_i = Maximum overtime production possible during period i
D_i = Demand (market) during period i
I_i = Inventory at the end of period i
r = Regular-time cost of production, per unit
v = Overtime cost of production, per unit
c = Cost of carrying the inventory per unit per period

* E.H. Bowman, Operations Research, Vol. IV. No. 1, 1956.

Availabilities	Period 1	2	3	4	Inventory	Slack
I_0	0	c	$2c$	$3c$	$4c$	0
M_1	r	$r+c$	$r+2c$	$r+3c$	$r+4c$	0
Y_1	v	$v+c$	$v+2c$	$v+3c$	$v+4c$	0
M_2	X	r	$r+c$	$r+2c$	$r+3c$	0
Y_2	X	v	$v+c$	$v+2c$	$v+3c$	0
M_3	X	X	r	$r+c$	$r+2c$	0
Y_3	X	X	v	$v+c$	$v+2c$	0
M_4	X	X	X	r	$r+c$	0
Y_4	X	X	X	v	$v+c$	0
Requirements	D_1	D_2	D_3	D_4	I_n	L

Figure 33.1 Transportation Problem Method for Aggregate Planning

L = Total slack = $I_0 + \sum M_i + \sum Y_i - \sum D_i - I_n$

X = Very high cost, so that those cells are forbidden.

This model can be extended to consider several products separately. Each product will have a different requirements column, whereas the 'availabilities' rows would remain the same. A suitable unit of production can be chosen which could be common to all the products.

The linear programming and related transportation problem methods are no doubt quite useful particularly in the light of the availability of computers and software packages. However these are not dynamic in the sense that the requirements are considered to be rigid, inflexible or definite. They may not be so in practice and appropriate control action would be necessary. Moreover, the cost functions are assumed to be linear. The regular-time costs, the over-time costs and inventory costs are presumed to increase in direct proportion to the quantity which may not be a very truthful assumption.

HMMS (Holt, Modigliani, Muth and Simon) Model*

In the previous linear programming model the cost functions or relationships were assumed to be linear; that means, cost relations were assumed to consist of fixed elements, plus elements which

* C.C. Holt, F. Modigliani, J. Muth and H. Simon, *Planning Production, Inventories, and work Force*, Prentice Hall, NJ 1960.

varied directly in proportion to the variables specified in a plan—amount of overtime, amount of inventory, etc. The cost of carrying the first unit in inventory was supposed to be the same as the cost of carrying the one hundredth unit in inventory. The cost of hiring the first employee was supposed to be the same as the cost of hiring the one hundredth employee.

As such assumptions may not be appropriate in many cases, it might be better to use a non-linear model instead of simplified linear programming model.

The HMMS Model uses quadratic functions for the different costs such as overtime, inventory, hiring and layoff, backlog, etc. For this model the following costs are considered.

1. Costs relating to production level with optimal workforce
2. Hiring costs
3. Layoff costs
4. Overtime costs
5. Undertime costs
6. Inventory holding costs
7. Back-order costs

In this model a further refinement was made insofar as the time horizon was broken into discrete and identifiable units and the costs involved were expressed as a function of each time unit. If t represents the interval of time chosen (that means the period) and if *Wt* represents the workforce during time t, the regular pay-roll cost can be identified as:

$C_1 W_t + C_{13}$, where the sales are constant.

In Fig. 33.2 the way the costs of hiring additional workers or laying off the workers change with the number of workers involved in the hiring or firing operation is shown.

To Fig. 33.2 the HMMS model fits a quadratic function approximation. Thus, the hiring and layoff costs are expressed as:

$C_2 (W_t - W_{t-1} - C_{11})^2$, where $W_t - W_{t-1}$

gives the change in the workforce level.

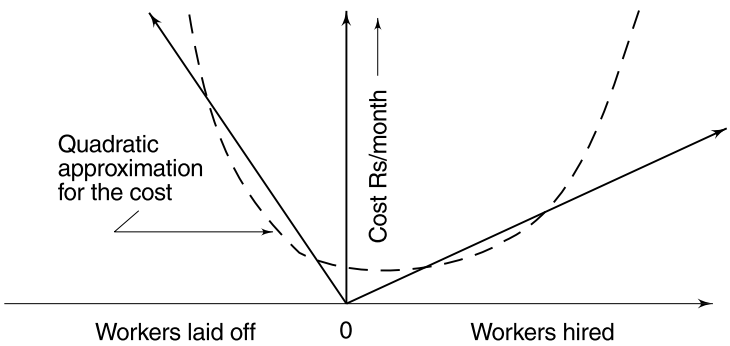


Figure 33.2 HMMS Model: Hiring and Laying Off Costs

Overtime costs are incurred when production levels exceed the regular-time production capacity of the workforce. These costs depend on two variables: the size of the workforce at a given time and the aggregate production rate. For a given production rate, the larger the workforce level, the less the overtime that is required. The quadratic function to fit the overtime costs is as follows:

$C_3 (P_t - C_4 W_t)^2 + C_5 P_t - C_6 W_t + C_{12} P_t W_t$

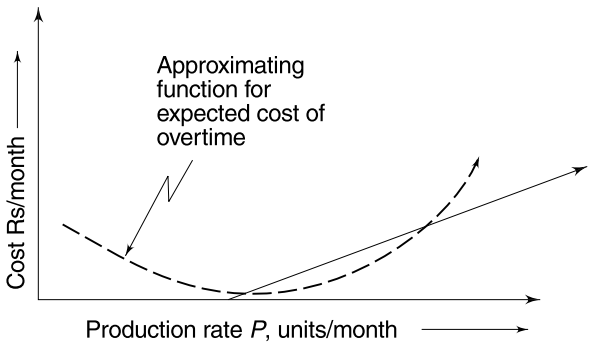


Figure 33.3 HMMS Model: Overtime Costs

Figure 33.3 expresses graphically the above given relation between the production rate and the overtime costs.

The fluctuations or the variations in demand from period to period can also be accommodated by variations in the inventory level, as mentioned before. This includes the strategy of having back orders. The form of the quadratic expression for inventory-related costs is as follows:

$$C_t\,[(I_t - (C_8 + C_9\,S_t)]^2$$

where I_t represents the inventory level in the t th period and S_t represents the sales rate or the demand rate for the same period.

Thus, the total cost in period t can be expressed as:

$$\begin{aligned} C_t = {} & C_1\,W_t + C_{13} \\ & + C_2\,(W_t - W_{t-1} - C_{11})^2 \\ & + C_3\,(P_t - C_4\,W_t)^2 + C_5\,P_t - C_6\,W_t + C_{12}\,P_t\,W_t \\ & + C_7\,(I_t - C_8 - C_9\,S_t)^2 \end{aligned}$$

Since each period's decision has repercussions which extend into the future, several production periods must be considered. The objective is to schedule production in such a way as to minimise production and employment cost. If there are N periods, the model can be expressed as:

Minimise $$C_N = \sum_{t=1}^{N} C_t$$

where each C_t is given by the previously mentioned equation.

Now we have some constraints for each of the time periods. They are:

$$I_t = I_{t-1} + P_t - S_t$$

The method of solution is to obtain the derivatives of C_N with respect to W_t and I_t, setting these derivatives to zero and then eliminating the variables. The solution leaves two decision variables W_t and P_t. The solution as obtained below (the constants which figure below were obtained for a specific situation) is in terms of two Linear Decision Rules for W_t and P_t. Hence the HMMS model is also referred to as the Linear Decision Rules (LDR) model.

$$P_t = \begin{bmatrix} +0.458\,S_t \\ +0.233\,S_{t+1} \\ +0.111\,S_{t+2} \\ +0.046\,S_{t+3} \\ +0.014\,S_{t+4} \\ -0.001\,S_{t+5} \\ -0.007\,S_{t+6} \\ -0.008\,S_{t+7} \\ -0.008\,S_{t+8} \\ -0.007\,S_{t+9} \\ -0.005\,S_{t+10} \\ -0.004\,S_{t+11} \end{bmatrix} + 1.005\,W_{t-1} + 153.0 - 0.464\,I_{t-1}$$

and

$$W_t = 0.742\,W_{t-1} + 2.00 - 0.010\,I_{t-1} + \begin{bmatrix} +0.101\,S_t \\ +0.0088\,S_{t+1} \\ +0.0071\,S_{t+2} \\ +0.0055\,S_{t+3} \\ +0.0042\,S_{t+4} \\ +0.0031\,S_{t+5} \\ +0.0022\,S_{t+6} \\ +0.0016\,S_{t+7} \\ +0.0011\,S_{t+8} \\ +0.0008\,S_{t+10} \\ +0.0004\,S_{t+11} \end{bmatrix}$$

The first rule, or the solution, that resulted here is the production rule setting the aggregate production rate. It incorporates the weighted average of the forecast extending to 11 months into the future. As is seen above, the weight is heaviest on most recent months and diminishes rapidly. This implies that the sales orders or the demand which is well into the future has little impact on current production levels for this particular example. The second term, 1.005 W_{t-1} represents the impact that employment levels in the previous month have on production levels in the current month. The greater the previous level of workforce, the higher will be current production. The last two terms reflect the impact that the previous month's inventory has on the current production level. For a large ending inventory the sum of the two terms is negative and production will be decreased. This is the way the rule responds to past forecasting errors.

The second decision rule computes the size of the workforce for a particular time period. The last set of terms reflect the impact that the forecasts have on the current workforce level.

It should, again, be emphasised here that the weightages as shown in the solutions above are pertaining to a particular situation studied by the authors of this model. It is also worth noting that the ultimate decision rules of the very complex situations are simple enough to be manually used.

The Control Process

We have briefly touched upon production planning above. But as we have indicated earlier, the demand forecasts in reality, however meticulously prepared, are always subject to variations or fluctuations. The actual demand may depart from the forecasted demand that was used to establish the production plan. Actual production may also not equal planned production. Since these fluctuations cannot be avoided, we must find some means of making periodic adjustments in the production plan as these variations of the actual demands from the forecasted demands are known. The objective of this adjustment is to prevent excess inventories or deficiencies in inventories. Let us take an example. Suppose the production plan is as follows:

Month	*Production Plan (units)*	*Month*	*Production Plan (units)*
Jan.	450	July	350
Feb.	400	Aug.	400
Mar.	350	Sep.	400
Apr.	300	Oct.	500
May.	300	Nov.	550
June	350	Dec.	550

Suppose, as planned, 450 items are produced in the month of January. Of these, 405 items, say, are meant for sale during the month of January and 45 items are meant to bring the buffer-stocks up to 100 items at a certain percentage service level. But if only 355 items are actually sold or delivered from the stockroom, the actual inventories will be higher than the planned inventories by 50 items. We have to adjust our production plans for the coming months in order to account for these 50 items; otherwise, we will end up increasing our inventory carrying costs by an amount equivalent to 50 items for the rest of the year. If our production lead-time for this item is one month, at the start of January we cannot change the planned production for February. We will have to make adjustments in the production plan during March. The aim is to bring the inventories back to 100 items (buffer stock) at the end of the month of March. We could schedule March production, therefore, at 300 items. This figure is computed as follows:

Revised March Production Plan = Original March Production Plan + Original February Production Plan – Revised February Production Plan + Planned Current Inventory – Actual Current Inventory = 350 + 400 – 400 + 100 – 150 = 300.

Suppose at the end of February we discover that 440 items instead of the forecasted 400 items were sold in the month of February. We had already planned for 300 units in March which we cannot change, because it will take us one month to effect the adjustments in our plans. The earliest month where we can make adjustments is the month of April. The original production plan for the month of April will have to be revised according to the following computation:

Revised April Production Plan = Original April Production Plan + Original March Production Plan – March Revised Production Plan + Planned Current Inventory – Actual Current Inventory = 300 + 350 – 300 + 100 – 110 = 340 itmes.

We can proceed in a similar manner making the revisions for the production plans for the next months. The same production levelling procedure can be mathematically expressed as follows:*

$$P_{T+1} = P^*_{T+1} + P^*_1 + P^*_2 + \ldots + P^*_T - P_1 - P_2 - \ldots$$

$$- P_T + I^*_0 - I_0$$

where T = Lead time, the lag in making a change in production rate effective (1 month in the preceding example)

P_{T+1} = Production level being determined

$P_1, P_2, \ldots$ up to P_T = Production levels already set for intervening months

$P^*_1, P^*_2 \ldots$ up to P^*_T, P^*_{T+1} = Production budgets set under the preliminary plan

I_0 = Inventory actually on hand at present

I^*_0 = Inventory planned to be on hand at present

The same equation can be described as follows:
Revised Production Plan = Original Production Plan + Effects of Demand Variation.

Suppose we want to adjust the production rate by only a fraction of the discrepancy between the planned and actual stock on hand. If K represents the fraction used (K varying between 0 to 1.0), the above control rule would be modified as follows:

$$P_{T+1} = P^*_{T+1} + K[P^*_1 + P^*_2 + \ldots + P^*_T - P_1 - P_2 - \ldots$$

$$- P_T + I^*_0 - I_0]$$

The significance of K which is called the response factor is as follows: If K had a value of 1.0 then for every change in the forecast demand we would increase or decrease our production plans for a future period by the corresponding amount. This is 100% proportional response. If demand fluctuations are erratic and vary widely from an average figure, the production level will have to vary just as widely. This may be undesirable. It may not be necessary to keep changing the established production plans because a random increase in demand would probably be followed by off-setting decreases in later periods.

On the other hand, if we decide not to make any changes in the original production plan, no matter how the actual demand varies as compared to the forecasted demand, we actually mean that the K factor has a value of zero.

In practice, the K factor has a value between 0 and 1. The larger the value of K or the response factor, the closer will the production rates (against the planned production rates) follow the variations between forecasted demand and actual demand. The higher value of the response factor will

* *Source* 1. J.F. Magee and D.M. Boodman, *Production Planning and Control*, 2nd Edition, Tat McGraw-Hill, 1980.

2. Readings on Production Planning and Control, *Mantual on Production Planning and Control*, Economic Development Foundation, Manila, Asian Productivity Organisation, Tokyo, 1972.

allow us to keep lower amounts of safety stocks. The lower value of the K factor will require that we should have higher amounts of safety stocks. An analogy can be given here. Suppose your car is following another car. The distance between the two cars would represent, here, the safety stock. Your car, which is analogous to the production rates will have to follow the car in front which is analogous to the sales demand. There is a certain lead-time or lag in your reflexes as you try to change the speed and direction of your car according to the changes made by the car in front. If you try to accelerate when the car in front accelerates and decelerate when the car in front decelerates, at the same rate, then your car (production rates) can stick very close to the car in front (demand). But this will require a lot of effort on your part as a driver, and this effort is analogous to the cost of changing the production levels. If however, your car accelerates or decelerates also when the car in front accelerates or decelerates, but at only, say, half the rate of the car in front, then it will be necessary that your car should stay at a longer safety distance from the car in front in order to avoid bumping into it. This is analogous to having higher safety stocks if you have a *K* factor of lower value. But at the same time you will now have to concentrate less or put in less effort. This is analogous to reducing the production level change related costs. So, correct value of the response factor will depend upon which cost is significant. If the cost of changing the production levels is more significant, then the *K* value should be low; if the cost of maintaining the safety stock is more significant, then the *K* value should be higher.

After making these adjustments to the planned production we should compare the value of the adjusted planned production with the available capacity. If the adjusted planned production is in excess of the available capacity there are two alternatives:

1. Not to make any compensation for the excess planned capacity; or
2. To add the excess adjustment to the levelled (adjusted) planned production in the periods (months in our case cited above) immediately following.

So, a production control system should have the following three significant elements:

1. A forecast of demand expressed in aggregate units.
2. A production plan specifying the production and inventory levels, in the same units.
3. A control procedure to take care of forecast errors and of consequent effects on the inventory levels planned.

For what type of production systems are these aggregate planning concepts and models suitable? In the case of high-volume standardised products where 'assembly line' concepts are applicable, there is a simple and direct application of the models. The levels of regular time production can be varied by changing the 'rate of the assembly line' and correspondingly 'balancing' the assembly line. (The Line Balancing technique will be presented in the next section of this chapter.) The application of the aggregate planning concepts gets to be more difficult when the homogeneity decreases substantially as in the job-shop type of production making it difficult to express the capacities in aggregate terms. However, this is not an unsurmountable difficulty. Whatever may be the product variation, in production we are interested in the capacities and demands on specific work centres, e.g. stamping capacity, turning capacity, etc. Thus a master load plan can be prepared. However, the demands are quite uncertain, making forecasting a more difficult exercise. So aggregate planning also becomes difficult to that extent. However, in closed job-shop type situations, where the product variety is less (the unit is a 'captive unit' of the parent or outside company), the forecasting is more easy. This type of system is more amenable to aggregate planning than the open job-shops mentioned earlier. The level of certainty is higher in this closed

job-shop. In the project type of production system (such as manufacture of huge chemical plant vessels, boilers, aircrafts, ships), the various processes or activities are interrelated in a complex but definite manner. This calls for (not an aggregative approach but,) a system whereby these definite complex inter-relationships of the jobs are taken into account. Therefore, the principles of Network Analysis (PERT/CPM) are quite useful in time-scheduling and in the allocation of resources. The 'network' would give the schedule, both detailed and aggregate. This technique is described in Chapter 36.

In spite of some of the aforementioned variations and limitations, aggregate planning is a very essential activity which provides the foundation for detailed production planning activity required for the day-to-day management of production. Without it, the daily production scheduling would be a directionless exercise.

ASSEMBLY LINE BALANCING

For high volume mass or continuous production a Line layout is preferred. In this, the equipments are laid out according to the sequence of operations that must be performed on the raw material to convert it into the finished product. The sequence of the equipments and the sequence of the stages through which the raw material progresses from the raw material stage to the finished product stage correspond to each other. Such a Line Layout is preferred in most of the assembling operations where a number of components have to be put together to produce the final product. This is called the Assembly Line.

Production Planning in Mass Production Systems In a mass type of production system, such as the assembly line, the production planning problem basically boils down to (i) establishing the production rates of the final product from the line and (ii) obtaining this production rate with the optimal work force level. The assembly line confers special benefits by significantly reducing production-and-inventory costs by virtue of significantly, the smooth and regulated flow of the material through the series of operations at a uniform rate. The more an assembly line resembles a moving conveyor passing through a series of 'work-stations' at a uniform rate the better are the advantages from such a layout. Interrupted flow and delays or stoppages will increase the costs associated with this layout. In fact, the flow rate of the materials through the entire path of the assembly line (this flow rate being the rate of production of the desired final product) depends on the rate of flow through a bottle-neck operation.

If one of the operations takes 10 minutes,whereas all the other operations take less than 10 minutes, then the rate of production of the product will be one unit per 10 minutes. The material on its way through different departments has to wait at various departments, after the job is over, till it can be taken up for the next operation. If we have an operator at each of the work stations, all the work stations (excepting the work station where it takes 10 minutes) will experience idle-time, e.g. the operator manning the operation taking 2 minutes will be idle for (10 – 2) = 8 minutes. The main problem before the assembly line layout is to reduce these idle-times: or, to put it in other words, the problem is to have as much equality of output at each working station as possible. This equalising of the output rates at different work stations is termed as 'balancing'. And hence the term 'Assembly Line Balancing'.

Grouping 'Elemental Tasks' How can one achieve the balance if an operation takes 2 minutes, whereas the next operation takes 10 minutes? It can only be achieved by adding some more work at the work station taking 2 minutes and making the total work component more or less equal to 10 minutes. The balancing of the line really means to group the various work elements or elemental tasks involved in production into different work stations in such a way as to have more or less equal working time at each of the work stations.

When this balancing is carried out the product will be produced at the rate of one unit of product per 10 minutes. It is possible that we desire a higher rate of production than this, say 12 units of product per hour (the line balanced for 5 minutes). In such a case the elemental tasks which have times less than 5 minutes have to be grouped to form work stations, so that at each work station the total amount of time taken is equal to or less than 5 minutes. Of course, the elemental tasks taking more than 5 minutes, such as the one which took 10 minutes, need to be shared by two operators so that the production rate through that operation does not exceed 5 minutes. So, the assembly line work can be grouped or it can be split and then grouped, if necessary.

Estimating Time for Elemental Tasks The first thing to do in line balancing would be to gather information on the number of elemental tasks or work elements involved and the time required for each one of these elemental tasks.

Sequencing Relationships between Elemental Tasks The next thing to do is to gather information on technological or other sequences of the operations. Grouping for balancing the line is okay;but not all the work elements can be grouped on an ad hoc basis. The requirements of the sequence of operations and the direction of flow is to be kept in mind. For instance, in binding a book we may have work elements of **(i)** trimming papers to size, **(ii)** punching holes through the paper, **(iii)** tying the papers, **(iv)** placing the hard cover over the tied papers, etc. In this one cannot group the 'trimming of papers' with 'placing of hard cover over the book': because from this stage it cannot go for 'punching the holes' and 'tying up the papers'. It means, the sequence of the elemental tasks is an important information in line balancing. This is expressed in the form of a 'precedence diagram' so as to facilitate the grouping.

The basic data required for line balancing are therefore:

(i) a list of all the elemental tasks,
(ii) estimation or calculation of the time requirement for each of the elemental tasks,
(iii) technological sequencing requirements between the different elemental tasks.

Considerations, Other than Technological Sequence Of course, we have assumed that when two different work elements are grouped together, both these jobs can be handled by the same operator. We have assumed that the operator has such multiple skills.This may or may not be true or may be partially true. This is a constraint which needs adequate consideration while balancing the assembly line. Another constraint is that some operations may need to be done in a particular location and therefore it may not be possible to group the elemental tasks freely. For instance, the task of tightening nuts might need the use of compressed air which may be available only at certain locations; therefore, this elemental task cannot be assigned to any work station freely. Such a constraint may be called 'constraint of fixed location'.

Other constraints may be the positional constraint of the semi-finished product. Take the case of a television set being assembled at a particular work station, only the back of the television set may be available for the operator to perform a task. He may not be able to work on the front side

of the television. Such constraints of 'orientation of the semi-finished product' also deserve due consideration.

Before we enter into the analysis or method of grouping the elemental tasks, we may provide definitions of certain terms used frequently in the assembly line balancing procedure.

(a) *Elemental Task or Work Element* This is defined as the smallest work unit beyond which further sub-division of work will not make much sense.

(b) *Work Station* A work station is a location on the line layout where a certain group of elemental tasks are performed. The work station may have one or more operations and may have one or more of the same equipment. Similarly, an operator can be shared by more than one work station.

(c) *Station Time* Based on the group of elemental tasks assigned to the work station, the 'station time' is the total amount of time required to perform that group of elemental tasks.

(d) *Cycle Time* This is the amount of time required to produce one unit of the finished product. This is also the total amount of time available at each of the work stations. The cycle time is different from the station times and has to be equal to or greater than any of the station times.

(e) Balance Delay This is defined as follows:

Balance Delay =

$$\frac{\text{Total idle-time for the assembly line}}{\text{Total time taken by a product from the first work station to the last work station}}$$

$$= \frac{100\left[nC - \sum_{i=1} t_i\right]}{nC} \quad \ldots \text{ if expressed as a percentage}$$

where n = Total number of work stations

C = Cycle time

t_i = Time for the ith elemental task.

Since the sequencing of operations is determined already, the only production planning and scheduling that can be done in assembly line production is: to fix a realistic production rate and arrange to achieve it with a minimum number of people on the line.

Basic Production Planning Problem

We can say that the production planning or scheduling problem in assembly line type of production is either of two types:

(i) Given a production rate (or cycle time), deciding on the grouping of elemental tasks to find out the number of work stations optimally required. Here the optimality refers to minimising the Balance Delay on the line.

(ii) Given the number of work stations, to find out the minimum cycle time (that is, the maximum production rate) possible.

Before we proceed to the methods of 'Balancing', it may be noted that the same elemental task should not be assigned to more than one work station. The work station should be formed in such a way so as not to disturb the technological and other sequencing requirements.

Let us first solve an Assembly Line Balancing problem visually.

Example The assembly line for a children's tricycle has the following work elements identified and the sequences indicated:

Work Element Nomenclature	*Description of the Work Element*	*Immediate Predecessor of the Work Element*	*Work Element Time (minutes)*
A	Drill and make adequate provisions		
	for the fixing of wheel on the handle bar	Nil	4
B	Drill and make adequate provisions for the		
	fixing of wheels on the skeleton of the cycle	Nil	4
C	Fix seat support system and other skeleton of the cycle frame	B	3
D	Fix handle-bar to the seat support system	A, C	2
E	Fix plastic seat	D	2
F	Fix plastic back-rest	D	3
G	Mount the front wheel	E, F	5
H	Mount the rear wheels	E, F	8
I	Install rubber mountings on the handle	G, H	1
J	Install bell on the handle	I	1

For the above, the precedence diagram (Fig. 33.4) is given.

The cycle time for this problem is 8 minutes, since this is the maximum amount of station-time.

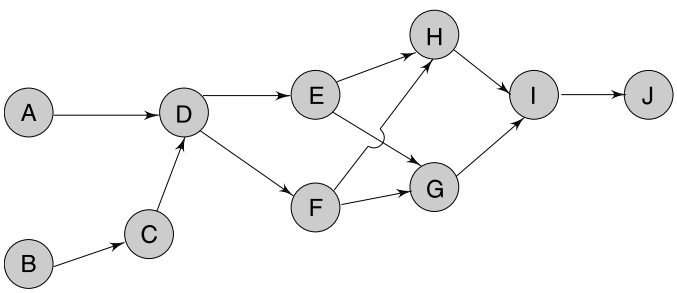


Figure 33.4 Precedence Diagram for the Tricycle Problem

If each elemental task is manned by one operator, then the Balance Delay

$$= \frac{100\left(10\times 8-34\right)}{10\times 8} = 57.5\%$$

Visual Grouping of Work Elements How can one group the work elements to reduce the Balance Delay, if the rate of production (8 minutes per tricycle) is to be the same? We have to check the Precedence Diagram visually. The following grouping is one possibility:

Work station 1: A and B : 8 minutes

Work station 2: C, D and F : 8 minutes
Work station, 3: E : 2 minutes
Work station 4: H : 8 minutes
Work station 5: G, I and J : 7 minutes

This gives a Balance Delay = $\frac{100(5\times 8-34)}{5\times 8}$ = 15%

We could have grouped the stations differently, as follows:

Work station 1: B and C : 7 minutes
Work station 2: A, D and E : 8 minutes
Work station 3: F and G : 8 minutes
Work station 4: H : 8 minutes
Work station 5: I and J : 2 minutes

Balance Delay in this grouping also is the same, that is 15%, because the number of work stations remains the same.

It does not seem to be possible in any way to reduce the number of work stations. Any one of the above groupings would produce equivalent results.

Although the above problem was simple enough to solve visually, more complex problems involving a large number of elemental tasks need methods other than visual. The Heuristic methods are of much use in Assembly Line Balancing. The analytical methods, due to extreme complexity of computation, are of little use.

Heuristic Method *Moodie and Young's method* The heuristic method suggested by Moodie and Young is illustrated below for the tricycle problem:

This method first constructs two matrices from the precedence diagram (Fig. 33.4) shown earlier. These matrices are:

1. *P*-matrix, which is the immediate precedence matrix; and
2. *F*-matrix, which is the immediate follower matrix.

In the example given earlier, these are constructed as given in Fig. 33.5. Work element numbers 1, 2, 3, …, 10 in this figure refer to the elements A, B, C, …, J in Fig. 33.4.

P-matrix				*F*-matrix			
Work Element No.	Immediately Preceding Element Nos.			Work Element No.	Immediately Following Element Nos.		
1	0	0	0	1	4	0	0
2	0	0	0	2	3	0	0
3	2	0	0	3	4	0	0
4	1	3	0	4	5	6	0
5	4	0	0	5	7	8	0
6	4	0	0	6	7	8	0
7	5	6	0	7	9	0	0
8	5	6	0	8	9	0	0
9	7	8	0	9	10	0	0
10	9	0	0	10	0	0	0

Figure 33.5 Initial *P*-and *F*-Matrices for the Tricycle Problem

The heuristic method goes as follows:

Step No. 1 Check the work element numbers of the rows having all zeros in the *P*-matrix. If there is only one such row, assign that work element to work-station No. 1. If there are multiple number of rows having all zeros, assign the largest element (largest in terms of element time) to the work-station.

Step No. 2 Go to the *F*-matrix and note the element numbers in that matrix against the earlier assigned element.

Step No. 3 Having noted the numbers in the *F*-matrix, go back to the *P*-matrix to the rows indicated by these element numbers. In these rows, replace the assigned element number with a zero.

Step No. 4 Continue to assign to the work-station by going back to steps 1, 2 and 3, with the constraint that the total station time should be equal to or less than the cycle time. Whenever this restriction is reached, start the 2nd work-station.

These are the only basic steps which are repeated again and again till the P-matrix has all zeros.

The solution to the tricycle problem has been given below:

Step No. 1 We note in Fig. 32.5 that work element Nos. 1 and 2 in the *P*-matrix have all zeros. The elements 1 and 2 both have equal times, that of 4 minutes. Therefore, we assign arbitrarily element No. 1 to the first work-station.

Step Nos. 2 and 3 Corresponding to element No. 1 in the *F*-matrix, the row reads as 4, 0, 0. Therefore, we go to *P*-matrix against element No. 4 and replace the element identification No. 1 in that row with a zero. Now row 4 in *P*-matrix reads as 0, 3, 0. Since the cycle time has been taken as 8 minutes earlier, more and more elements may be assigned to this station. Therefore, we go to Step No. 1 once again.

Step No. 1 Only one unassigned row with all zeros in the *P*-matrix is available—that corresponding to element No. 2. Therefore, assign this element to work-station No. 1. Before assigning this element, cheek that the total station time does not exceed cycle time. This condition is satisfactorily met—work element 1 and 2 for the first work-station totalling the station time of 8 minutes.

Step No. 2 We go to the *F*-matrix and read the row corresponding to the newly assigned element No. 2. The row reads 3, 0, 0.

Step No. 3 Therefore, we go to the *P*-matrix to read the row corresponding to element No. 3 and replace the 2 with a zero. Now the *P*-matrix row corresponding to element No. 3 reads 0, 0, 0. We go back to Step No. 1.

Step No. 1 Element No. 3 is the only element in the *P*-matrix which has all zeros in the row. Therefore, we assign this element to the 2nd work-station.

Step No. 2 Going to the *F*-matrix corresponding to element No. 3, we read the row as 4, 0, 0.

Step No. 3 Going to the *P*-matrix corresponding to element No. 4, we replace the assigned element 3 with a zero.

Now in the *P*-matrix, the 4th row reads as 0, 0, 0.

The procedure goes on in the fashion indicated above. Based on the heuristic, the assignment of elements to the work-stations will be as follows:

Work Station	Element No.	Element Time	Work Station Time
1	1 and	4	8
	2	4	
2	3	3	8
	4 and	2	
	6	3	
3	5	2	2
4	7	8	8
5	8	5	7
	9 and	1	
	10	1	

Thus, this solution gives 5 work stations: which is similar to what we got earlier visually. Note the identity of solutions obtained by this heuristic and by the visual method. Although the heuristic method seems like a tedious procedure, its advantage lies in solving large assembly line problems which may not be possible by a simple visual checkup. Moreover, the heuristic method can be programmed for use in a computer and the authors of this method have given a Fortran programme in IBM 7090.

Kilbridge and Wester Method The other heuristic method developed by Kilbridge and Wester is as follows:

1. The precedence diagram is constructed with the work elements being placed in different vertical columns. In this column I of the diagram comprises work elements which need not follow any elements. The work elements which are immediately following these are shown under column II. Those work elements immediately following the work elements in column II are shown in column III and so on. Construction of the precedence diagram, 'column-wise', is the first step in this heuristic method. Note that all the work elements are as far to the left of the diagram as they can be (provided there are only technological sequencing restrictions and no other fixed location and/or positional constraints).

The precedence diagram has been shown in Fig. 33.6.

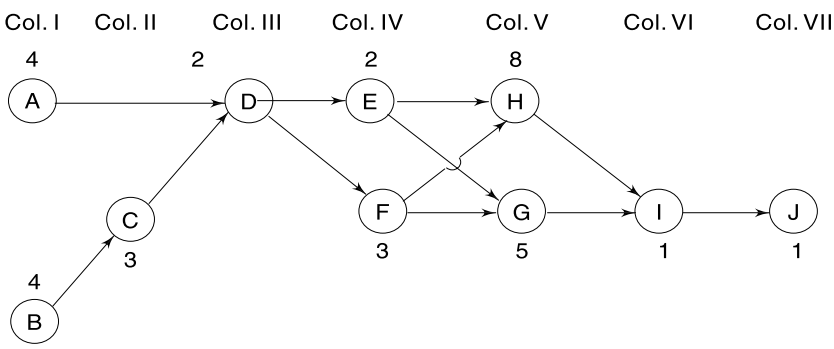


Figure 32.6 Precedence Diagram for the Tricycle Problem—Kilbridge and Wester Method

2. After this step, a table is constructed based on the precedence diagram, where (a) the column number of the precedence diagram, (b) the work elements comprising that column with, (c) their time of operation, and (d) remarks regarding the work elements 'moveability to the right' are indicated. Such a tabular representation corresponding to Fig. 33.6 is given in Fig. 33.7. It so happens that in this problem only element No. 1 can be moved to the right to the extent of the II column. The rest of the elements are not moveable. So the problem becomes simple. But, it will serve to illustrate this heuristic method.

The table constructed from the Precedence Diagram, for this heuristic, is given in Fig. 33.7.

Column Number of Precedence Diagram	Work Element Number	Remarks about Moveability	Work Element Time	Sum of Time	Cumulative Time
I	1	I → II	4		
	2		4	8	8
II	3		3	11	3
III	4		2	13	2
IV	5		2		
	6		3	18	5
V	7		8		
	8		5	31	13
VI	9		1	32	1
VII	10		1	33	1

Figure 33.7 Table for Fig. 33.6—Kilbridge and Wester Method

Having represented the precedence diagram in terms of the table given in Fig. 33.7 we group the work elements into a work-station: moving from column I-to-column II-to-column-III, and so on, taking care that the total station time does not exceed the cycle time. To balance the line, we can take advantage of the moveability of some of the work elements to the right hand side, so that if in the grouping of later work stations some gaps in the idle-time are to be filled, this could be done by moving the moveable work elements to the right hand side and assigning them to the desired work-stations. In our example, since only work element 1 is moveable, very little advantage exists. As per the heuristic method, we go down to column I and try to group as many elements as possible in the first work station with the restriction that the total work station time does not exceed the cycle time of 8 minutes. This is easily done by grouping elements 1 and 2. These add up to an ideal station-time of 8 minutes. This forms the station number 1.

Going down to columns II, III and IV, we group the work elements 3 and 4 to get the station-time of 5 minutes. There is still a gap of 3 minutes to be filled in this station. Therefore, we go to column IV. We can choose any element from this column; element 6 is the ideal choice making the total station-time of 8 minutes.

Now element 5 remains in column IV with a time of 2 minutes. We now move to the next column, i.e. column V and see that the elements 7 and 8 have, respectively, times of 8 and 5. Since column IV and column V are adjacent columns, we can combine element 5 and element 8 to get the station time of 7 minutes. Element 7 with a time of 8 minutes can form a station by itself. Now we are left with

elements 9 and 10 which are grouped into a work station with a total time of 2 minutes.

So the solution is:

Work station 1 : Elements 1 and 2, Station-time 8.
Work station 2 : Elements 3, 4 and 6, Station-time 8.
Work station 3 : Elements 5 and 8, Station-time 7.
Work station 4 : Element 7, Station-time 8.
Work station 5 : Elements 9 and 10, Station-time 2 minutes.

Other Methods for Assembly Line Balancing There are many other heuristic methods such as the Computer Method of Sequencing Operations for Assembly Lines (COMSOAL), as also other heuristics by Helgeson and Bernie, by Jackson, and by Bryton. It should be noted that none of the heuristic methods assures optimality; only a near-optimal or a feasible solution can be easily obtained by these methods. Salveson as well as Gomori and Dantzig have suggested the use of Linear and Integer Programming formulation for assembly line problems. But such a formulation makes the problem more complex and therefore, is not computationally possible. Inspite of the fact that assembly line has been a very common feature in the past many decades, a satisfactory analytical solution to get a purely optimal solution to the line balancing problem has not yet been found.

SOLVED PROBLEMS

1. Hyderabad Forgings (HF) does its annual production planning over four quarters. Its demand projections for the coming year are as follows.

Quarter	*Demand (tonnes)*
I	80
II	120
III	100
IV	90

HF's workforce can produce 70 tonnes of output per quarter. The workforce needs to be increased, but that is going to be a distant plan. Overtime can be used. Of course, the output rate during the overtime period is observed to be 25 per cent greater than that during the regular time. But there is a legal cap on the overtime limiting it to a maximum time of 20 per cent of the regular time in any quarter. Overtime costs 40 per cent more than the regular time production.

HF can subcontract to smaller company in nearby town of Medcherla at a premium of 50 per cent of the cost of the regular production. The regular time costs are Rs. 100,000 per tonne (does not include the cost of materials). Inventory carrying cost is Rs. 50,000 per tonne per year. As a management policy, no shortages are allowed.

Suggest an economical aggregate production plan for HF. Assume zero inventories of the product at the beginning of the plan year. What is the total production cost for this plan?

Answer

The aggregate production planning options are:

1. Regular time production
2. Overtime production in addition to regular production

3. Subcontracting in addition to regular production
4. Producing in regular time plus overtime and carrying the inventory to the next quarter.

Regular time production capacity per quarter is only 70 tonne. Since the demand in all four quarters exceeds 70 tonne and there is no starting inventory at the beginning of the year, it is clear that in each of the four quarters, in addition to the regular time production, other production options will also have to be exercised.

In order to prioritise these options, their respective per tonne costs of production are compared as follows.

- Regular time production cost: Rs. 100,000 per tonne
- Overtime production cost: 100,000 × (140/100) = Rs. 140,000 per tonne
- Subcontracting cost: 100,000 × (150/100) = Rs. 150,000 per tonne
- Cost of producing in overtime and carrying the inventory to the next quarter: 140,000 + (50,000 / 4) = Rs.152,500 per tonne

As is clear, the options are preferred in the same order as above.

There is no limit on the amount to subcontract. Therefore, the last option of carrying inventory to the next quarter, which is the most expensive option, will not be used.

The approach to the aggregate planning will be:

(i) Produce during regular time.

(ii) If this quantity is not adequate to meet the demand, produce the additional quantity in overtime.

However, the maximum overtime production possible in a quarter is 20 per cent of the regular production capacity = (0.20) × (70) × (1.25) = 17.5 tonne.

Hence, in any quarter the maximum that can be produced in regular-plus-overtime would be = 70 + 17.5 = 87.5 tonne.

(iii) If in any quarter the demand exceeds 87.5 tonne, the quantity over and above 87.5 tonne will have to be subcontracted.

The aggregate production plan can now be stated as given in the following table.

	Output (in tonne) obtained through			
	Regular	*Overtime*	*Subcontract*	*Total*
Quarter				
I	70	10	–	80
II	70	17.5	32.5	120
III	70	17.5	12.5	100
IV	70	17.5	2.5	90

The production costs for this aggregate production plan are as follows.

Quarter I: (70 × 100,000) + (10 × 140,000) = Rs. 84,00,000

Quarter II: (70 × 100,000) + (17.5 × 140,000) + (32.5 × 150,000) = Rs. 1,43,25,000

Quarter III: (70 × 100,000) + (17.5 × 140,000) + (12.5 × 150,000) = Rs. 1,13,25,000

Quarter IV: (70 × 100,000) + (17.5 × 140,000) + (2.5 × 150,000) = Rs. 98,25,000

Total production costs: Rs. 4,38,75,000

2. Silver Beach Hospital in Chennai is a medium-sized well-known hospital. Dr. Veronica Simon, the Chief Administrative Officer of the hospital is planning for capacity in the

intermediate range time-horizon of six months. The demand on the capacity of the hospital is measured in terms of number of bed-days available per month. For instance, if 20 beds are needed for 5 days, then the demand is for $20 \times 5 = 100$ bed-days. In order to add to the number of bed-days, more resources such as nurses, auxiliary midwife nurses (ANMs), ward boys, etc. would be needed. Silver Beach Hospital finds it relatively easy to hire the additional staff on a monthly basis. During any month, for every 100 bed-days or a fraction of it, one unit of staff is required. The wage bill for one unit of staff works out to Rs. 5,000 per month.

There are 35 beds in the hospital. These cannot be increased in the six-month time horizon, because that would require obtaining several licenses and permissions from the State and City health authorities.

Unlike in a manufacturing industry, the bed capacity cannot be stored. At best, the hospital can postpone the surgical and other cases to a future date when the beds are available. However, it is not possible in many cases (e.g. child-births) as it leads to effective loss to the hospital in terms of both present and future business. The cost of such backlog is estimated to be Rs. 350 per bed-day of backlog.

The only way the hospital can meet the increased demand is through hiring additional staff and laying them off when not required. The cost of recruiting and lay-off is significant at Rs. 10,000 and Rs. 15,000 per unit of staff, respectively.

Dr. Veronica Simon, the Chief Administrative Officer, estimates the demand in the future months to be as follows.

Month	*Demand (bed-days)*
January	500
February	900
March	1000
April	300
May	900
June	400

At the beginning of January, a staff strength of 5 units is available. By the end of the month of June, whatever may be the plans during the in-between months, the staff strength has to come back to 5 units.

Advise Dr. Simon about the aggregate operation plan for:

(a) Average level of staff strength and for

(b) Overall cost-effectiveness.

Calculate the total costs under the above two alternatives.

Answer

The total estimated demand for the hospital over the next 6 months is (500 + 900 + 1000 + 300 + 900 + 400 =) 4000 bed-days. The average demand is 4000 / 6 = 667 bed-days per month. Since each unit of staff can take care of 100 bed-days of work, the hospital would need 7 units of staff on an average per month.

(a) Plan of Operation with Average Level of Staff Strength

For an average level of staff strength, one may provide 7 units staff every month except for the first month (January). The following table shows the costs of recruitment, wages, lay-off and backlog under this aggregate plan of operation.

Month	*No. of Staff (Units)*	*Wages Cost (Rs.'000)*	*Recruitment Cost (Rs.'000)*	*Lay-off Cost (Rs.'000)*	*Work done (Bed-days)*	*Backlog (Bed-days)*	*Backlog Cost (Rs.' 000)*
Jan	5	5 × 5	–	–	500	–	–
Feb.	7	7 × 5	2 × 10	–	700	200	70
Mar.	7	7 × 5	–	–	700	500	175
Apr.	7	7 × 5	–	–	700	100	35
May	7	7 × 5	–	–	700	300	105
Jun.	7	7 × 5	–	2 × 15	700	–	–
	Total:	200	20	30	4000		385

Total relevant cost under this policy: (200 + 20 + 30 + 385) = Rs. 635,000.

Note: The layoff has taken place at the end of June and the cost has been taken into account.

(b) Cost-efficient Plan

It is given that the capacity can be changed only in steps of 100 bed-days. For every 100 bed-days of backlog, the cost is: 100 × 350 = Rs. 35,000. This is the minimum cost incurred in case of a backlog. If instead 1 extra unit of staff is provided, it incurs the cost of 1 unit of wages = Rs. 5,000. The cost of 1 unit of wages, 1 unit of recruitment and 1 unit of layoff totals (5000 + 10000 + 15000 =) Rs. 30,000. Therefore, for cost-efficiency, backlog should be avoided as far as possible.

The hospital has 35 beds and hence its maximum capacity in February with 28 days is 980 bed-days. Its capacity in months with 31 days is 31 × 35 = 1085 bed-days. In months with 30 days, it is 30 × 35 = 1050 bed-days maximum possible.

So, maximum possible capacity is not a limitation.

One may plan the operations in this hospital as follows.

Month	*No. of Staff (Units)*	*Wages Cost (Rs.'000)*	*Recruitment Cost (Rs.'000)*	*Lay-off Cost (Rs.'000)*	*Work done (Bed-days)*	*Backlog (Bed-days)*	*Backlog Cost (Rs.' 000)*
Jan	5	5 × 5	–	-	500	–	–
Feb.	9	9 × 5	4 × 10	-	900	–	–
Mar.	10	10 × 5	1 × 10	-	1000	–	–
Apr.	9	9 × 5	–	1 × 15	300	–	–
May	9	9 × 5	–	-	900	–	–
Jun.	5	5 × 5	–	4 × 15	400	–	–
	Total:	230	50	75	4000	–	

Total relevant cost under this plan: (230,000 + 50,000 + 75,000) = Rs. 355,000.

This cost is considerably lower than that for the earlier operation plan.

QUESTIONS FOR DISCUSSION

1. Why is an intermediate range production plan called an 'aggregate' production plan?
2. What are the merits and demerits of the Transportation Problem method of aggregate planning?
3. How do the aggregate planning methods of the Transportation Problem and Linear Programming compare?
4. What are the advantages of the HMMS model over the Linear Programming model?
5. The HMMS and other sophisticated models have not been very popular in practice. What may be the reasons?
6. What could be the application of Goal Programming in aggregate planning?
7. Do you see any limitations in the HMMS model in a multi-product situation?
8. How would forecast errors affect the Linear Decision Rules?
9. Explain the relationship between the materials management and production planning functions.
10. 'A control system should be stable and efficient.' Elaborate this statement in the light of Production Control suggested in this chapter.
11. What is the purpose of Assembly Line Balancing?
12. Assembly Line Balancing be used in service industry ? Give examples.
13. Sathya Industries has the following demand forecasted for the next 12 months.

Month	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Demand (units)	900	700	800	400	500	800	900	300	200	800	700	700

The firm can have the strategies of overtime, sub-contracting, and inventory in its aggregate planning of production.
Given the following details, develop an optimal production plan for the firm. (The demands of the customer are always met.)

(a) Regular-time production capacity (at a work force level of 24 persons) : 600 units per month, maximum
(b) Overtime production capacity : 100 units per month, maximum
(c) Beginning inventory : 50 units
(d) Desired inventory at the end of 12 months : 150 units
(e) Cost of regular production : Rs. 100 per unit
(f) Cost of overtime production : Rs. 160 per unit
(g) Cost of sub-contracting : Rs. 180 per unit
(h) Inventory Carrying Cost : Rs. 36 per unit per annum

14. If in Problem 13 hiring and layoff strategies are allowed, and if the relevant cost details are as follows, how would the production plan change?

Hiring cost per person = Rs. 500
Layoff cost per person = Rs. 400
No. of days in a month = 25

15. Super Power Batteries Limited's production plan is to produce 800 units per month for the first 3 months, 650 units per month for the next 3 months, 500 units per month for the third quarter, and 850 units for the last quarter. The actual demand observed is:

Month:	1	2	3	4	5	6
Demand: (units)	900	600	500	800	1000	900
Month:	7	8	9	10	11	12
Demand: (units)	700	700	600	500	500	700

What are the Production and Inventory levels in the various months for a control number $K = 0.25$ with a lead time of one month for production level changes?

16. The precedence relationship and the task-times for an assembly line are given below:

Task	*Immediate Predecessor*	*Time, (min.)*
a	–	3
b	a	4
c	–	7
d	c	4
e	d	7
f	e	10
g	e	7
h	–	2
i	b,f	9
j	h	9
k	i	7
l	g	8
m	j	4
n	m, k	10
o	l	6
p	k	2
q	o	8
r	p	5
s	q, n	3
t	r	7

u	s	4
v	t, u	3
w	v	9
x	w	1

(i) Balance the line for a production rate of 4 units per hour.

(ii) What number of work stations are required if the line is to be balanced for a production rate of 3 units per hour?

34 Scheduling

Detailed day-to-day planning of operations is called scheduling. It deals with questions such as:

(a) Which work centres will do which job?
(b) When should an operation/job be started? When should it end?
(c) On which equipment should it be done, and by whom?
(d) What is the sequence in which jobs/operations need to be handled in a facility or on an equipment?

'Day-to-day' implies a short time horizon and not the literal meaning, although scheduling is often done on a daily basis. As is obvious by now, while the long-range and intermediate plans are of much use at higher or middle organisational levels, scheduling is of immediate significance for the lower managerial and first-line supervisory positions. Needless to mention again, production scheduling operates within the framework of flexibilities of the aggregate intermediate range plan.

Continuous production systems such as the process plants or mass production systems such as assembly lines may not have much need for day-to-day planning because the operations are repetitive or continuous for several days together. Of course some of the activities that cannot be anticipated earlier and other minor deviations need to be planned and accommodated on a daily basis. The production levels, the necessary production facilities, inputs and manpower requirements have to be planned for a long stretch of time, as long as the production run. Techniques such as Line Balancing could be used for optimum utilisation of the resources.

In the project type of production system, Network Analysis helps is planning and controlling the component jobs. Everything can be planned much ahead of time. Even within an activity there may be need to subdivide and plan for the micro-activities. (But this has limited managerial significance.)

JOB-SHOP TYPE PRODUCTION

The job-shop type of production system is more concerned with day-to-day scheduling. There would be a variety of jobs. Each job has a variety of operations to be performed. The operations are not usually the kind that last for days; most of them are done within hours or fractions of hours.

The variety of jobs and operations generate a multiplicity of semi-finished items which may have to wait for further operations to be done on them. When hundreds or thousands of such variations in operations-or-materials are to be handled, a systematic detailed daily plan is called for. Scheduling involves basically:

(i) Assigning different jobs to different facilities.

(ii) Sequencing the jobs and the operations at a facility or on a machine, so as to achieve the production departments' objectives; and

(iii) Monitoring the achievement and accordingly revising the schedule or changing the priorities of jobs/operation so as to rectify the deviation (this is the 'control' action).

Item (i) above is called Shop Loading. If two or more facilities (or machines) are equally capable of performing the same job or set of jobs, and if the different facilities (a) take different times to complete the same job and (b) have different total production capacities, then the first problem that arises in scheduling is that of assigning jobs to facilities. Note that 'sequencing' of jobs or operations is only the next step, i.e. after the said assignment. This 'assignment' is called Shop Loading. If such a choice of equally capable work centres does not exist, then the shop-loading problem is only one of checking on available capacity. One needs then to concentrate on sequencing of jobs/operations on a facility/machine.

It must be clarified here that despite the manufacturing-oriented terminology, all these principles and techniques are equally applicable for scheduling the operations in the service industries.

Shop Loading Methods

Shop loading can be done using simple charts as depicted in Figs. 34.1 and 34.2.

Facility/Work Centre		1	2	3	4
Time available (capacity)		90	45	135	45
Job No:					
108	Hours Required	9	14	4	10
	Hours Available	1	31	131	35
117	Hours Required	11	9	19	7
	Hours Available	70	22	112	28
126	Hours Required	8	5	11	7
	Hours Available	62	17	101	21
135	Hours Required	4	3	5	5
	Hours Available	58	14	96	16
144	Hours Required	10	7	6	9
	Hours Available	48	7	90	7
153	Hours Required	2	2	5	2
	Hours Available	46	5	85	5
..		..	..	..	..
..		..	..	..	..

Figure 34.1 Shop Loading Register

One may even use simple charts for loading purposes, as shown in Fig. 34.2.

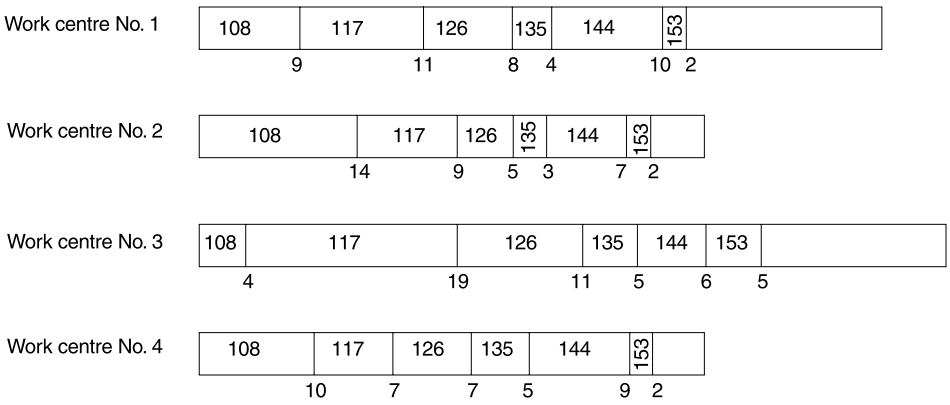


Figure 34.2 Shop Loading Chart

Strictly speaking, in cases such as mentioned in Figs. 34.1 and 34.2 where loading is of finite type, the loading problem needs to be solved simultaneously with the accompanying sequencing problem. However, when the same jobs (or operation) can be done by a number of work centres (although with different efficiencies), the problem is distinctly one of assigning the jobs to work centres based on appropriate criteria such as minimum cost or time.

Index Method

A heuristic method of loading, which would yield better results than the simple and intuitive methods shown in Figs. 34.1 and 34.2 is the Index Method. Supposing time is the criterion, 'indices' are calculated for the different process times (if done in different work centres) with the lowest process time having the base index of 1.0. The lowest index jobs are then assigned to the work centres, keeping in view the limitations of the capacities of the centres. The next lowest index

Job	Work Centre			
	1	2	3	4
	Days	Days	Days	Days
A	10	9	8	12
B	3	4	5	2
C	25	20	14	16
D	7	9	10	9
E	18	14	16	25
No. of days available	20	20	20	20

Figure 34.3 Shop Loading–Illustrative Problem

	Work Centre							
	1		2		3		4	
Job	Days	Index	Days	Index	Days	Index	Days	Index
A	10	1.25	9	1.13	8	1.00	12	1.5 0
B	3	1.50	4	2.00	5	2.50	2	1.0 0
C	25	1.78	20	1.42	14	1.00	16	1. 1 4
D	7	1.00	9	1.28	10	1.42	9	1.2 8
E	18	1.28	14	1.00	16	1.14	25	1.7 8
Days available	20		20		20		20	
Days assigned	7		14		8		18	

Assumption: Jobs cannot be split.

Figure 34.4 Solution by Index Method

jobs are then assigned to the work centres (without exceeding the constraints on capacities), and this process is repeated till all the jobs are assigned. This is a heuristic method and the solution obtained may not be optimal; however, it could be near optimal.The Index Method is illustrated by means of Fig. 34.3.

The illustrative problem given in Fig. 34.3 can be solved by the Index Method, as shown in Fig. 34.4. Jobs that are assigned are underlined. Note that in this example, time is the criterion.

In a different context, this method is useful when a worker can operate different machines and he can be so assigned.

Assignment Problem

The OR technique of Assignment Problem can be very useful in loading. The gist of this technique is given in a flow diagram (34.5).

Let us apply this algorithm to our earlier problem (Fig. 34.3)

(a) Matrix for the problem is drawn. The problem is one of minimisation (of time).

	Work Centre				
Job	1	2	3	4	(5)
A	10	9	8	12	0
B	3	4	5	2	0
C	25	20	14	16	0
D	7	9	10	9	0
E	18	14	16	25	0

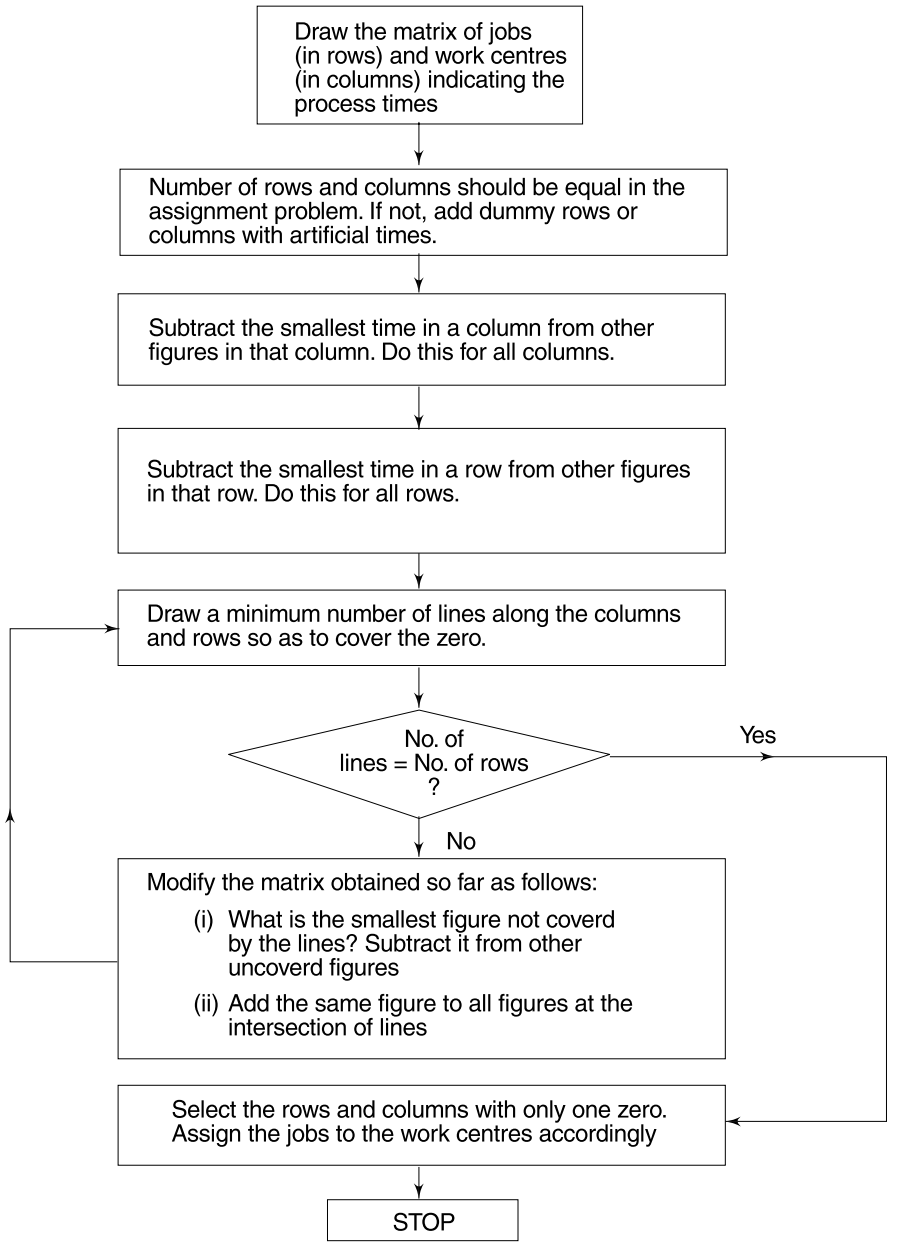


Figure 34.5 Assignment Problem : Flow Diagram of the Steps Involved

(b) Column subtraction gives:

	1	2	3	4	(5)
A	7	5	3	10	0
B	0	0	0	0	0
C	22	16	9	14	0
D	4	5	5	7	0
E	15	10	11	23	0

(c) Row subtraction gives the very same result as in the earlier step.

(d) Let us cover the zeros.

	1	2	3	4	(5)
A	7	5	3	10	0
B	–0–	–0–	–0–	–0–	–0–
C	22	16	9	14	0
D	4	5	5	7	0
E	15	10	11	23	0

(e) We need to modify the matrix. The smallest uncovered figure is 3. Subtracting it from all uncovered figures and adding it to the intersection point of the lines, we get:

	1	2	3	4	(5)
A	—4–	–2–	–0–	–7–	0
B	—0–	–0–	–0–	–0–	–3–
C	19	13	6	11	0
D	1	2	2	4	0
E	12	7	8	20	0

(f) Repeating the step outlined in (e) is necessary. According, we get

	1	2	3	4	5
A	—4–	–2–	–0–	–7–	1
B	—0–	–0–	–0–	–0–	–4–
C	18	12	5	10	0
D	0	1	1	3	0
E	11	6	7	19	0

and next

	1	2	3	4	5
A	5	2	0	7	2
B	1	0	0	0	5
C	18	11	4	9	0
D	0	0	0	2	0
E	11	5	6	18	0

This is further modified:

	1	2	3	4	5
A	3	0	0	5	2
B	1	0	2	0	7
C	16	9	4	7	0
D	0	0	2	2	2
E	9	3	6	16	0

Further modification yields:

	1	2	3	4	5
A	3	0	0	5	5
B	1	0	2	0	10
C	13	6	1	4	0
D	0	0	2	2	5
E	6	0	3	13	0

Now the number of lines are equal to the number of rows. So, the final assignment is:

C : Centre 5 (fictitious centre; hence, in effect, not assigned)
E : Centre 2
D : Centre 1
B : Centre 4
A : Centre 3

This result is not at all surprising since we could have obtained the same by a visual check of the time matrix.* The Assignment Problem corresponds one row member with one column. Thus

* Such visual checks do not usually give optimal results. With the number of rows and columns increasing, there will be greater difficulty in arriving at an optimal solution based only on visual inspection.

the dropping of one job is inevitable. The reader may consider the whether, why and how of the capacity constraints having/not having been taken into account.

SEQUENCING OR PRIORITISATION

While scheduling the job-shop type of operations system in addition to deciding which job should go to which work centre, it is also necessary to decide on the sequence in which the jobs are to be processed in any work centre. This relative prioritization determines the actual time schedule of the individual jobs. The priorities can be decided based upon one or a number of criteria. What these criteria can be, and their relative usefulness, shall be discussed in the coming pages.

How does any job priority rule influence the production output performance? Given a situation where there is one machine and a number of jobs waiting to be processed on that machine, the total time to process all the jobs is the same irrespective of the priority rule. However, if other characteristics of performance such as the average waiting time per job or average number of jobs waiting in line (and therefore the amount of work-in-process inventory) are relevant, then the priority rule does matter.

Now, imagine a set of jobs requiring the use of two machines, which are to be used one after the other. Depending upon the sequencing rule, even the total time for that set of jobs will vary. This is so because the jobs interfere with another; and while one job is being performed on a machine, the other job/jobs may have to wait. In an actual factory or any operations situation, a job involves a number of operations with the use of a number of machines. Therefore, the priority rules will have a significant effect on the shop performance. A job-shop can be thought of as a complex queueing system with probabilistic times, multiple channels, multiple servers, with different jobs requiring the use of different sets of servers. The priority rule or queue discipline has a very important role to play in a queueing system. In addition to being a complex queueing system, a job shop is a dynamic system where the relative urgency of the jobs is forever changing. This makes the situation even more complicated and less amenable to the use of analytical techniques of Queueing Theory for the scheduling of jobs and operations.

Simulation

Research has concentrated on the priority rules by simulating the production shop and determining the relative worth of the different rules. These shall be discussed in the latter part of this chapter. In addition to simulation, there are some optimisation methods available (such as Johnson's Rule), and also visual aids in the form of charts (such as the Gantt Chart).

The basic question to ask would be: Why do we need all these aids to find better ways of work flow planning and control? The reasons are:

There is pressure on completing the jobs by the promised due date to the customer (or as required by the customer) under the constraints of available machinery, manpower and materials capacity. The objective is to meet the demands with the least cost. If the cost was no problem and the machinery capacity was large, there would be no need to bother about sequencing. However, this is never the case and we need to achieve the best utilisation of machines and manpower, and keep as small work-in-process inventories as possible. The work-in-process is necessary to keep the utilisation of machinery and manpower at a high level. The relationship between this inventory and utilisation of manpower is shown in Fig. 34.6.

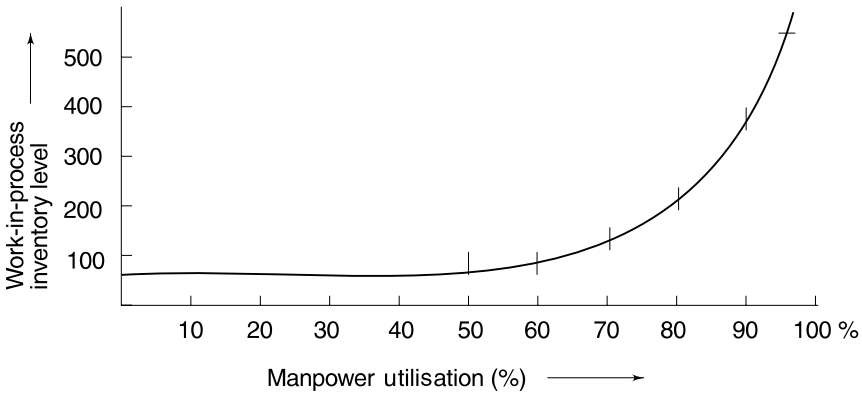


Figure 34.6 Relationship between In1ventory and Efficiency in a Conventional Job Shop*

Thus, if one cost component is lowered, the other cost component goes up. Therefore, a balance needs to be struck between them so as to have lowest total costs while meeting the market demands. And for this, the strategies available to us are that of assignment and sequencing of jobs in the shops.

Objectives of Sequencing

The objectives of appropriate sequencing are:

(a) Completing by the due date, or with as little delay as possible, as many work orders as possible.
(Note: This has three components: one is completing, another is on-time, and third is minimum delay which could be average delay or a range of delay.)

(b) Utilising the machinery and such other capital investment to the maximum extent possible.

(c) Utilising the manpower capacity to the maximum extent possible.

(d) Minimising the working capital investment in inventories of semi-processed materials.

The various approaches to scheduling and the resulting shop performance need to be measured against the above stated objectives.

Visual Aids

As stated earlier, one of the simplest approaches to scheduling is through the use of various visual aids, facilitating the planning of jobs through work centres and depicting the progress of jobs against what is planned. The earliest of such charts was developed by Henry L. Gantt during the early part of the twentieth century. This chart, called the Gantt chart (modified where necessary) is still a popular device. A Gantt Chart is shown in Fig. 34.7.

A Gantt Chart shows how each machine or work-centre is planned for work on different job orders—the scheduled start and finish times, the time reserved (or planned unavailability of the machine), the delays or production bottlenecks that have occurred and the time lost for that reason, the extent of actual completion of various jobs each day. This information could be very

* Source : J.L Colley, R. Lauded and R. Fair, Production *Operations Planning and Control*, Hidden-Day, 1977.

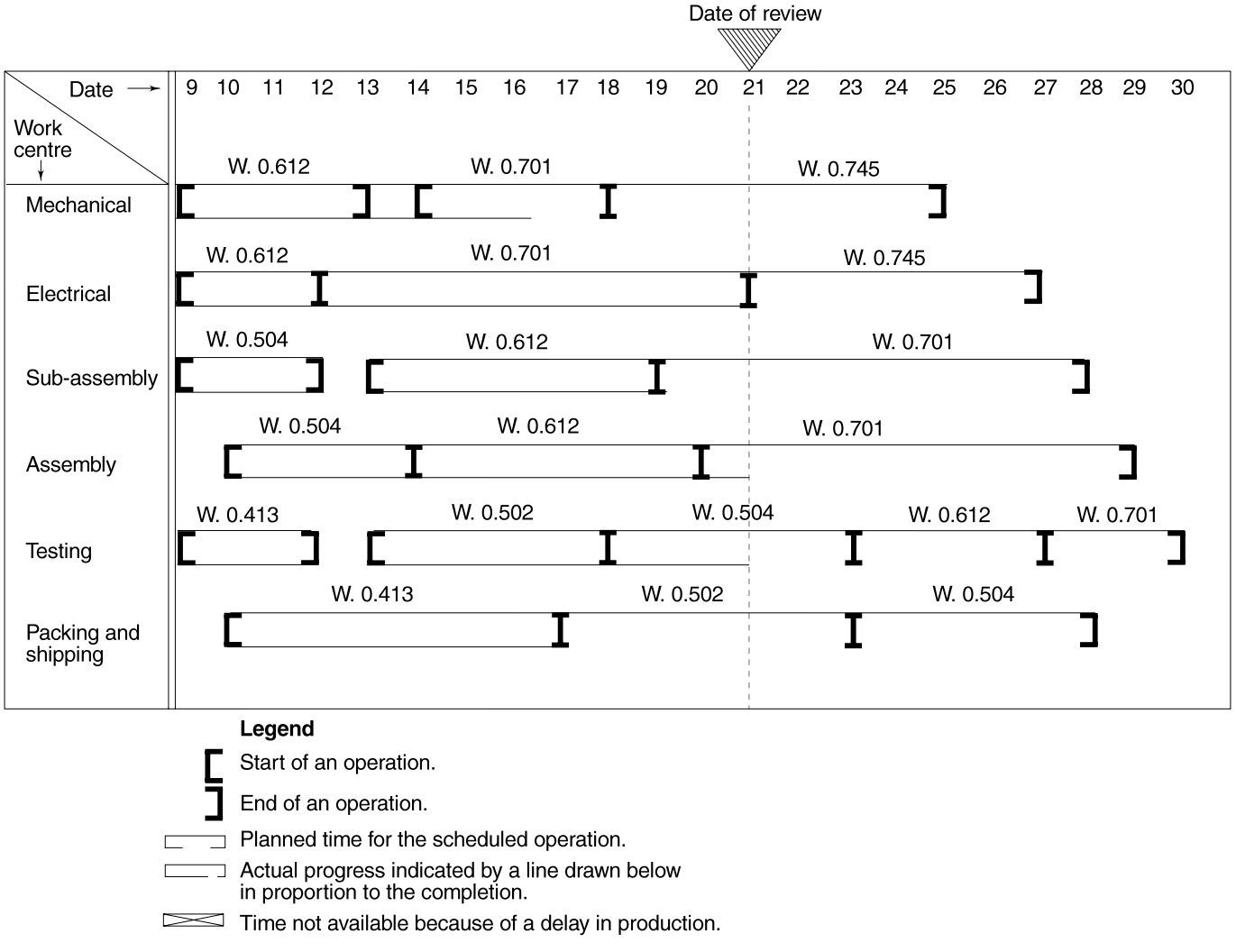


Figure 34.7 Gantt Chart for Scheduling and Progressing

useful for diagnosing the problems, if any, and taking appropriate rescheduling action wherever warranted.

Figure 34.7 showing a Gantt Chart indicates that there was a problem in the Mechanical work-centre earlier; at present, the work on the work order no. 701 has lagged behind by two days. Perhaps, the problems in the Mechanical centre have not yet been solved completely. While the Electrical centre has completed the job (Work Order No. 701) on schedule, the problem in the Mechanical Centre is probably affecting the work in the sub-assembly centre. The work on order no. 701 has lagged behind the schedule by one day. This has, in a chain reaction, affected the work in assembly by a delay of one day. The assembly centre is ready to start work on order no. 701. Testing activities are on schedule for other jobs—testing for order no. 701 is not yet done. The Shipping centre also has problems; it is lagging behind by four days.

The shipping senior supervisor feels that there are deliberate delays on the part of the workers in his department. Is this true? It needs to be investigated. If it is true, is it of any significance that the majority of the Mechanical and Shipping Centre workers belong to the same labour union? The problems identification process is thus helped by these scheduling and progress charts so that appropriate control action can be taken by the concerned managers.

Figure 34.8 shows a Sequencing Chart.

There are a number of versions of the Gantt Chart and other charts. Many 'Sched-U-Graphs' and similar large boards display the planned and actual status information in colours for better visual effect.

It may be noted that however big or small, on paper or on plastic boards, these charts are useful mainly for progressing and for taking corrective actions, i.e. for control purposes. However, schedule planning for optimal results is not possible with these simple charts. They cannot indicate the most suited priority structure (sequencing) or even optimal loading. Moreover, with the increasing complexity of products and therefore the number of machines, manpower and material inputs

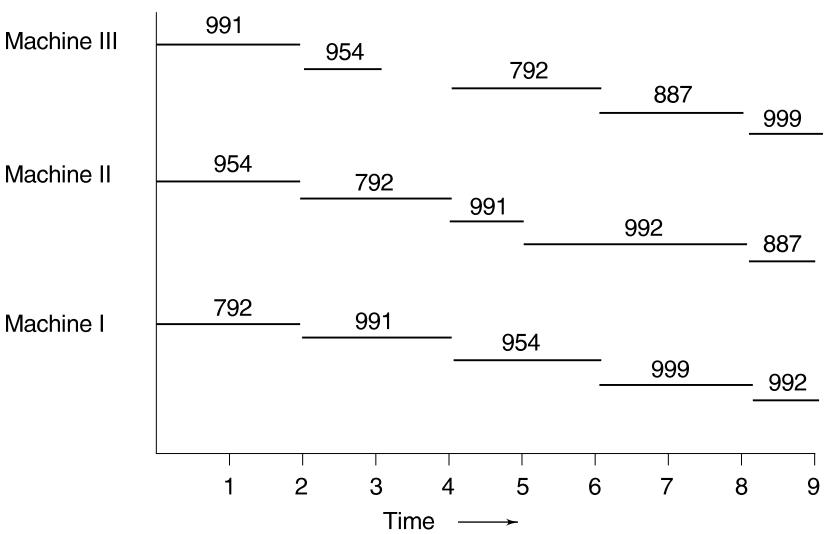


Figure 34.8 Sequencing Chart
Note: Numbers indicate jobs

that go in, the simplistic charting procedures are slowly becoming less and less relevant (even for schedule control purposes).

Johnson's Rule

S.M. Johnson* presented a sequencing rule for a situation where there were n jobs to be processed through two machines/work-centres. All the jobs followed the same sequence of the machines (and hence we may call the machines as M_1 and M_2). The rule resulted in minimum total completion time for the n jobs, by minimising the total idle-times of the machines. The n could be any number. The rule is rather simple. First, arrange the $2n$ job operations in the two machines, in the order of their processing times (shortest processing time first). If the shortest average processing time happens to belong to M_1 then this job is placed first. Had the shortest average processing time belonged to M_2, then the job would have been placed last in the sequencing list. Let us call the job J_1. Having thus assigned the job, we turn our attention to the next shortest average processing time. Again the same rule is applied and the job is placed either as early as possible immediately after J_1 (which has already been assigned), or immediately before J_1 (in case J_1 was sequenced to go last), depending upon whether this second least processing time belongs to M_1 or M_2. This process is continued till all jobs in the list are exhausted. It may be advisable to draw a time-scaled chart, showing the operations on the two machines, which brings out the idle-times of the machines succinctly.

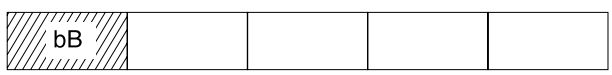
Example Maiden Charm (Un) Limited's beauty products, baby 'Blue', virgin 'White', shy 'Pink', daring 'Purple', and sensuous 'Black' go through two operations: Preparation and Finishing, at the respective two places and in that order. The operation times at these work-centres are given below:

	Preparation (hr)	*Finishing (hr)*
baby Blue	1	3
virgin White	4	2
shy Pink	5	4
daring Purple	2	5
sensuous Black	3	7

How should the above items be sequenced so that the total completion time is minimised?

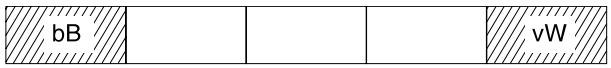
Let us apply Johnson's Rule for optimal sequencing.

Since the shortest time is for baby Blue (bB) and it occurs in preparation, it is placed at the start of the sequence.



Now, omit bB from the list. In the remaining, the shortest time, viz. 2 hr, is for virgin White (in finishing) and daring Purple (in Preparation). Such a tie can be broken arbitrarily. Let us choose virgin White. Since this shortest time occurs in the second operation (finishing), this items is placed at the end of the sequence.

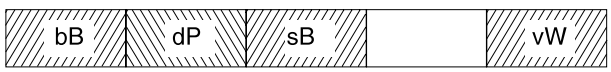
* S. M. Johnson, 'Optimal Two three-Stage Production Schedules with Set-up Time included', *Naval Research Quarterly*, Vol., No.1, 1954, pp. 61—68.



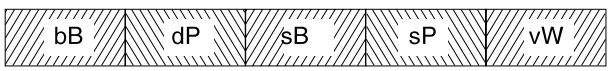
Remove vW from the list. In the remaining three, obviously daring Purple has the shortest time. Since this occurs in the first operation (preparation), it is placed as early as possible, that is immediately after baby Blue.



Remove daring Purple from the list. Out of the remaining two, sensuous Black has the shortest operation time of 3 hr occurring in the first operation (preparation). Hence it is placed as early as possible in the sequence.



The remaining one, shy Pink, is placed in the only place left in the sequence. We have the sequence giving the minimum total completion time:-



The final diagram (Fig. 34.9) shows both the operations and idle-times. (It has been assumed that the second operation should follow immediately after the first operation; there should not be any time in between).

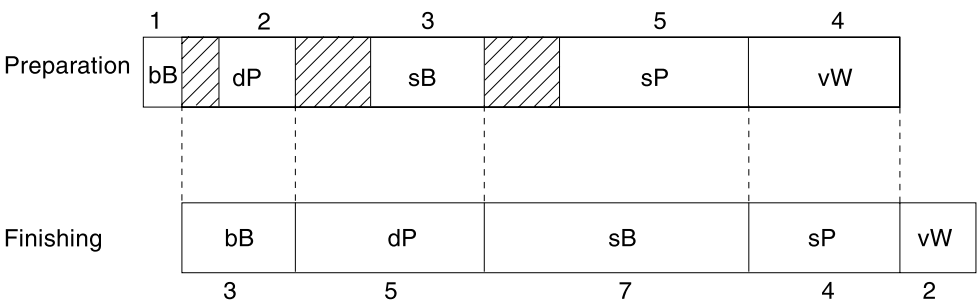


Figure 34.9 Example Applying Johnson's Rule

The total completion time for all the products is 22 hr. The total idle-time is 5 hours. The reader may try various other sequencing alternatives and check up that the application of Johnson's Rule has resulted in the minimisation of total completion time and of the total idletime.

Jackson* has extended Johnson's Rule to a situation where, there are n jobs and 2 machines, but

* J.R. Jackson, 'An Extension of Johnson's Results on Job-Lot Scheduling'. *Naval Research Logistics Quarterly*, Vol. 3, No3, 1956.

the jobs can have different processing orders $M_1 \rightarrow M_2$ or $M_2 \rightarrow M_1$ or just M_1 or just M_2. According to Jackson, the jobs will be divided into these four categories. The jobs in $M_1 \rightarrow M_2$ and $M_2 \rightarrow M_1$ categories are sequenced as per Johnson's Rule. Finally, the jobs are all put together as given below:

$M_1 : M_1 \rightarrow M_2$ jobs before jobs in M_1 category before $M_2 \rightarrow M_1$ jobs.
$M_2 : M_2 \rightarrow M_1$ jobs before jobs in M_2 category before $M_1 \rightarrow M_2$ jobs.
For jobs in just M_1 or just M_2 category, any arbitrary sequence is used.

Extension of Johnson's Rule to Three Work Centres Johnson's Rule can be used also for a situation of n jobs with three machines and a processing order requirement of $M_1 \rightarrow M_2 \rightarrow M_3$ for all the jobs, provided the following condition holds good:

Either Minimum of $t_{i_1} \geq$ Maximum of t_{i_2}

or Minimum of $t_{i_3} \geq$ Maximum of t_{i_2}

where t_{ij} is the operation time for job i in machine j.

If the above condition holds good, we can set up two new machines with operation times as follows:

$$t_{i\,\text{new1}} = t_{i_1} + t_{i_2}$$

$$t_{i\,\text{new2}} = t_{i_2} + t_{i_3}$$

For these 'new' machines, now Johnson's Rule is applied as usual.

Example Let us extend the earlier Beauty Products example. Suppose the 'preparation' operation is to be preceded by a 'pre-preparation' operation for all the five products. Let the times for the three operations be:

	Pre-preparation	*Preparation*	*Finishing*
baby Blue	7	1	3
virgin White	6	4	2
shy Pink	8	5	4
daring Purple	9	2	5
sensuous Black	10	3	7

We note that, in this example.

Minimum of $t_{i_1} = 6 \geq$ Maximum of $t_{i_2} = 5$

Therefore, Johnson's Rule can be applied.

The new fictitious work centres with their times are as follows:

	Work-Centre I Operation time (hr)	*Work-Centre 2 Operation time (hr)*
baby Blue	7 + 1 = 8	1 + 3 = 4
virgin White	6 + 4 = 10	4 + 2 = 6
shy Pink	8 + 5 = 13	5 + 4 = 9
daring Purple	9 + 2 = 11	2 + 5 = 7
sensuous Black	10 + 3 = 13	3 + 7 = 10

Applying Johnson's Rule we get the solution in the following steps:

(i) bB goes last in the sequence.
(ii) vW goes last-but-one in the sequence, i.e. just before bB.
(iii) dP goes just before vW.
(iv) sP goes just before dP.
(v) Obviously sB comes first in the sequence.

The optimal sequence is thus:

sB	sP	dP	vW	bB

The schematic diagram (showing idle-times) is shown in Fig. 34.10.

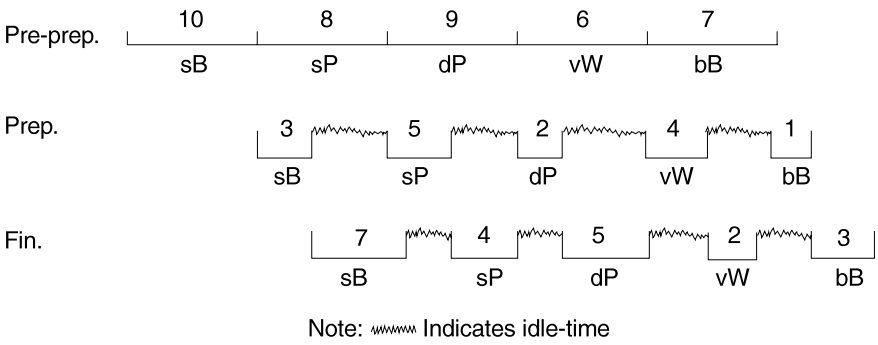


Figure 34.10 Application of Johnson's Rule to 3 Work Centres

The total time for all the five jobs is 44 hours. This is the minimum time in which all the five jobs go through the three operation/work centres.

It may be mentioned here that, in a significant proportion of cases where the said condition does not hold good the application of Johnson's Rule has still been found to produce optimal results. Moreover, even if such an application were not to produce optimal results, Johnson's Rule would still serve as a useful approximation or starting point.*

Despite the utility of such optimisation algorithms, their field of application is limited. In a situation where we have a number of work-centres and many more jobs to be processed through a maze of technological sequence and add to this, the uncertainty in product designs, routes, processes, operation times, etc. it is almost impossible to apply analytical techniques or optimisation algorithms based on mathematical analysis. As mentioned in the earlier pages, the job-shop can be thought of as a complex network of waiting lines, where the analytical formulae of Queueing theory do not find any use but the basic general concepts underlying the Waiting Line problem find utility in tackling the problem of scheduling.

Since the entire system is 'dynamic', in the sense that new unknown urgent jobs may enter, machines may breakdown, materials may arrive late and/or be of different quality, workers may be absent, etc., we require operational rules (thumb-rules) for dispatching, i.e. deciding which job should be taken up next, one job having been just completed on a machine. These rules are nothing but 'queue discipline' decisions for the shop.

* Cambell, Dudek and Smith (*Management Science*, June 1970) have applied and adapted Johnson's Rule to a multiwork centre situation to get near-optimal results.

Study of Dispatch Rules by Performing Simulation Runs

A number of queue disciplines (i.e. dispatch rules) were studied for their effectiveness, measured against a number of criteria or shop objectives, by performing 'simulation runs' at well-known companies' plants. These studies can be classified as:

(i) *Studies on machine-limited systems* (M-system): Where the queues occur only because the machines are not available. Whereas, the availability of an operator is no problem.

(ii) *Studies on labour-and-machine-limited systems* (LM System): Where the operator operates more than one machine. So, the queueing occurs on account of either the unavailability of the operator or of the machine or both.

It may be noted that the dispatch rules are to be weighed against various shop objectives. For instance, a rule that always assigns a machine with a job that has the minimum process time amongst the jobs that are waiting at the machine, will quickly clear a number of jobs but would continuously keep pushing the jobs with long operation times towards the end of the queue resulting in abnormal delays for the completion of such jobs. Which means, while the Mean of the distribution of job-completions is good, the Standard Deviation of the distribution of job-completions is in trouble (i.e. very large). Therefore, while using these rules in practice, one should look at the totality of the effect on the shop.

One of the important studies on dispatching rules in a machine-limited system (a study by *e*., LeGrande, conducted at Hughes Aircraft in El Segundo, California) is presented in Table 34.1. The Hughes fabrication shop had 1000 machines, 400–500 workers, 1800–2500 orders in process, and it completed 100–150 orders per day. The shop was simulated and the sequencing rules were evaluated.

Table 34.1 shows 6 rules and 10 criteria against which the performance was measured. (Although, as mentioned earlier, the objectives of sequencing are basically four:

1. Meeting due dates/minimising delays
2. Utilising machinery as much as possible
3. Utilising manpower as much as possible
4. Minimising working capital investment

The same can be expressed in many other ways to take care of various aspects of each of the basic criteria.

Table 34.1 LeGrande Study*

*Criteria**	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Total Relative*
Relative Weight	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*Rank*
Rule											
MINPRT	1.00	.83	1.00	.20	1.00	1.00	.76	.91	1.00	1.00	8.70
MINSOP	.87	1.00	.63	1.00	.73	.52	.96	.99	.92	.92	8.54
FCFS	.86	.54	.54	.20	.73	.38	.84	.98	.93	.93	6.93
MINSD	.84	.48	.46	.22	.68	.36	.91	1.00	.99	.91	6.77
MINDD	.94	.62	.64	.24	.84	.51	1.00	.91	.87	.87	7.52
RANDOM	.84	.68	.79	.20	.67	.66	.80	.93	.92	.91	7.40
*Criteria**	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*Total Relative*
Relative Weight	*2*	*5*	*5*	*5*	*1*	*1*	*4*	*2*	*3*	*2*	*Rank*
Rule											
MINPRT	2.00	4.15	5.00	1.00	1.00	1.00	3.04	1.82	3.00	2.00	24.01
MINSOP	1.74	5.00	3.15	5.00	.73	.52	3.84	1.98	2.76	1.84	26.56
FCFS	1.72	2.70	2.70	1.00	.73	.38	3.36	1.96	2.79	1.86	19.20
MINSD	1.68	2.40	2.30	1.10	.68	.36	3.64	2.00	2.73	1.82	18.71
MINDD	1.88	3.10	3.20	1.20	.84	.51	4.00	1.98	2.61	1.74	21.06
RANDOM	1.68	3.40	3.95	1.00	.67	.66	3.20	1.86	2.76	1.82	21.00

* Key to Criteria:

1. Number of orders completed
2. Per cent of orders completed late.
3. Mean of the distribution of completions
4. Standard deviation of the distribution of completions.
5. Average number of orders waiting in the shop.
6. Average wait time of orders.
7. Yearly cost of carrying orders in queue.
8. Ratio of inventory carrying cost while waiting to inventory cost while on machine.
9. Per cent of labour utilised.
10. Per cent of machine capacity utilised.

Key to the Dispatch Rules:

MINPRT Minimum processing time next operation.

MINSOP Minimum slack per operation—time until due date less total processing time remaining, divided by number of operations left.

FCFS First-come-first-served.

MINSD Order with earliest (minimum) planned start date in schedule of this work centre.

MINDD Order with earliest (minimum) planned due date in overall schedule.

RANDOM Orders randomly selected.

(The above table is taken from: R.I. Levin, C.P. McLaughlin, R.P. Lemone, and J.F. Kottas, *Production/Operations Management*, Tata McGraw-Hill Publishing Co., New Delhi, 1972.)

* E. Legrande,' 'The Development-of factory simulation System using Actual Operation Data,' *Management Technology*, Vol. III. No. 1, 1965

The relative performance of the rules under each criterion is expressed in figures 1.00 (for best performance) downwards. It may be noted that the table is presented in two parts: (i) with equal weightage for all the criteria, and (ii) with differential weightages for different criteria. The idea of differential weighting is quite appropriate in practice and one will have to evolve one's own criteria-and-weightage system. However, the criteria presented in the table are quite sufficient. Also, while looking at the results in the table, one should be cautious that if the size of the shop, type of the shop, and the jobs and the workload change then the results may also change to some extent. However, the results of LeGrande's study can be used to provide a general guidance.

Relative Performance of Various Dispatch Rules

According to the Study, the Minimum Process Time rule (MINPRT, also known as Shortest Operation Time rule or SOT) appears to do well in terms of efficient use of machinery and manpower, and completes a large number of jobs. However, it is the Minimum Slack per Operation rule (MINSOP) which appears to do best in reducing the delay in completion of jobs. This may be so because the MINPRT rule pushes the long operation time jobs way back in the queue all the time, resulting in some serious delays. It may also be seen that these two rules did significantly better than the rest of those given in the table. In fact, even a RANDOM sequencing rule performed better than many other rules.

Since MINPRT and MINSOP rules performed well and compensated each other in certain areas, some have suggested a combination of the two rules, or to put it more accurately, MINPRT rule with intermittent usage of MINSOP rule.*

Other modifications could be to have the MINPRT rule with a rider that there is a limit on the amount of time a job is allowed to wait. The rule is then truncated and the job that has been waiting longest is taken up next. This strategy discards the ill of MINPRT where the jobs with long processing times get inordinately delayed. But this is done at some cost to other criteria.

Minimum Critical Ratio Rule

Instead of MINSOP, another rule which has immediate intuitive appeal is the Minimum Critical Ratio rule, where,

$$\text{Critical Ratio} = \frac{\text{Time remaining for due date of the job}}{\text{Time needed to complete the job}}$$

To illustrate this rule: Suppose we have the following jobs at a work centre today; today's date is 9.

Job	*Due Date*	*Remaining Processing Time*	*Critical Ratio*
A	23	6	(23 – 9)/6 = 2.33
B	19	5	(19 – 9)/5 = 2.00
C	16	4	(16 – 9)/4 = 1.75
D	18	10	(18 – 9)/10 = 0.90
E	11	2	(11 – 9)/2 = 1.00

* R.W. Conway, W.L. Maxwell and L.W. Miller, *Theory of Scheduling*, Addison-Wesley, 1967.

Hence, job D needs to be sequenced first, followed next by E, then C, B, and A in that order. The critical ratio of less than 1.00 indicates that the job is behind schedule; more than 1.00 indicates that there is much slack time available; 1.00 indicates it is on schedule. The jobs with a ratio less than 1.00, need their processing times to be shortened, if feasible, so that their due dates can be met.

In the case of machine-,limited systems presented so far, another interesting study is by Nanot* who studied six different job-shop structures and ten different dispatching rules with over 2.44×10^6 orders processed.

Nelson's Study of Labour-and-Machine Limited System

In many situations, the machines may not be the only limiting factor and labour may also be equally unavailable. These systems are quite complex for analysis, as they involve a number of parameters such as the number of work centres, the number of machine operators, the efficiency of a labourer in a work-centre, labour assignment procedure, queue discipline at the work centre, etc. For such a labour-and-machine limited system Nelson** conducted simulation studies with

(i) machine queue disciplines (q) of First Come First Served (FCFS), First in System First Served (FISFS or FIFS), and Minimum Process Time (MINPRT or SOT);

(ii) labour assignment (to machine) procedures (1) of:

1= 0, random assignment of idle labour among machine centres with work in queue.

1 = 1, assignment of labour according to the labour-and-machine limited systems counterpart of the FCFS queue discipline for machine-limited systems.

1 = 2, assignment of labour according to the labour-and-machine limited systems counterpart of the FISFS queue disciplines for machine-limited systems.

1 = 3, assignment of labour according to the labour-and-machine limited systems counterpart of the MINPRT queue discipline for machine-limited systems.

1 = 4, assignment of labour to the machine centre with most jobs in queue, LNGQ.

Nelson's experimental model consisted of a pure job-shop with a statistical arrival process. There were 4 machines, and the number of operators were varied from 1 through 4. It had a completely centralised control wherein each operator on completing an operation was given his next assignment by the central control. The results of the experiment in terms of the mean time in system (f'), mean number in system (x'), variance of the time in system (S^2_f), and variance of the number in system (S^2_x) are given in Table 34.2, and are also presented diagrammatically in Fig. 34.11 (given only for the number of operators, 'n', equal to 3 and 4). The significant aspects of the results are that there is a similarity in the behaviour of the machine-, limited and the labour-and-machine limited systems regarding the ranking for effectiveness on the criteria of mean and variance of the time in system for the different queue disciplines. This has some practical implications.

Changes in the queue discipline produced larger changes as compared to the machine centre selection procedures. However, the latter were capable of improving the mean and variance simultaneously.

The LNGQ machine selection procedure was found most effective in conjunction with MINPRT or FISFS in reducing the mean or variance of the time in the system, respectively.

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* Y.R. Nanot, 'An Experimental Investigation and Comparative Evaluation of Priority', *Disciplines in Job-Shop Like Queueing Networks,* Ph.D. Dissertation, UCLA, 1963.

** R.T. Nelson, ' Labour and Machine Limited Production System's, *Management Science*, Vol. 13, No. 9, 1967.

Table 34.2 Nelson's Study—Labour-and-Machine-Limited Systems

Size of Labour	*Statistic* →		f', x'			S^2_f			S^2_x		
Force	*Q-Discip. q* →		*FCFS (1)*	*FIFS (2)*	*SOT (3)*	*FCFS (1)*	*FIFS (2)*	*SOT (3)*	*FCFS (1)*	*FIFS (2)*	*SOT (3)*
$n = 4$			17.7	17.7	9.4	488	295	612	201	205	24
		0	11.0	11.0	7.0	200	125	295	76	80	17
	M/c Centre	1	10.2			173	173		54		
$n = 3$	Selection /	2		10.5			102			63	
	Procedure	3			6.6			343			15
		4	10.1	10.1	6.4	169	97	281	50	53	11
$n = 2$		0	8.7	8.7	6.2	158	147	186	65	67	23
		1	8.7			153			49		
		2		8.7			147			67	
	" /	3			5.0			285			10
		4	8.7	8.8	5.1	154	89	293	46	48	9
$n = 1$		0	8.3	8.3	5.5	157	174	176	74	69	24
		1	8.3			149			48		
		2		8.3			174			69	
	" /	3			4.2			296			9
		4	8.3	8.3	4.4	150	174	298	45	69	8

The labour-and-machine-limited systems, since they consider both the limitations, have much practical relevance. However, these systems have a number of parameters and complexity, and have enough scope for further research in the area of scheduling.

Application of Priority Rules to Service Sectors

Many research studies have applied the concept of priority rules to various service sectors such as courts, hospitals, etc.

The applicability of the concept of dispatching or priority rule in the service sectors such as a Criminal Court has been illustrated by the study of Shapiro.* The delays in the hearing of cases in courts are ubiquitous. The cases are rescheduled a number of times and witnesses, lawyers and policemen have to spend a lot of their valuable time waiting. These things could be minimised by using a proper prioritising system (dispatching rule) in the hearing (scheduling) of cases in the court (work-centre). In Shapiro's system, the prioritisation was done based on certain factors such as the seriousness of the charge, whether the dependent was in or out of jail, and the time elapsed since the dependent was put on trial. The process times for the cases were computed by the use of

* Quoted in R.G. Schroder, Operations Management- 2nd Edition, McGraw-Hill, 1985. (S. Shapiro, An Acnomated Court Sched using system, presented at the 12th American Meeting of the Institute of Management Science, Detroit, Michigan, Sep. 1971)

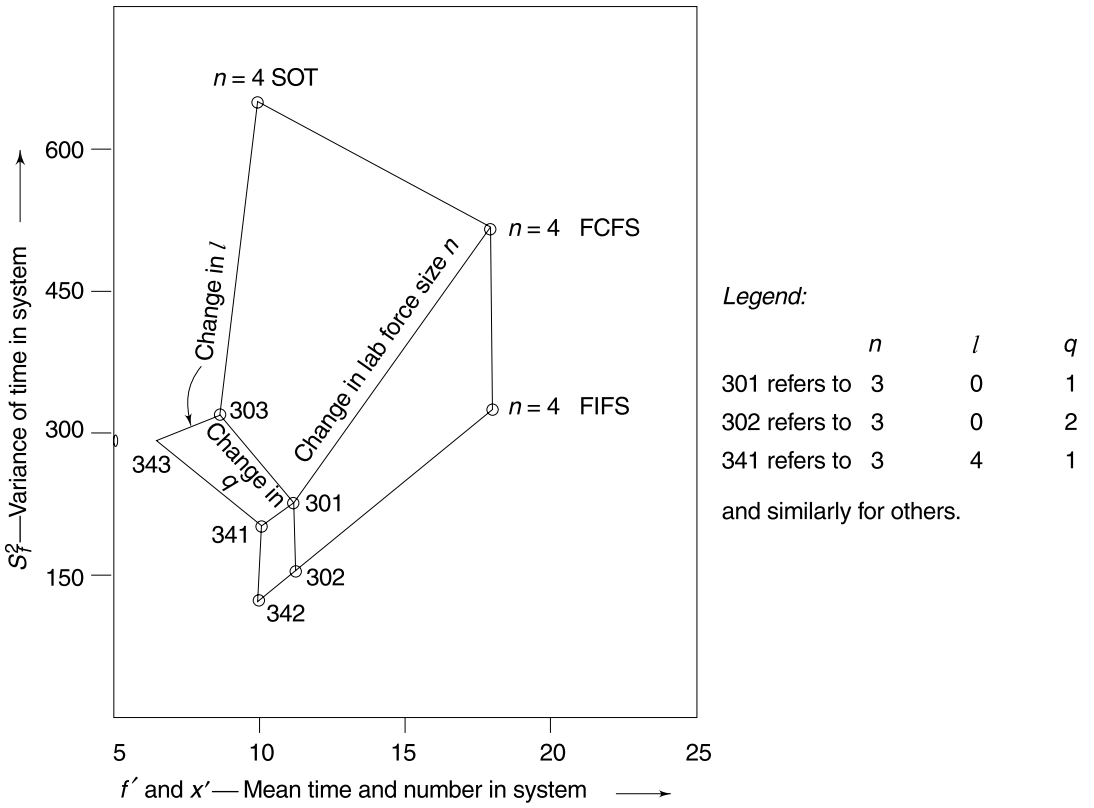


Figure 34.11 Nelson's Study—Labour-and-Machine Limited Systems

a regression model with a number of variables such as the seriousness of the offence, number of witnesses, the judge handling the case, etc. The system was dynamic and every day the priorities were recalculated.

Another study suggesting usage of the prioritisation principle in the service sector was by Shearon.*He studied the operation of a suite of operating rooms in a large general hospital. The results pointed out that Longest Operation First rule was more beneficial. This rule enabled the most variable operations to be completed first, because, the longer operations are generally more variable.

The point that was being made in the last few pages was that a rational selection of the prioritisation rule (or a set of rules) helps in a better achievement of the objectives of the operations system—whether it be a manufacturing shop or a system rendering only service.

USE OF COMPUTER FOR SCHEDULING

With the complex flow of a huge number of jobs through an equally huge number of machines, the modern day job-shop of a sizable company needs the help of a Real-time or Simulation system for efficient scheduling of the operations. The ultimate decision should be taken by the section

* W.T.Shearon Jr., A Study of Hospital Operating Suite Scheduling Procedures, M.S. Thesis, North Carolina State University, 1969.

supervisor on the shop floor who is aware of things that a computer cannot be aware of, such as the human factors which can make things work when they do not seem to and vice versa, and many other subtle aspects and infrequent possibilities. The scheduling time horizon could be every shift or daily or weekly or some other time in between, all of which depend upon the shop's characteristics such as order cycle time, average processing time, etc.

The availability of a computing machine has opened up avenues of quick digestion of a number of facts, their analysis, presentation of possible decision alternatives, future scenarios under different assumptions, etc. all in a very very short time so that our response to the situation is quick, appropriate and timely. Time is the essence, and we have reached a stage where we can handle the dynamic situation in the actual plant with an equally quick response in order to take advantage from the situation or to at least reduce losses.

SCHEDULING IN MASS, CONTINUOUS AND PROJECT TYPE PRODUCTION SYSTEMS

The scheduling aspects mentioned so far have been concerned with the job-shop (open and closed shop) type of production, in the main. It has been mentioned earlier that for a mass assembly line production (or continuous type), the planning problem, in both the time horizons—intermediate and short-term—is one of setting the rate of production from the line and arranging the various production centres on the line accordingly. Line Balancing would be helpful in equalising the output rates from the various work-points on the mass production line and in reducing the idle-time of labour. Unlike the job-order situation, here the production control activity does not consist of following up each particular job-order from one work centre to another; rather, it consists of maintaining an uninterrupted flow of the identical items as they go through the number of operations on the assembly/process line. It is like seeing that a stream of water flowing through a system of channels (converging into a major channel) does not get logged at any place. In a project type of production system, where one complex unit or item is to be produced involving a number of operations—many of them to be done one after the other in a sequence dictated by technology or limitations of resources, hence, the product developing its shape and getting value added as the time flows—the network analysis techniques such as PERT/CPM are quite useful in scheduling, monitoring and control of production. While in a continuous or line production the 'flow' is with respect to space, in the project type production the flow is with respect to time.

LINE OF BALANCE (LOB) TECHNIQUE

There is one variation of the project type production—a system where the project consists of producing a single batch of products where the delivery of the product is not at one point in time but is spread over many intervals of time according to a prior-agreed schedule between the manufacturer and the customer. For example, a batch of boilers, a batch of combat aircraft, a batch of computers to be delivered according to a schedule, are the type of situations which fall into this category. For the scheduling and control of it, a graphic technique called Line Of Balance (LOB) is quite useful.

As is obvious from the above discussion, for LOB the following information is needed:

(i) The contracted schedule of delivery.

(ii) The key operations, in the making of the product, which need to be controlled.

(iii) The sequence in which the key events (of start or completion of operations) are connected.

(iv) The expected/observed lead times of these events with respect to the completion of the final event, i.e. delivery of the finished product.

Based on the above, a diagram pictorially comparing the planned vs actual progress at each control point (i.e. key event) can be constructed for any particular review date. This diagram which looks like a 'line' with steps for the planned achievements, along with bars showing actual progress on the review date, is called the Line Of Balance diagram.

Example No-defects Electric Company has entered into contract with Never-fail Power Board for the supply of transformers, as shown in the table below.

Date	*Number of Units to be Delivered*	*Cumulative Number to be Delivered*
1st Jan.1987	2	2
1st Feb. 1987	2	4
1st Mar. 1987	3	7
1st Apr. 1987	4	11
1st May 1987	5	16
1st June 1987	5	21
1st July 1987	5	26
1st Aug. 1987	5	31
1st Sept. 1987	5	36

The schedule of delivery is expressed in the form of an 'objective chart' as shown in Fig. 34.12.

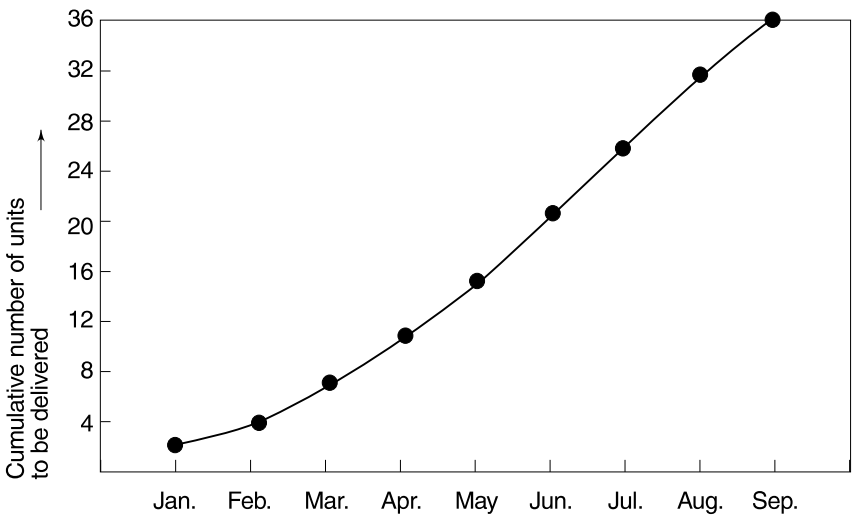


Figure 34.12 Objective Chart–LOB

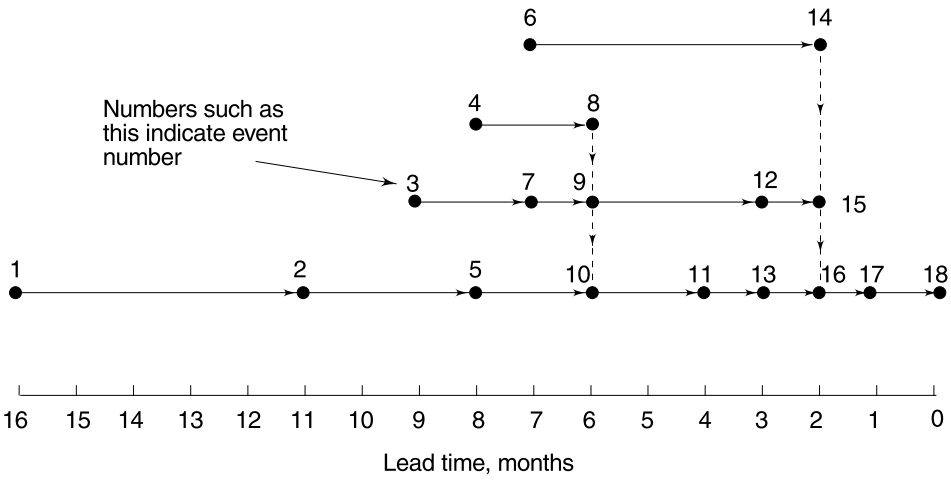


Figure 34.13 Precedence Diagram—LOB

The detailed flow of operations and the fabrication plan can be quite complex especially in terms of the number of details. However, the purpose of LOB is for progress control and accordingly suitable 'key' control points or events may be selected. It is also necessary to estimate the 'lead times' of these events with respect to the final delivery, i.e. how long before this final event should each other event take place? These times are the latest possible completion times of these various activities or, in other words, the late times for the occurrence of these events.

The various 'key' events are then linked in a precedence diagram (Fig. 34.13). In order to keep our example simple, let us have the key events and their lead times as given in Table 34.3 followed by Fig. 34.13.

Based on the Objective Chart and the Precedence Diagram, the progress is monitored at the various control points in terms of comparing, the extent of completion that *should have been*, to the observed *actual* extent of completion of the various key events on a *review date*. The 'should have been' extent of completion for the receipt of sub-contracted steel items (event number 8) on November 1, 1986 (review date) is computed as given in Fig. 34.14. Marking the lead time of 6

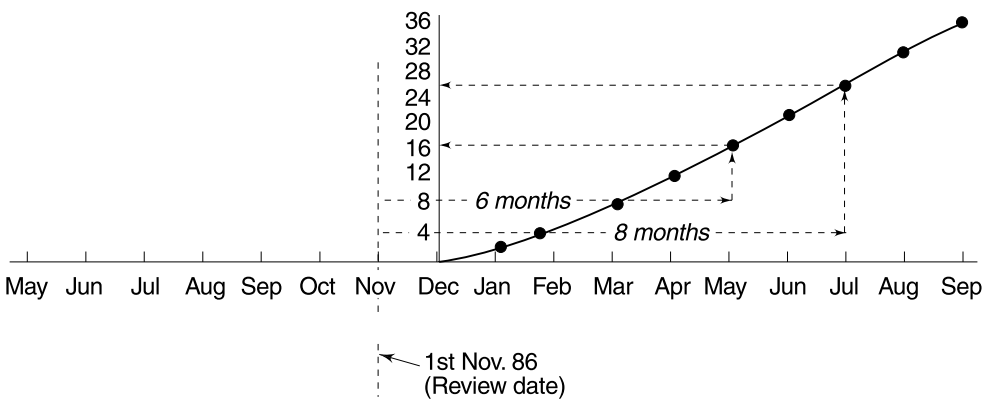


Figure 34.14 Computation to Determine the LOB

months (for event 8) from the review date onwards, we see that this event must be completed for 16 transformers. Similarly, for event 5, the raw materials for the manufacture of Cu-components should have been received, so far, for 26 transformers. From the bill of materials we can calculate what 26 transformer—equivalents mean. For all the control points, the 'should have been' extent

Table 34.3 Control Points—LOB

Event Number	*Key Event*	*Lead Time (months)*
	Design	
1	Begin design	16
2	Complete design	11
	Cu-Components	
2	Place orders for materials	11
5	Receive the materials and start the manufacturing Step-I	8
10	Complete mfrg Step-I and begin mfrg. Step-II	6
11	Complete mfrg Step-II and Begin mfrg Step-III	4
13	Complete mfrg Step-III and start testing	3
	Steel-Components	
3	Place orders for materials	9
7	Receive the materials and start mfrg Step-A	7
4	Initiate sub-contracting for items	8
8	Receive sub-contracted items	6
9	Complete mfrg Step-A and start mfrg Step-B	6
12	Complete mfrg Step-B, and start testing	3
15	Complete testing	2
	Auxiliaries	
6	Place orders on suppliers	7
14	Receipt from suppliers	2
	Final Assembly	
16	Start of final assembling	2
17	Completion of assembling and start testing	1
18	Start delivery of the final product	0

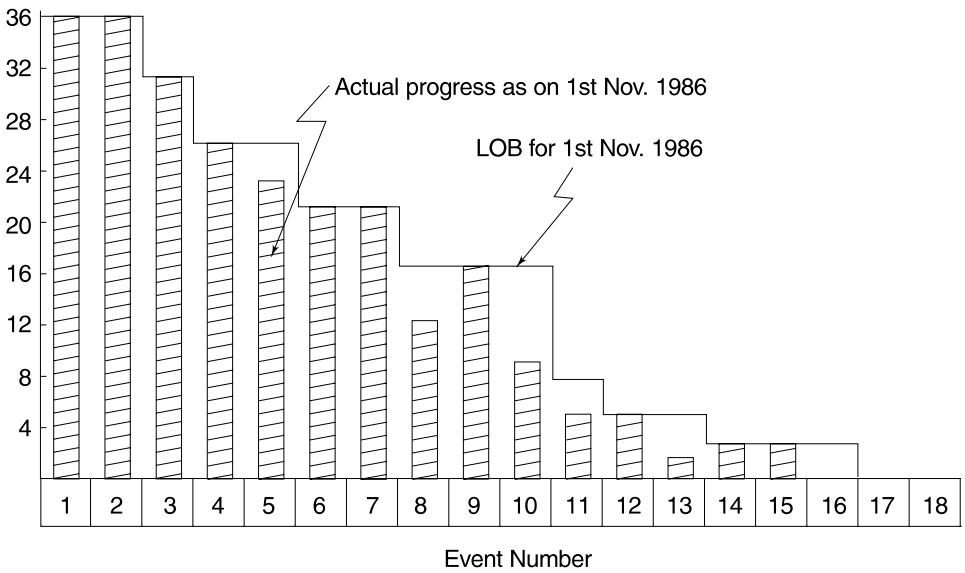


Figure 34.15 Line of Balance (LOB) and Progress Monitoring

can be calculated in a like manner on a particular review date. This information is presented in Fig. 34.15.

The comparison of 'should have been' and 'actual' provides valuable information. For instance, from Fig. 34.15 it is noticed that there are some serious problems in the purchasing area. Neither the Cu-raw materials nor the sub-contracted (bought out) steel items have been received by the company to the extent necessary. This has in turn handicapped the various manufacturing operations in the company. Actually, by now the final assembly work should have started, but it is at a stand-still. The purchase department seems to have sent all the purchase orders on time; so, why the delays from the suppliers?

Besides providing information as to whether the production is low or the inventories are high in certain key areas, the LOB also gives diagnostic information.

LOB helps the top or middle-level production manager/planner in identifying problems such as production bottlenecks, supplier-failures, excess inventories of raw materials and work-in-process, etc., and take appropriate control action. With more number of events or control points, it may be easier to focus on the problem area/s. The more detailed LOB, if used manually loses its value to the extent of the increase in the complexity. However, if the complexity is taken care of with the use of a computer,* the LOB technique of monitoring can be quite useful in the case of single batch production of an important product which is to be delivered in different numbers at different calendar dates as per an earlier established schedule.

SCHEDULING IN SERVICES

Time aspects are very important in services. In fact, punctuality or timeliness is one of the important attributes in services quality. When manufacturing started getting characteristics of service, a whole new paradigm and management technology of Just-in-Time production came into being.

* A case study using a microcomputer is presented in : A Hosmi and F. Guedifi Lob using a microcomputer' Industrial Engineering Aug., 1981.

Time Delays in Services are Difficult to Correct

In the manufacturing industry, any delay in the production of an item can be taken care of by holding an inventory of that item. If the production of an item is delayed, the same is supplied to the customer through the already held inventory. But, services cannot be inventoried. Hence, no such corrective action is possible. Services have to be done on a clockwork basis—the right things have to be done at the right time.

Presence of Customer in service Operations Makes it More Difficult to Manage Time

As mentioned in the chapter on supply chain management, a customer may also be a supplier of inputs. He himself may be the input. A customer is, thus, a customer, a supplier and an input. This makes matters much different for services as compared to manufacturing. Take for instance the case of a software solution provider to the overseas customer. It is expected that the overseas customer contacts the service provider as per the planned schedule and with the asked for data, failing which the entire work schedule of the service provider goes haywire with consequent ill effects on the service provider's efficiency.

Possible Actions for Managing Time

In scheduling services, what is a best schedule from the firm's perspective may not match up with with is the best schedule from the customer's perspective. This calls for an optimisation from the viewpoint of both the parties. This is called as 'bidirectional optimisation' i.e. doing best from two perspectives— the customer's and the service firm's.

Bidirectional Optimisation

For instance, in the case of a mobile service, a 'time window' is reserved for each customer. the customer is or will have to be available in that time window for the service worker to arrive and carry out the desired service. But, while the service provider would prefer a large time window, so that any uncertainties in service delivery times can be taken care of, the customer typically would like to hage a narrower window so that his time is not wasted waiting for the service. Therefore, a balance has to be struck between the interests of the customer and the service provider. This can be worked out with the use of mathematics, statistics, operations research techniques and simulation.

Creating Additional Capacity

Some of the problems of meeting desired time schedules can be solved by having additional service capacity. In the case of services, production capacity mainly refers to the manpower capacity i.e. the number of worker-hours that are available with the service facility. However, the firm cannot keep on adding and laying of manpower as per the fluctuating demand on the service facility. Hence, the service firms resort to one or more of the following actions.

Use impersonal Means of Services Provision

The fire can transfer some knowledge to the customer by impersonal means. For example, instead of an airline wasting its personnel's time in informing the customer about cancellation and baggage rules and regulations, it can put up the same information on its website and ask customers to access it.

Use of Technology

In some cases, technology can substitute for service manpower. An example is the coffee vending machines found in many cafeterias. Cutomer collects a token on making payment and then inserts the token in a slot of the machine and makes his choice of cappuccino, coffee with or without milk, coffee with or without sugar, etc. Indian Railways have ticketing machines in the suburban stations of Mumbai where the customer can press a button for the desired destination station and insert required money and get the ticket for the journey. In both of these cases, a machine substitutes the service manpower.

Enhancing the Skills of the Customer

A service person may be substituted by the customer himself. The customer voluntarily does the job earlier performed by the service person. Buffets where is self-service are an example. The point is in making the customer feel happy to render this part of the service to himself. He should see value in self-service. He should not grumble and do this job; it will not work for long.

The above example was about the part of a service that was quite simple for the customer to perform. Not all services or components of services are that simple. In such cases, the customer needs to be trained in performing certain service tasks. For example, teaching a patient or his attendant to change surgical dressing could save significant fraction of the nurses' time. Checking one's own temperature and blood pressure are other such labour saving method. But, the customer needs to be trained in these tasks that are not very simple.

Outsourcing and offshoring

A service firm may perform just those activities that are core to its business. Rest of the activities can be outsourced within the same country or abroad (offshoring). Outsourcing can free up considerable number/amount of manpower resources. Hence, with limited resources a service firm can meet the deadlines of its customers.

Minimising Idle Time of the Manpower

When the idle time of the service personnel is minimised, more productive capacity is available and hence the time deadliness are met more number of times. Keeping the services workers busy by proper allocation of work is the mantra.

Dynamic Scheduling

City taxies or Radio taxies in the metros of India are one such example. The central control office allocates the passenger requests to a taxi in its pool of taxies according to the availablity of the taxi and its proximity to the customer. The central control office keeps tracking the taxies and dispatching them as and when they become available. Different customers are thus allocated dynamically to different taxies. This dynamic allocation results in maximum utilisation of the taxies (and their respective drivers). It also results in a customers getting a taxi on time. Thus, both the customer and the taxi service firm benefit.

Training the Customer

Customer behaviour has considerable effect on the productivity of the service firm. A good customer can facilitate the delivery of the service. A bad one can cause delays. If a patient cooperates, a surgical operation has more chances of its completing it successfully and on time. A customer needs to know, before the services is performed, as to which behaviour leads to what kind of results. According to the need of the particular service, the customer should be trained as to what

is expected of him and as to how a different behaviour could have negative effects on the service generation and delivery system and on the service he himself is going to receive.

Incentives and Penalties

In order that the customer falls in line with the desired cooperative behaviour, the service delivery system should have incentives and penalties. It should reward a customer who has trained well and who has the appropriate behaviour towards the task. It may have penalties for any customer doing otherwise.

Social Pressure

Sometimes, for simple tasks that a customer does, the social pressure could be the reason. For instance in McDonald's or KFC, customers queue up and are already well prepared about what to select from a given choice of menu (which is displayed right in front view on the wall). The customer collects his own plate and carries it in search of a seat. He gets a glass of water, salt and ketchup, and napkins on his own. After enjoying the meal, he even clears the plate in an appinted receptacle. If a customer does not do so, he is thought of as an odd person by the other customers in that facility. There is hardly any 'waiter' service.

Thus, with minimal manpower resources, the time aspect is managed efficiently. Customer involvement in service production, which could otherwise have been an impediment, is cleverly used to receive services from him voluntarily. Customer does not ask McDonald's to change the way the meat is cooked or French fries are fried. The product design, the production process, the product packaging and offering are entirely decided by the company. The customer's presence in the service delivery only enhances the efficiency of the delivery system where the customer is a helpful participant.

ISSUES OF FLEXIBILITY IN PLANNING AND SCHEDULING

The purpose behind long range planning, aggregate planning and production scheduling is basically sound, viz., to take stock of the capacities available and match the same vis-a-vis the demands on the production facility. However, this planning process should not lead to rigidities. Long range plans are there to show the directions and not to rigidly fix unalterable boundaries for any action in the future. For, any action in the future would have to depend upon the customers' requirements at that point of time in the future. It is always good to know as to what capacities we have, what flexibilities are available and accordingly plan for the forecastable future demands on the organisation and on the facility. Towards this purpose, long range plans, aggregate plans and production scheduling do make some sense. However, these plans should not be thought of as frozen or as freezing the future options allowing only limited flexibilities for manoeuvring in the face of changing customer preferences and demands.

These days, the basis of competition in business is flexibility. Today's market demands that the needs should be met almost instantly. Even engineering goods like machine tools, diesel engines, motors, pumpsets are expected to be delivered, so to say, 'off the shelf'. The customers no longer expect any excuses about inflexibilities in the production/delivery system. Customer satisfaction is of paramount importance. Costs, although still important, take a back-seat. The customers need variety of products/services, and in time. The new business philosophy is to satisfy the customer 'just-in-time' at the time the customer desires the services. Timely satisfaction of demands, many a time varied demands, is now the basic minimum which the customers expect.

In such a situation to talk about making plans for the next five years or more and sticking to them exactly as planned and working out details of other planning horizons makes only a limited sense.

Whether the company is manufacturing products or it is a hospitality industry, the customers of both these organisations expect the very same thing, which is 'Service'. No physical product is viewed only in terms of its tangible benefits; it is seen in conjunction with the entire service package that comes with it. This is not to say that it includes only after-sales-service. Service is also being provided by the production or operations function. These functions should also be oriented towards providing service to the customer. Such intangibilities and uncertainties therefore, require flexibilities.

The challenge now and in the future is: How are we going to build long term flexibilities and responsiveness in design, engineering, production, manpower planning, etc.? How are we going to build such capabilities to respond to customers' needs? What are needed are the flexibilities of product mix, of volume, of specifications or quality requirements, of place and time utility. Towards this objective, the operations systems in the developed world are using Flexible Manufacturing Systems (FMS), Materials Requirement Planning systems (MRP), the Enterprise Resource Planning systems (ERP), the Just-In-Time system and several other novel ways to meet the customers' requirements.

For several decades, the Indian industry and business were insulated, cloistered in a shell without effective interaction with the outside world of business. The economic reforms process was initiated in 1991. However, the Indian industries are yet far from being customer-friendly and flexible to the level required. There has been progress, but there is yet a lot more to be attained. Whether the Indians like it or not, whether the Indian industrialists and businessmen would like to make their presence felt abroad or not is not the question. For, the world is not waiting. The multinationals with their products, services, new technologies and new management philosophies and perspectives have started arriving in India in large numbers. Even for making business within India, the Indian industry/business has to compete with these multinationals. Therefore, the Indian industry/business has to become world-class and adapt itself to the new situation rapidly. They have to change their long range plans, aggregate plans and even some of the production schedules in order to meet the rapidly and/or suddenly changing market conditions. The distinctions between long range, intermediate range and short range are getting blurred. The very concept of long range planning and aggregate planning is undergoing a rapid transformation. Plans are there to provide guidance and not to create rigid boundaries. Aggregate planning has to be made with these dynamic changes in mind. Planning has to be more and more concerned with assessing, balancing and building *capabilities*, which are different from capacities. It is no longer a one-way process in time from the long range to the intermediate to the short range. It is also being driven from satisfying the present to readying the capabilities for the future to unfold.

SOLVED PROBLEMS

1. Following jobs are at a foundry today. It is Jan. 10 (10th of January) today.
   Prioritise them according to:
   (a) MINPRT (also called SOT)
   (b) MINSOP
   (c) Critical Ratio

(d) MINDD
(e) LOT

Job Name	Time Required for the Present Operation (Days)	No of Operations Remaining including the Current	Total Remaining Processing Time (Days)	Due Date for Delivery
A	2	5	14	Jan. 30
B	1	2	5	Jan. 20
C	5	3	9	Jan. 19
D	4	5	11	Jan. 24
E	3	5	9	Jan. 29

Answer

(a) MINPRT or SOT rule puts the job with the current operation's shortest operation time first. The prioritisation according to this rule would be in the order: B, A, E, D and lastly C.

(b) MINSOP rule puts the job that has Minimum Slack per Operation (MINSOP) first, where : Slack per Operation = (Time until due date less total processing time remaining) divided by (the number of operations remaining)
For example: For Job A: Slack per Operation (SOP) = [(30 -10) – (14)] / (5) = 1.20
The SOPs for different jobs are calculated and the jobs prioritised in the following order:

Job	*SOP*	*Order or Rank for Scheduling*
C	[(19 -10) – (9)] / (3) = 0.00	1
D	[(24 -10) – (11)] / (5) = 0.60	2
A	[(30 -10) – (14)] / (5) = 1.20	3
E	[(29 -10) – (9)] / (5) = 2.00	5
B	[(20 -10) – (5)] / (2) = 2.50	4

(c) The job with the smallest Critical Ratio is scheduled first, where:
Critical Ratio of a job is the ratio of time remaining for due date for that job and the remaining processing time for that job.
For example: For Job A, the Critical Ratio = (30 -10) / (14) = 1.429
Similarly, the critical ratios for other jobs are calculated and the jobs prioritised as shown below.

Job	*Critical Ratio*	*Order or Rank for Scheduling*
C	(19 – 10) / (9) = 1.000	1
D	(24 –10) / (11) = 1.273	2
A	(30 –10) / (14) = 1.429	3
B	(20 –10) / (5) = 2.000	4
E	(29 –10) / (9) = 2.111	5

(d) MINDD or Minimum Due Date rule puts the job with the "earliest planned due date in the overall schedule" first.

The relative priority of the jobs is as follows.

Job	*Due Date in Overall Schedule*	*Order or Rank for Scheduling*
C	Jan. 19	1
B	Jan. 20	2
D	Jan. 24	3
E	Jan. 29	4
A	Jan. 30	5

(e) Longest Operation Time (LOT) rule puts the job with the "longest operation time for the current operation" first.

Thus, Job C has the longest operation time for the current curing process. Next would be Job D with a processing time of 4 for the current curing operation. The job sequencing or prioritisation is, therefore:

Job	*Operation Time for Current Process*	*Order or Rank for Scheduling*
C	5	1
D	4	2
E	3	3
A	2	4
B	1	5

Comment: It may be noted that once a certain job is underway in the work centre, the other jobs wait. With the passage of time, the critical ratios and SOPs of the jobs may change. The earlier calculated priorities may not hold good. Moreover, if and when new jobs arrive, the priorities will change. Thus, the prioritisation process is quite dynamic. Moreover, when rules like SOT push the jobs with long operation times to the end of the queue, a "truncation" may become necessary so that the accumulated jobs are pushed through the production system.

It merits mention here that the usage of dispatch or prioritisation rules as presented here, assumes that the set-up times and costs of various operations are *independent* of the processing sequence. Moreover, all these rules relate to a situation where machines are the only limiting factor and labour is not viewed as a factor in the queue discipline decision.

2. Metropolitan Magistrate's Court has the following cases to be handled today. Some of these cases have to be disposed of by 1:00 p.m., some by 3:00 p.m, while the others may be disposed of by 5:00 p.m, the day's closing time. The lunch recess is between 1:00 p.m. and 2:00 p.m. Knowing the nature of the cases, the court's administrator has an estimate of the time taken by each of the cases. He has to sequence these cases before the court starts. The court starts at 9:00 a.m.

Sequence the cases by (a) MINPRT rule and by (b) LOT (Longest Operation Time) rule. For these rules compute:

(i) Average time spent in court,
(ii) No. of cases completed later than specified, and
(iii) Average amount of delay per case.

The administrator has to decide on the sequencing before the court starts and once the cases are sequenced, there can be no change possible.

Case	*Time estimate (minutes)*	*Need to be disposed of by*
A	60	1:00 p.m.
B	30	5:00 p.m
C	90	5:00 p.m.
D	20	3:00 p.m
E	120	3:00 p.m
F	10	3:00 p.m
G	80	5:00 p.m

Answer

Consider the sequencing rules one at a time.

(a) MINPRT rule:

Case	*Time Required*	*Starts at*	*Ends at*	*Time from 9:00 a.m. (minutes)*	*Delay (minutes)*
F	10	9:00	9:10	10	0
D	20	9:10	9:30	30	0
B	30	9:30	10:00	60	0
A	60	10:00	11:00	120	0
G	80	11:00	12:20	200	0
C	90	12:20	2:50	350	0
E	120	2:50	4:50	470	110
				Total: 1240	110

(i) Average time spent in court = Total flow time for all cases / No. of cases
= 1240 / 7 = 177 minutes

(ii) No. of cases completed later than specified = 1

(iii) Average amount of delay per case = 110 / 7 = 15.7 minutes

(b) LOT rule:

Case	*Time Required (minutes)*	*Starts at*	*Ends at*	*Time from 9:00 a.m. (minutes)*	*Delay (minutes)*
E	120	9:00	11:00	120	0
C	90	11:00	12:30	210	0
G	80	12:30	2:50	350	0
A	60	2:50	3:50	410	170
B	30	3:50	4:20	440	0
D	20	4:20	4:40	460	100
F	10	4:40	4:50	470	110
				Total: 2460	380

(i) Average time spent in court = 2460 / 7 = 351.4 minutes
(ii) No. of cases completed later than specified = 3
(iii) Average amount of delay per case = 380/ 7 = 54.3 minutes

3. Pearlwhite & Co. Ltd. makes different brands of toothpastes among other products. In making the toothpastes, the company blends the required ingredients and then fills the blended paste into tubes. The following work-orders for the different brands have arrived at the plant where this blending and filling take place.

Brand of the Toothpaste	*Estimated Time* for Blending (minutes)	*Estimated Time* for Filling, (minutes)
Come-hither	20	10
Freshen-up	40	35
Good Morning	15	35
Puppy-love	50	20
Soul-mate	30	60

(a) Sequence these brands using Johnson's Rule. What is the time taken to produce all the above toothpastes? Assume that the blending and filling of different brands can be done smoothly one brand after the other with no break, if necessary.

(b) If the brands arrive at the plant in the same order as given in the table above, and if a First Come First Serve (FCFS) dispatch rule is to be observed, what is the time taken to produce all the above toothpastes? Compare the results of (a) and (b).

Answer

Step1: The shortest processing time is 10 minutes and occurs in the second operation (filling). Hence this brand (job), viz. Come-hither is placed last.

X X X X C

Step 2: Of the remaining four brands (jobs), Good Morning has the next lowest processing time, 15 minutes, and that happens for its first operation (blending). Hence, this brand is placed at the beginning.

G X X X C

Step 3: Now, three brands (jobs) remain to be sequenced. The lowest process time is for Puppy-love in the second operation (filling). Hence, this job is put at the end but earlier to Come-hither (which has already been sequenced). The sequencing done so far is shown below.

G X X P C

Step 4: Only two brands (jobs) remain for allocation in the sequencing order. Between the two, Soul-mate has the lowest process time in blending (first operation). Hence, it is placed after Good Morning as shown below.

G S X P C

Obviously, the Freshen-up brand is placed in the last remaining slot. Sequencing is now complete and looks as below.

G S F P C

In order to find the total time needed to complete all the jobs, the jobs and process times may be shown to scale.

15 25 40 50 20
GGG**SSSSS**FFFFFFFFPPPPPPPPPCCCC .....Blending
35 60 35 20 10
ggggggssssssssssssssf f f f f f f f f f p p p p c c c .....Filling

Note: *Figures above show process times (in minutes) for each brand. Diagram is drawn to approximate scale.*

The above diagram (graph) drawn to scale shows that the total time to complete all the jobs is 175 minutes (15+35+60+35+20+10=175 minutes).

(b) If the First Come First Served (FCFS) sequencing rule is followed, then the schedule drawn to scale would look as follows.

20 40 15 50 30
CCCC FFFFFFFFGGGPPPPPPPPPPSSSSSSSS . . ..Blending
10 (30) 35 35 20 (5) 60
ccc//////////////**ffffffffffffffff**ggggggggg**pppp**///sssssssssssssss ... ..Filling

Note: *Figures above show process times (in minutes) for each brand. Diagram is drawn to approximate scale.*

Idle times are shown in parenthesis and are depicted as hash /////.

From the above diagram (graph), it is seen that the total time for completing all jobs is 215 minutes (20+10+30+35+35+20+5+60=215 minutes).

The second operation (filling) is idle twice, for 30 and 5 minutes, waiting for the blended material to get ready for brands Freshen-up and Soul-mate respectively. FCFS rule has performed poorly compared to Johnson's rule.

QUESTIONS FOR DISCUSSION

1. Differentiating between Loading and Scheduling. In a clear-cut distinction between the two possible under all production situations? If so, where is it possible and where is it possibel ?
2. Discuss the use of the Gantt Chart for scheduling purposes.
3. What are the limitations of an Assignment Problem technique for loading purposes ?
4. Under what circumstances can Johnson's Rule be used ? How does it bring about optimatlity ? Can it ibe extended to a situation, say, with 5 processes and 10 machines ? (Quote research literature, if necessary.)
5. Would the LOB technique be more useful to the General Manager (Production) or to a Plant Superintendent ? Explain.
6. What are the scheduling problems in Line production ?
7. What are the scheduling problems in services?
8. In additions to Assembly Line Balancing, what additional ways can you think of for increasing the productivity of the production line ?
9. What are the merits of having a Job-order type system of production and of a Line production? How would you design a system which may get the good point of both? What might be the pre-conditions for such a novel system?
10. If there is a wide viration in the yields of different production operations in a production system, will you advocate the use of the LOB technique? (Assume that the situation is one of single batch production).

11. LOB uses the precedence diagram (with respect to time) similar to a PERT/CPM network. In what ways is LOB different from the PERT/CPM type of analysis ?

12. What is the use of having Dispatch Rules? Why has so much research been done on the various Dispatch Rules?

13. What is the lead time? George Plossl has said "Lead Time is what you say it is". Analyse this statement for its meaning and ramifications.

14. Discuss the problems in routing and scheduling, that might be faced by an airline such as Air India in its domestic operations. How would you go about helping Air India, as an Operations Planning expert?

15. Astrolonger Asha (AA), Palmist Pamela (PP) and Numerologist Nafisa (NN) have opened a 'Solace Centre'. There are the following solace seekers today. All 'seekers' shall be seen by all the three, i.e. AA, PP and NN. However, no more than the following shall be seen today. Knowing their problem, the 'solace givers' estimate their (advice) times. Advice them about the optimal sequence in which the seekers should be seen by the trio.

Solace seeker \ *Solace giver* →	*Estimated Time, (Minutes)* *AA*	*PP*	*NN*
Troubled Tommy	30	15	50
Worried Waman	25	20	35
Confused Cawasji	70	30	40
Jumbled Jamuna	15	10	40
Pained Panna	50	25	35

(In case you make any assumptions, mention and explain them.)

16. An MBA student has taken a number of courses this term. As usual, each professor has given a 'term paper' to write and submit. The due dates and the a mount of work remaining to be done on each paper are mentioned as follows:

	Term-paper on	*Date to be Submitted*	*Estimated Work Remaining*
a.	Seminar on Operations Mgt (SOM)	Dec. 19	14 days
b.	Advanced Finance (AFIN)	Dec. 10	3 days
c.	Marketing-II (MKT-II)	Dec.5	10 days
d.	Marketing Research (MR)	Nov. 30	7 days
e.	Safety & Maintenance (SAM)	Dec. 3	9 days

If today is 25th November, help the student schedule by the Critical Ratio method. Can you schedule by MINSOP?

If the professors have different modes of penalising the late submission of papers, as given below, suggest a priority schedule. Explain your answer.

Term Paper	*Negative Points per day*
SOM	5
AFIN	10
MKT II	2
MR	2
SAM	4

17. Five professors of the MBA program have given assignments to be ready in a day. Five over loaded MBA students sit down together. The time requirement, in hours, for each of the students for any assignment is given below. In addition, the time each of the students goes to bed (must) is also indicated.

Student	*Assgnment*					*Must go to Bed at*
	I	*II*	*III*	*IV*	*V*	
Wily Waman	2	5	1.5	3	5	10 pm
Tricky Theresa	4	2	3	1	4	11 pm
Bhola Babloo	1	3	4	2	1.5	9 pm
Don't matter Damle	1.5	2.5	3.5	3	3	10 pm
No-good Nagarajan	5	4	3.5	2	4	12 midnight
It is now 7 p.m.						

Assuming that they have read and followed this chapter, who would do which assignment? Will they be able to do all the assignments?



35 Project Management—I

WHAT IS A PROJECT?

Minor repair work in a plant facility or building a dam and irrigation network are both projects. Any work that has a well defined objective or goal to the sequence of the multitudinous activities required to be performed can be defined as a project. An IT software development contract with a definite objective is also called a 'project'. In short, a project has an end. Technically speaking, the 'end' is termed as the 'sink'. The various starting points of the project are called the *sources*. A project can have a number of sources, but only one sink.

The technical definition aside, the management of projects on a scientific basis is gaining continuous acceptance in India. It has received Government approval since the last two decades or so, when the Planning Commission stipulated that a sanction for any project costing over Rs. 20 crore, should be accompanied by a scientific project network and other analysis.

ELEMENTS

Project management is a scientific way of planning, implementing, monitoring and controlling the various aspects of a project such as time, money, materials, manpower and other resources. The objective of such an exercise is to achieve the basic objectives or goals set forth while formulating a project. Project management, in fact, comprises various elements such as (i) identification of the project, (ii) technical and financial appraisal of the project, (iii) economic or socio-economic appraisal of the project when necessary, (iv) proper formulation of the project, (v) plan for implementation of the project, (vi) actual implementation of the project, (vii) monitoring the implementation to see that the project has not deviated considerably from the predefined targets and budgeted resources and time, (viii) control action/rectification action for the deviations, and (ix) evaluation either at the end of the project or few years after the completion of the project to gain hindsight as to what went right or wrong vis-a-vis the pre-defined objectives of the project and what lessons can be learnt so as to transmit the same knowledge to other similar or related projects to be executed in future.

PROJECT MANAGEMENT IN INDIA

Project management as a science seems to have evolved around the Second World War and got much importance due to the various nuclear, aerospace, and other defence programmes of the United States in the 1950s and 1960s. The principles underlying project management have been utilized also by industry and by various public systems in the developed countries. Project management in India started gaining momentum around the mid 1960s. It is yet to gain full-fledged acceptance by industry, and more so by our public systems.

Although we are approaching the year 2000, still many project feasibilities in large private industries and in public systems are done without the necessary attention to the basics, and lacking in adequate rigour and attention to details. A feasibility study gone wrong is a perennial source of problems for the project during its implementation and its operation. There may be delays in completion and cost over runs. There may be problems in scales and operating revenues, break-even volumes, actually available capacities and profits before tax. Other problems could be concerning continuation of the availability of raw materials, appropriate quality of manpower, proper strategic alliances, proper technology transfer, and adaptation and absorption. In public systems, the proposed benefits of the project may not reach the intended people.

ELEMENTS OF FEASIBILITY ANALYSIS

The first step of project management is project identification and appraisal which is also often called project feasibility analysis. This comprises the following elements:

1. Generation of project ideas
2. Screening of the generated ideas
3. Detailed evaluation of the screened project ideas.

Generation of Project Ideas

This first step, besides providing an inventory of ideas, also facilitates the basic structuring process, so that only the 'right' projects enter into further detailed analysis. The generation of project ideas can come only through the objectives which need to be achieved by the authorities planning the investment in the project. The basic structuring process is provided by the "objectives" of the nation or a region or an organisation. Unless a clarity of the objectives (either long-run or short-run) is achieved, the crucial project ideas may not be considered. The resources available are limited whether it is a small organisation, or a region or a nation. Therefore, a thorough exercise right in the beginning of the generation of project ideas is absolutely essential, if the limited resources are to be properly utilized. A project is generally a heavy-investment and long-term proposition unless it happens to be a short-term project such as a maintenance project. For instance, a nation has to be clear whether it wants to invest in heavy industry which will yield fruits only after a very long term, or whether it wants to invest heavily in short-term yielding and labour-intensive projects in agricultural or rural development. Even in agriculture, one may think of either a major irrigation or minor irrigation projects in terms of their relative emphasis. The overall and specific objectives of the national or regional or organisational policy drive the ideas-generating machine.

A company has to ask, for instance, 'What kind of business am I in', because the company cannot have a number of businesses due to limitation of monetary resources. A proper target-market orientation or market-segmentation probably needs to be done in a broad manner right in the

beginning of the exercise of project management. The public works projects may be the result of two broad categories of policy objectives: (1) socio-economic policy objectives; (2) internal and external security policy objectives. The former objective of socio-economic policy could be brought about by: (i) providing extension of markets and achieving higher level of utilisation of resources, and (ii) by increasing factor and product mobility. The second objective of improving internal and external security can be brought about by the Public Works Department by providing extended facilities for the mobility of security resources. Such objectives need to be concretely spelt out and the priorities amongst the objectives should be established; otherwise the idea generation may be an exercise in the wilderness.

During the idea-generation stage, the ideas arising within the objectives need to be tempered or filtered simultaneously by the constraints present for the nation or the region or the organisation. The constraints are of the following types:

1. Constraints of physical resources,
2. Constraints of human resources and organisational (structural/cultural) constraints, and
3. Constraints of financial resources.

The various project ideas must lie within the limits defined by the constraints. The effect of this is to limit the number of ideas to a feasible minimum.

Screening

The process of generating ideas should, so far, have been carried out without any inhibitions and preconceived notions, excepting the guiding and creative influence of objectives and constraints. This process should, by now, provide the analyst with enough ideas to work on.

Not all project ideas need to be analyzed in detail, though. At a point of time, for a particular region, society, nation, or for an organisation certain things are of higher priority than others. For instance, in the border areas of our country, the priority is for security against external aggression. Development of the economy of the region would be of second priority. Of course, much depends upon the particular time, the internal and external political affairs of the region or state, or the environment in which the organisation or company may be working, etc. But it should be understood that the measures of priorities, however, crude, will provide the analyst with a means to find out clearly which project idea needs to be primarily considered and which should only be of secondary or tertiary interest. These primary projects provide us with a shorter list of project-ideas that need to be evaluated further in much detail.

Another screening which needs to be applied to this short-list is the detailed analysis of the existing facilities thus eliminating project ideas which would essentially be duplications of the existing ones. In this analysis the following criterion may be applied.

The criterion is that of effective capacity, which is weighing various elements of the existing facilities to determine how adequately the priority objectives are being met. A new project should be considered to the extent the existing facilities fall short of the demand for the particular priority objective. The criterion of effective capacity can be easily understood for the public systems projects. For commercial organisations these may need to be supplemented by a thorough study of the market. Three questions are important:

1. How big is the market?
2. How much is it likely to grow?
3. How much of it can the project accommodate?

For new projects, one may study the import statistics, the existing indigenous production, the end-use for which the product or the derived products might be put, the demand for related or substitute products, the market competition, the demographic and economic factors, etc. The possibilities of expanding the market by improvement in the quality of the product, or by generating cost economies through the use of cheaper raw materials, cheaper labour; or the cost advantages due to particular location should be borne in mind while answering these market-oriented questions. Such analysis of the market will eliminate or screen some of the projects from further detailed final considerations.

After the screening, the analyst is left with ideas conforming to priority objectives which are not currently met and which fall within the limits of constraints. This shortlist now needs to be analysed in detail.

DETAILED EVALUATION

This essentially involves the following steps:

1. Analysis of technical feasibility
2. Measurement of cost
3. Measurement of benefits
4. Comparison of the benefits and costs

Technical Feasibility

Technical feasibility is a broad-level exercise, to start with, to determine what kind of technology would be needed for the different earlier screened project-ideas. The questions could be for example: Is there enough water to construct a dam and a power station? What is the rainfall in the catchment area? What kind of terrain is it? Therefore, what kind of dam could be constructed? Is it technically possible to construct a dam and a power station in that region? What seepage is expected in irrigation-canals? If it is a road-building project, then one may investigate: What is the topography of the region? Are there floods in that region (washing out or blocking the road periodically)? etc. Therefore, is it technically feasible to construct such a road? Such analysis should be done with the help of engineers or scientists in the field who have the competence and up-to-date knowledge to assess the technology available. If a project is found to involve such technical requirements which may not be indigenously available or may be available at only a very high premium from foreign countries, it can be avoided keeping in view the objectives and priorities of the nation, region or organisation. Speaking of Government projects or national or regional level projects, one may be justified in experimenting with new technology or very high priced imported technology, but, such justification may not be there for projects of the profit-oriented private industry. The private industry may avoid experimental or obsolescent projects. New process or machinery, although apparently quite well tested under laboratory or pilot-plant conditions, may not produce the desired results under commercial mass production conditions. Commercial criteria and governmental or public systems criteria may often be quite different.

Capital and Operating Costs

After having done a preliminary technical feasibility survey, one may proceed with the measurement of costs, benefits and their comparison for different projects.

To a private organisation, costs include capital as well as operating expenses. The costs may be that of land, housing, machinery, raw material, fuel, power, labour, water, transportation, etc. These different aspects of costs need to be investigated not only for one but several alternate locations, including cost on delivery of imported items. It should be remembered that the costs include not only equipment and other fixed costs, input materials and labour, but also transportation and other aspects. Therefore, a plant or site location problem is inevitably connected with a cost feasibility or financial feasibility analysis.

While investigating the proposed plant sites, the estimates of the total production costs in several alternative output sizes should be calculated. Sometimes, there may be a conflict between the plant size needed for meeting the economic demand and the size needed to obtain the optimum cost of production. In such cases a size which would be somewhat larger than the existing market can justify, and somewhat smaller than that required for lower cost production is recommended. This financial feasibility phase of investigation involves a considerable amount of field work but the extent of such an analysis should not exceed 1 to 2% of the total possible project cost.

While costing commercial projects, an allowance may be made for unforeseen cost at the rate of 10 to 20% of the total project cost.

The working capital requirements may also be estimated on the basis of the volume of production expected and the estimated production cost, the length of time cycle from the moment the raw material enters the plant till the customer pays for the goods, the payments for the supplies and labour which must be made during this span of time, etc.

The benefits for the private organisations are the sales revenues which could be estimated after the estimation of sales volume based on production capability, product quality, size of the market, amount of competition in the market, product price and many other internal and external environmental factors. It should also be noted that the full capacity can be achieved over a period of time, and also that the market can be created only slowly.Therefore, the slow growth of production capacity as well as that of the market capacity should be taken into account while calculating either the revenues or costs.

Especially for the private organisations, it is imperative that in addition to the cost-benefit analysis, a rigorous cash-flow analysis is done for the short-term and long-term future. Because, many a time the profitability may be good but the timings of the cash outflows and inflows and their magnitudes may not match.

SOCIAL COST-BENEFIT ANALYSIS

For public system projects, particularly involving projects with social objectives and Government projects, the market is the society at large. For instance, for railway projects, the market comprises passengers and the freight transport users. Therefore, the considerations of market could be quite different from that of private organisations. In addition, not all costs or benefits can be measured only in financial terms, they should be viewed in terms of the disadvantages and advantages to the society over a long range of time. Such an analysis which keeps in view the larger interest of the society is termed as Social Cost-Benefit Analysis and is an integral part of any public systems project formulation procedure.

For Social Cost-Benefit Analysis the costs expressed at market prices need many adjustments to reflect the real cost. The taxes, fees, cess, duties, etc. on various commodities have to be excluded from the costs. The market price may not reflect the opportunity costs of labour due to various

wage laws. The real costs of unskilled labour may be less than the market wages, and those of the skilled labour may be more than that of the market wages. If the labour employed on a project has no *other* employment possibility, then the cost of the labour in social terms may be zero. Only those costs need to be considered where the scarce resources are being weaned away from other areas of the economy or other projects. The cost of environmental damage should also figure in the social cost-benefit analysis. Extraction of either iron ore or the mining of coal might seem to be lucrative financial projects; but some of them might do irreparable damage to the environment and therefore to the society as a whole. In many countries due to such considerations, the strip-mining of coal has been totally abandoned. USA is one such example. The foreign-exchange component cannot be costed by the pegged value of the exchange rate. It may need to be costed at a higher rate which reflects the true conditions in the foreign exchange market.

As seen above, the costs related to the society are complex and therefore social cost-benefits analysis needs to be done with much care. An example of a social cost-benefit analysis is presented in the Appendix to this chapter.

Similar to the measurement of cost, the measurement of benefit is fraught with a number of difficulties while dealing with social cost-benefit analysis. There are direct benefits as well as indirect benefits and many of them cannot easily be expressed in monetary terms as they are non-marketable public goods and have no price equivalence. For instance, the major benefits of a public-works highway project are: (1) greater mobility for people and goods thus leading to economic development, (2) benefits of fast, cheaper, comfortable and reliable transport facility with fewer expenses and less damage to goods.

The major benefits (for the above public works highway project), which are direct, can be calculated in terms of increase in income due to: (a) increase in movement of various commodities, (b) increase in passenger traffic. In case of the 'new road, it may be calculated with the following equation: $Y = x\ L\ e$,

where Y = Income
x = Average number of vehicles per annum both ways
L = Length of new roads
e = Average earnings per vehicle kilometre

The income for goods and passengers can be estimated separately as the values of x and e are likely to be different in each case. The indirect benefits such as the comforts, convenience, reliability, etc. cannot be well expressed monetarily and are therefore quite often excluded from the analysis.

Conceptual Problems and Difficulties

The conceptual problems and difficulties in doing a social cost-benefit analysis can be summarized:

1. Some benefits and costs are not measurable in monetary terms.
2. When it is a situation of multiple projects, which is true in the case of many governmental or public systems, it is difficult to apportion or allocate the expected benefits amongst the different projects.
   This is so because the exact component of the expected benefits may not be directly attributable to each individual project. The benefit expected may be as a result of the intergrated developmental projects. For example, we all know that rural development is the result of various projects such as major irrigation, minor irrigation, providing infrastructure

facilities, credit facilities, provision of fertilizers and seeds, development of rural industries, and the integration of a host of other such developmental projects to get the desired beneficial effect. In such cases, the location of the developmental benefits to any one of the projects is definitely a difficult exercise.

3. Public systems projects, which are development-oriented projects, may alter the income distribution of the people who make use of these projects. This redistribution of income may alter the price structure significantly from what it was at the time of the initial project feasibility analysis. This would therefore pose questions regarding the validity of the project feasibility analysis.
4. We have seen in Chapter 6 that a particular discount rate of interest is assumed in the calculations. This assumed rate of interest of the comparison of costs and benefits, is actually an assumption regarding the public's time preference rate of interest: which means that it is the rate of interest to be charged for the future flow of benefits which will come as a result of the sacrifice of current consumption by the consumers (i.e. public). This expression of time-preference also raises questions regarding the entire cost-benefit comparison and feasibility analysis.

Inspite of such difficulties of applying the cost-benefit principles to public systems projects, the objective of such analysis is sound. In the absence of such analysis, we shall only be disregarding the effect of various public projects on the people for whom it is primarily meant. Moreover, for many public projects for instance, road building, there is little or no financial return to be gained. In such cases, there is no alternative but to resort to social cost-benefit analysis since financial analysis is either out of the question or not of much help.

The cost-benefit information can be used to rank the technically feasible projects and thus select projects optimally. The analysis may be Financial Feasibility Analysis and/or Social Cost-Benefit Analysis. The principles of capital budgeting and the choice of projects under limited availability of funds have already been discussed in Chapter 6.

Projects which look financially feasible, may need to be looked at more rigorously through Technical Feasibility Analysis. The idea is to screen the project initially with a broad technical and financial analysis. Those that are obviously not very good ideas may thus be rejected and rigorous analysis of technical and financial or economic feasibility can be applied to the remaining project-ideas.

PROJECT FORMULATION

Although project formulation and appraisal process was mentioned in a stepwise or sequential fashion, it should be emphasised that there is much feedback or to and-fro interaction in the entire project formulation process. The processes of considering financial, manpower, organisational or other resource constraints, the process of technical feasibility and the processes of the financial, and socio-economic feasibility all have various feedbacks. There are various grey areas within all these considerations and there are many flexibilities within the constraints and therefore the entire project formulation and appraisal process is a multi-round exercise where all the relevant aspects of checking the feasibility and relative comparison of the projects are taken care of.

Network Analysis

Although a few ranked projects can now be selected, the feasibility analysis cannot be complete unless we apply the Network Techniques. What may emerge after a network analysis, may be different from the earlier result. A technically and financially feasible project may encounter constraints of time; network techniques may clearly bring out certain errors of omission in the earlier analysis.

Network Analysis and Implementation Planning

Once a project has been selected, we move over to implementation planning for the same. This planning involves the time plan of the project (what work needs to be done and when?) the cost plan of the project (how much money needs to be spent and when?), the plan for the materials requirement for the project (what materials are required and when?), the manpower plan for the project and plans for various other resources. In this planning process Network Analysis techniques are used. PERT (Programme Evaluation and Review Technique) and CPM (Critical Path Method) are two such techniques.

As with many management science techniques, the network analysis techniques originated with the Second World War. These techniques are part of Operations Research which were first utilised in the American Polaris Missiles Project. PERT was the first of the network analysis techniques. Over the years, network techniques have gained much acceptance in civilian projects all over the world.

Comparison of Bar Charts and Network Techniques

Network techniques are in essence a modification of the age-old Bar Chart techniques of controlling the various works in a project. The Bar-Chart has certain drawbacks or difficulties, i.e., it is not capable of depicting proper relationships in time between various jobs to be done in a project. Moreover, once the relationship in time of the different jobs in a project is shown in the form of a Bar-Chart, it is difficult to change these Charts. The Bar-Charts are, therefore, somewhat 'static' in character. The network technique helps to overcome this difficulty. PERT and CPM network techniques allow the project planner and implementer to show graphically the proper sequencing and relationships-in-time between different jobs in the project and to concurrently indicate the requirements of time, money, materials, manpower and other resources on the network chart itself.

We shall restrict ourselves to a description of the Critical Path Method (CPM) over here. Later, we shall introduce the related technique of PERT. But it needs to be reiterated here that both these techniques have much in common and they fall under the general category of network techniques.

Whether our purpose is to draw a network for CPM or to draw a bar-chart, the basic requirement for both these graphical techniques is to analyse the various work components of the project and therefrom get a listing of the jobs to be performed in the project from the beginning to the end of the project. This would help us to proceed in a systematic manner rather than listing the jobs in a haphazard manner. Such a systematic listing of jobs can only produce a systematic graphical representation of these jobs, their inter-relationship with one another with respect to time and their resource requirements.

Design of the Organisation

The very word 'job' connotes that someone has been assigned the responsibility for a task and that the responsibility for the completion of that should also be clearly understood by the person who is responsible for the job. It also follows that unless the various jobs are planned by taking into account the responsibility and the authority to carry it out, the planning for the project becomes meaningless. Therefore, the organisation of the project as a whole becomes an extremely important starting point for the building up of a network.

The work of implementing the project can be broken down into certain major packages or work elements. This division of labour, naturally, has to be done keeping in view the organisation of the project. The organisation of the project can be done in several ways depending upon various factors as mentioned below.

(a) Geographic A project may be carried out at two or three different locations so far removed that it becomes necessary to control these work components as individual units under the responsibility of the head of that unit. For instance, in a hydel project, it may be necessary to build two or three different dams at different locations. Because of the distance and the geographical separation of the locations, it may become necessary to treat the work package at these different locations as comprising one aggregate individual unit.

(b) Functional The work in the project may be of different kinds, for instance, civil, electrical, mechanical, geological, etc. These functional areas of the work need to be organised separately.

(c) Productwise Sometimes the work components in the project need to be grouped by means of the product such as the water conductor system, the dam, the irrigation channels, etc. Such a grouping will simplify the organisation of the project work in some cases.

(d) Timewise The project can sometimes be divided into Phase-I, Phase-II, Phase-III etc. based on the time-phasing of the project. In each phasing a major chunk of the project work is done. In such a case, it may be necessary to organize the work of the project according to the time phasing.

The above discussion indicated how the work of a project could be broken down to organise it in a fashion which would suit that particular project. This 'Work Break-down Structure' is the first important step in finding or listing the different jobs that comprise a project. Once the project is broken down at a gross level in a few work packages, these work packages can then be further broken down into smaller work packages, again according to either geographical or functional or product or time considerations. The main point is to recognise the importance of properly organising the total work structure of the project. Unless the work structure of the project is broken down into its component elements in accordance with the structure of the organisation found necessary, the implementation of the project cannot proceed in a systematic manner. The above aspects of the division and further division of the work are very important before one proceeds with the drawing of the CPM or PERT charts.

What is an Activity?

As the work of the project gets sub-divided further into smaller and smaller work packages, one may reach a point where further sub-division of the work will be senseless either in terms of con-

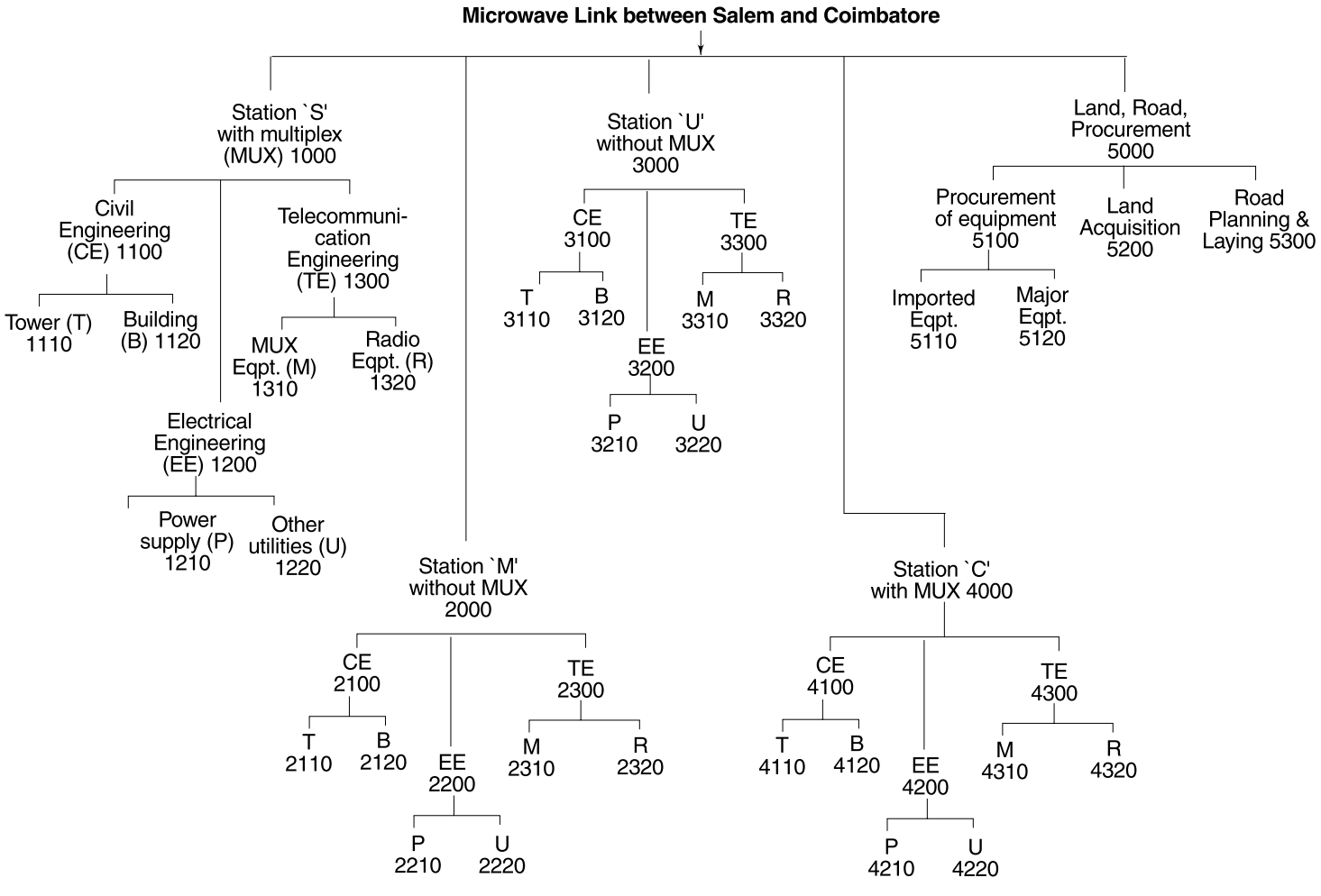


Figure 35.1 Few Levels of Work Breakdown Structure

Note: Adapted from a workshop report prepared during a training programme on Project Implementation, Monitoring and Evaluation conducted by the Indian Institute of Management, Bangalore, during August 1977 (DPAR, Government of India sponsored the programme).

trolling the work or in terms of measuring the work. The smallest sub-division of the work is called a "job" or an "activity". Based on the above-mentioned broad principles, a listing of activities or jobs is possible. In fact, because we have proceeded in a systematic manner from the gross level to the detailed level division of the work, this procedure simplifies the identification of each of the jobs. This sub-division also helps in proper responsibility accounting. An example of the *Work Breakdown Structure* (upto a certain level of breakdown) is shown in Fig. 35.1.

Sequencing Relationships between Activities

After a list of jobs or activities is obtained, the next task would be to find the inter-relationships between these different activities. The inter-relationships to be considered initially are those of a technological nature. The technology would dicate that certain jobs could be done only when one or more other jobs are completed. Or the technological aspects may be such that some of the activities or jobs can be done independently, which means one job does not have to wait for the completion of the other job, or that they can be done simultaneously. This relationship between the jobs reflects the arrangement of the different work components considering different availabilities of the resources such as equipment, materials or money. One should not consider such restrictions or limitations while making the initial arrangement of the work. It would be better if initial relationships between jobs are shown entirely based on technological consideration. When we refer to 'relationships' we are referring to whether a particular job needs certain other jobs to be completed or whether it can be done simultaneously with some other job or jobs. Thus, relationships are basically of two kinds: (a) Series, (b) Parallel.

While drawing the PERT or CPM charts, it is sufficient to know whether and which other jobs are immediately preceding the job in question. For each of the jobs listed, if we have a list of the corresponding 'immediate predecessors', this information would be sufficient to draw the CPM or PERT network.

Once the organisational and the technological aspects of the project are clear, the rest of the work of putting these details in the form of a PERT or CPM chart is merely mechanical. We shall discuss these mechanical details below.

Principles of Network Representation

As we said earlier, we shall limit ourselves to the Critical Path Method. At this point, we will assume that we have arrived at the listing of the jobs or activities and their inter-relationships. Our job is now only to show these in the form of a graph or a pictorial representation.

A job or an activity is shown as an arrow between two full circles as shown in Fig. 35.2.



Figure 35.2 An Activity

The tail of the arrow represents the start of the activity and the head of the arrow represents the end. The circles at these respective ends, therefore, represent the start and the end of the particular

job or activity. These circles are called 'events' or 'nodes'. Two jobs, where one job follows another are represented in Fig. 35.3.

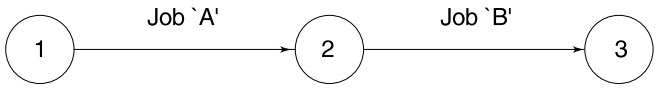


Figure 35.3 Activities in Series

The node or event 2 represents the completion of job or activity 'A' as well as the beginning of job or activity 'B'.

For easier nomenclature purposes, the activities are identified by their start and end events e.g. Job 'A' shown above can be called as job or activity (1, 2).

If two jobs or activities can be done simultaneously, they can be shown as in Fig. 35.4.

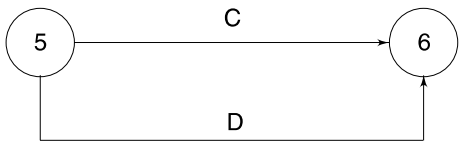


Figure 35.4 Parallel Activities

This representation is similar to what we see in electrical and electronic circuits. When all the activities in a project are represented in the convention indicated in Figs 35.3 and 35.4, the pictorial representation of the project looks like a diagram representing an electrical network. Probably, for this reason, CPM and the PERT Techniques are known as network techniques.

Let us refer back to Fig. 35.4 showing two simultaneous or parallel activities C and D. If we were to properly follow the nomenclature for the activities, then both 'C' as well as 'D' would be called activities (5, 6). Since we desire to have an independent nomenclature for each of the activities 'C' and 'D', we shall represent them as shown in Fig. 35.5.

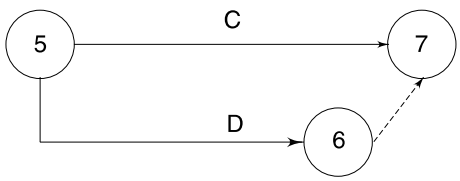


Figure 35.5 Use of Dummy Activity

Use of 'Dummy' Activities

The dotted arrow is included in Fig. 35.5 so that activities 'C' and 'D' have different nomenclatures, viz. (5, 7) and (5, 6). The dotted activity is in fact a non-activity, introduced only for facilitating

proper nomenclature, and therefore, it is an activity consuming neither time, money, material or any other resources. Such an activity is appropriately called a 'dummy activity'.

Dummy activities are also useful in other situations. Supposing activity C was dependent on the completion of activities 'A' and 'B', whereas activity 'D' was dependent only on the completion of activity 'B'. In such a case, the proper representation requires the use of a dummy as indicated in Fig. 35.6.

The other representation, avoiding the use of the dummy would not have properly represented the relationship between these activities. (Readers may try out the different representations and verify the validity of the statement.)

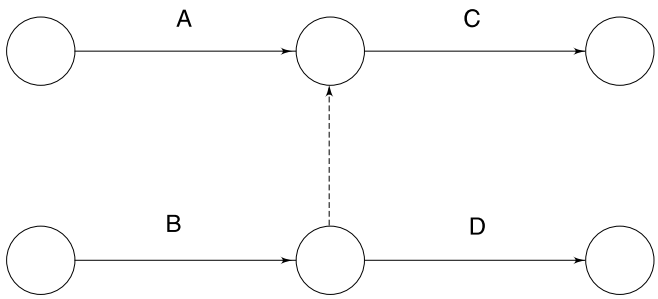


Figure 35.6 Use of Dummy Activity

Reverification of Sequencing Relationships

The CPM network is drawn with the help of the above-mentioned principles. It is better if one avoids the numbering of the events or nodes in the first attempt to develop the network. Different activities are best identified either by an alphabetical code or better still by a numerical code which can be easily derived from the detailed Work Breakdown Structure and activity listing. After the first trial of the network drawing is done, it is better to go back once again to the technical experts and to the top executives managing this project to verify the accuracy or validity of the different sequencing relationships between the different jobs. Quite often during this verification procedure, some important technological factors earlier omitted come to light. For instance in a state-level dairy development project, after drawing the network it was found that in the animal husbandry portion of the project an important activity had been missed. The activity of importing stud bulls from abroad had been considered; but, it was forgotten that the stud bulls imported from the colder countries in the West needed 'acclimatisation' to the Indian condition for as long a period as 6 months before they could be 'serviced'. This made a significant difference to the schedule of the project. It may be noted that only after a few trials and reverification of the 'sequencing logic' or the inter-relationships of the activities does the final form of the network emerge.

Numbering of the Events or Nodes

After this stage, one can number the different events in a systematic manner with the numbers increasing from left to right and from top to bottom. Since the flow of certain dummies may be

either vertically downwards or vertically upwards, depending upon the flow of the dummies one may number the succeeding events. Although such a numbering system helps in identifying the different activities easily, if one were to carry out further analysis on a computer, such a convention would not be absolutely necessary. What one should have is an independent identification for each individual activity in terms of the start and end nodes (events).

Use of Aggregated Networks and Part-Networks

For a large project, such as a hydel project for instance, the number of activities may run into thousands. Naturally, the complete CPM charts would be quite complicated. Although such a detailed network is definitely necessary and useful, not all the executives in the different hierarchical levels in an organisation will be interested in all the jobs indicated on such a network. The top level management may be interested in only a grosser sub-division of the work and not in too many detailed activities. Certain functional departmental heads will be interested in only activities related to the work of their departments and not in the complete CPM chart for the whole project. Because of these considerations, it is necessary that besides the Master Network there should be various other smaller versions of the CPM chart showing only limited portions of the network. Networks have to be presented to different executives according to their need for planning and their authority and responsibility for the component of work handled by them in the project. Wherever necessary the relationship of their components of the job with the other jobs in other departments will also be indicated in the networks which will be sent to them.

Other Tips for Drawing Networks

For more clarity, while drawing the network one should avoid the crossing of activity arrows. Also it is better to have a minimum number of dummies. It may also add to our understanding of the network if the network is 'stratified', i.e. if different activities are shown against the major Work Breakdown Structure to which they belong.

Once the network has been developed, the corresponding time, cost and other resource requirement figures need to be put on the different activities of the network, for the purpose of an analysis of the network. The purpose of the network is to provide a plan or a guideline for the implementation of the project and therefore, an analysis of the various resources required in light of their constraints, if any, as also of the time required to complete the various phases of the project is extremely important.

Estimation of the Time and Resource Requirements

For this purpose, it is necessary to get the relevant cost, time and resource requirement data for the various activities. These estimates are the heart of the project planning process. Although it appears quite simple to get the estimates, a lot of care needs to be exercised while putting the figures on an activity. There are various ways to get the time requirements of an activity. They could be drawn from the experience of previous similar work done elsewhere, it could be by means of work standards, or it could be an educated guess by the technical experts concerned. The choice of a particular technique depends upon the activity in consideration. However, one should not

be satisfied with one figure obtained from one person. The chances of error can be minimised by discussing such estimates with a number of people, in a number of sittings, so as to avoid the errors of either exaggeration, under-estimation, or omission. One may discuss with not only the group or person directly responsible for the work, but also with his boss, peers, and subordinates. A lot of commonsense and judgement is involved on the part of the planner in the estimation process. The estimation could very often be more an art than a science. Inspite of the difficulties that the estimation of the cost, time and resources are fraught with, good planning could never be done without such estimations however nebulous they may seem at first sight. This is not to say that all estimates are nebulous; many estimates can be hard figures which very few can question. The judgement process nevertheless has provided, in quite a majority of cases, very useful data for project planning.

The network having been developed and the estimates of various resources (inclusive of time) having been also indicated on the network, we are now ready for the analysis of the network with a view to provide important planning information for the project.

APPENDIX

A CASE STUDY ON SOCIAL COST-BENEFIT ANALYSIS*

In a major coastal city, a large area of very low Mean Sea Level is almost surrounded by the sea and the backwaters. Rain and tidal variations cause a flood situation in that area with considerable frequency. This causes much inconvenience to the people. A project idea has been conceived for having a storm-water disposal system for this purpose, by the Public Health Engineering Division.

If the strom-water disposal system comes into operation the following are the social benefits.

Benefits

1. *Savings in Cost due to Diversion of Traffic*

		Rs.
(a)	Savings in operating costs (*additional distance*) of vehicles:	
	(i) major floods	13,600
	(ii) minor floods	4,100
(b)	Savings in cost of time due to *delay*	
	(i) major floods	4,900
	(ii) minor floods	700
(c)	Savings in cost of time due to congestion of traffic in the diverted routes	
	(i) major floods	69,500
	(ii) minor floods	12,000
(d)	Saving in cost of additional operating cost due to congestion	
	(i) major floods	3,400
	(ii) minor floods	1,100
		Rs. 1.09,300

2. *Savings in Cost of Additional Repairs to Roads* (Assuming labour content 30% in the cost; unskilled labour to be 25% of total labour; and a shadow pricing of 50% for the unskilled.)

97,600

97,600

3. *Savings in Loss to Property in General and Loss in the Business Turnover for the Small Traders*

(NOTE: Small trade is in consumable goods: 50% of the loss in the turnover is taken as the loss to society.)

(i) major floods	1,32,000
(ii) minor floods	25,000
	1,57,000

* Adapted from the workshop exercise done during the programme on Project Implementation, Monitoring and Evaluation conducted by the Ind ian Institute of Management, Bangalore (sponsored by DPAR, Government of India, during Oct–Nov. 1979).

4. Savings in Costs due to Disrupted Communication Facilities such as Telephone, Telex, etc. (NOTE: Costs are due to irrecoverable losses in the revenue of wholesale business. Since most of the benefit may be enjoyed by the higher class of society, a low priority weightage of 50% is given for computing the cost to society due to these communication facilities disruptions.)

(a)	Loss of revenue—Telephone:	
	(i) major floods	1,98,300
	(ii) minor floods	1,98,300
(b)	Loss of revenue—Telex:	
	(i) major floods	58,000
	(ii) minor floods	58,000
(c)	Repair charges to lines and installations:	
	(i) major floods	20,000
	(ii) minor floods	20,000
(d)	*Weighted* loss of benefit from trade due to Telephone and Telex disruptions	
	(i) major floods	14,15,500
	(ii) minor floods	14,15,500
		33,83,600

5. Savings in Loss of Employment (Based on: local resident and neighbouring islands population and percentage working; an estimate of percentage loss of employment in major and minor floods; an estimate of unskilled/skilled ratio and a 50% shadow pricing for the unskilled)

(i) major floods	6,31,600
(ii) minor floods	3,15,800
	9,47,400

6. Savings in Loss to Foreign Exchange (Increased consumption of fuel has a foreign exchange component; shadow price for foreign exchange is 50%, i.e. benefit is 150%.)

(i) major floods	1,300
(ii) minor floods	400
	1,7000
TOTAL BENEFITS	Rs. 46,96.600

Costs The costs are as follows:

Year	Capital Cost (Rs. in lakh)	Maintenance Costs (Rs. in lakh)
0	50.00	0.00
1	50.00	1.20
2	50.00	1.44
3	50.00	1.44
4	60.00	1.44
5 and beyond	Nil	4.25

As the project goes through various phases of completion the benefits are available to some extent. Only from the fifth year the full benefits are available. A growth rate of 3% is assumed for the annual benefits. Accordingly a net benefit stream (net of costs) can be computed for the period of 25 years with a discount rate of 6%.

Total Net Present Value (NPV) of Benefits *minus* Costs = Rs. 457 lakh

= = = = = =

With a discount rate of 12%:

Total NPV of Benefits *minus* Costs = Rs. 162 lakh

= = = = = =

One may do a sensitivity analysis considering that only 50% of the annual benefits will be available:

At 6% discount rate the total NPV of Benefits *minus* Costs = 90 lakh

= = = =

From the above analysis the project appears to be socially beneficial and deserves serious consideration.



36 Project Management—II

TIME ANALYSIS

After developing the network, we turn our attention to the control of the project. In the control of the projects, the 'control of time' is undoubtedly very important. For this a procedure called Time Analysis is very helpful. The questions that are addressed by Time Analysis are:

1. What will be the completion time for the entire project?
2. At what points of time can we expect parts/phases of the project to be completed?
3. What are the activities which cause bottlenecks and need special management attention?
4. What slacks or free-times do different activities have?
5. Is time duration of the project acceptable? If not, what changes in the logic of the network may be done so as to complete the project within the desired time?

It needs to be mentioned at this point that the Critical Path Method (CPM) uses only one single time estimate for each of the activities, while the PERT technique uses three time estimates (optimistic, pessimistic, and most likely). Since we are dealing here with the Critical Path Method we shall depend on single time estimate for the different activities.

The time durations for the different activities are indicated in the network on top of each of the arrows representing a particular activity. Our first question is: how long will the duration of the project be? Since in the network there are many paths going from the beginning of the project to the end of the project, each of these paths will have a different total in terms of time duration. The project, represented as a network, could be viewed as a flow of different succeeding jobs from the beginning point of the project to the end point of the project. Naturally, the longest of these paths, in terms of time duration, will determine the duration of the project. The longest path is called the Critical Path, and hence the name of this method as the Critical Path Method.

CRITICAL PATH

Since the Critical Path is the longest path, all the activities falling on the critical path are "critical", which means that these activities have no slack. These critical activities, which are the bottleneck activities, need management's special attention since any time-delay occurring on any of these activities will delay the project as a whole. The other paths having less time duration will have a certain amount of slack which could absorb any delays occurring in the activities on these paths.

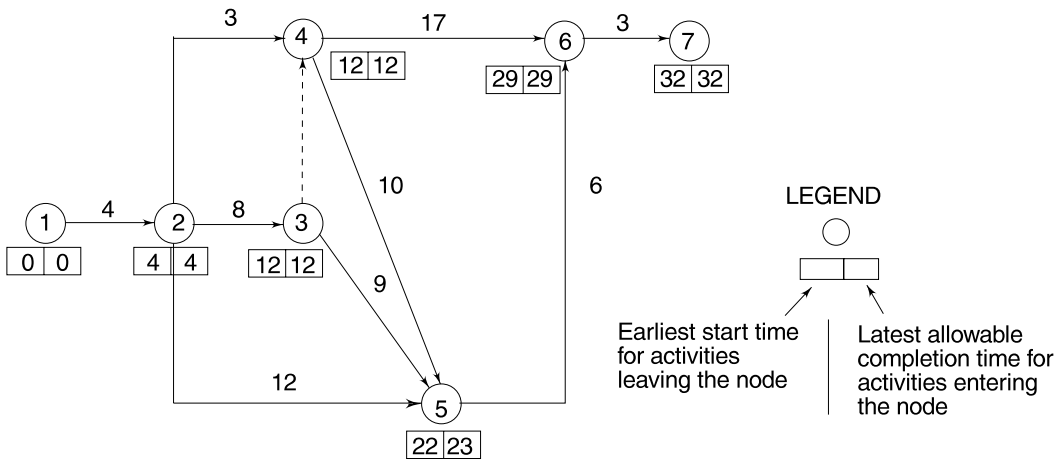


Figure 36.1 A Network Showing the Activity Durations and the Forward and Backward Pass Calculations for Time Analysis

This is an example of the principle of management by exception.

Although in smaller networks it is easy to find visually which is the longest path, and therefore, the 'critical path', the same is not the case with networks having a large number of activities. There is a systematic method by which one can find out the critical path and as well the slacks available to different activities on non-critical paths. We shall illustrate this method in Fig. 36.1.

Calculations on Earliest Start Times

Let us consider the Fig. 36.1. The earliest start time for activity (1, 2) is obviously zero. This will finish by time 4. Therefore, activities (2, 3), (2, 4) and (2, 5) can start at the 'earliest' time of 4. This is so, because these three activities are dependent on activity (1, 2). Activity (2, 3) can be completed at time period 12. Activity (2, 4) can be completed at its 'earliest' after a time period of 7. Activity (3, 5) originating from event 3 can start only after activity (2, 3) is completed which is after the end of 12 time periods. The activities starting from event 4 can start only after activities (2, 4) and (3, 4) are completed. Now (3, 4) is a dummy activity consuming no time at all. In fact, what we are saying is that activities (4, 5) and (4, 6) are dependent on activity (2, 3) through the dummy. Since activity (2, 4) is completed after time period 7 and activity (2, 3) is completed after time period 12, activities (4, 5) and (4, 6) have to necessarily wait till the end of 12 time periods. Unfortunately or fortunately, activity (2, 4) comes to a close much earlier in time and therefore has a slack. Even if activity (2, 4) is completed earlier than the completion of 12 time periods, we cannot start any of the activities (4, 5) or (4, 6). Thus, the 'early time' of event 3 is 12; early time of event 4 is also 12.

Now coming to event 5, we see that three activities, viz. (2, 5), (3, 5) and (4, 5) arrive at event 5. Or in other words, the activity emanating from node 5, which is activity (5, 6) is dependent on the completion of the above mentioned three activities. In order to find out when activity (5, 6) can start at its earliest, we shall have to find out which is the late finisher amongst the three activities (2, 5), (3, 5) and (4, 5). Activity (2, 5) can complete at the end of time period 16; (3, 5) can complete at the end of 21 periods; and (4, 5) can complete at the end of 22 time periods. Therefore, obviously, activity (5, 6) can start at its earliest only at the end of time period 22.

The reader may now verify the other early times of events 6 and 7. As you have seen here, the project can complete at its earliest at the end of 32 time periods. In this procedure, we have proceeded from the left-hand side to the right-hand side in the direction of the arrows. This procedure is called the 'forward pass'. As was seen above, the forward pass can give us the earliest start times of all the activities in the network.

Calculations on Latest Allowable Completion Times

Assuming that the latest allowable time for the completion of the project is the same as the earliest possible time at which it can be completed, which is at the end of 32 time periods, we shall try to get some more information on the activities by another procedure called the "backward pass". Here, we shall proceed from the right-hand side to the left-hand side in the opposite direction of the arrows. Let us illustrate.

Since activity (6, 7) has a time duration of 3, the latest time at which activity (6, 7) can be allowed to start is 32 – 3 = 29, which means that activity (6, 7) can start latest at the end of time period 29. Referring to Fig. 36.1, this also means that the activities feeding into node number 6, viz. activities (4, 6) and (5, 6) can be allowed to complete latest by 29. Coming to activity (5, 6), we see that it can be allowed to start latest at 29 – 6 = 23. This calculation of the latest allowable time for the start of the activities serves the purpose of not delaying the project, but at the same time allowing the activities to start as late as it is possible to allow them to do so.

Since the duration for activity (4, 6) is 17, the latest allowable time for the start of activity (4, 6) will be 29 – 17 = 12. If the latest allowable start time for activity (5, 6) is 23, this activity should not be affected or delayed unduly if we start activity (4, 5) at 23 – 10 = 13 time periods (end of it). So at node 4 we have two late times, viz. 13, coming from activity (4, 5), and 12 coming from activity (4, 6). Between these two if we were to choose 13, activity (4, 6) would have come to its completion after the end of 13 + 17 = 30 time periods. This is not what we want, because activity (6, 7) has to start at its latest at the end of 29 time periods. Therefore, between 12 and 13 which are the late times calculated at node 4 we shall have to choose the lowest of these two numbers which is 12. This is the latest allowable time for the completion of activities feeding into node 4, viz. activities (2, 4) and (3, 4). Otherwise, we would delay the entire project by one more time period.

The principle in the backward pass, therefore, is to calculate the late times at a node from all the arrows emanating from that node and choose the lowest of these late times.

Applying the above principle to the next node in question which is node 3, its late time is the minimum of (23 – 9 = 14) and (12 – 0 = 12). This is obviously 12.

The late time for node 2 is the minimum of (23 – 12 = 11) coming from activity (2, 5) and (12 – 8 = 4) coming from activity (2, 3) and (12 – 3 = 9) coming from activity (2, 4). The figure for the late time for node 2, is therefore, 4. The late time for node 1 is obviously zero. If we put these late times of the nodes also in the boxes adjacent to these nodes in the network, we see that nodes 1, 2, 3, 4, 6 and 7 have the equal early and late times. Remember, that the early times are shown on the left-hand side and the late times at the right-hand side in the boxes drawn adjacent to the events or nodes to fill in these early and late times as a convention. Usually, the critical path goes through such node for which the early and late times are the same.* We would expect our critical path to

* But, the converse is not true; that means al the paths going through such events, whose early and late times are the same, are not necessarily critical paths. Many of the activities on such paths may be found to have much slack as well.

be 1 – 2 – 3 – 4 – 6 – 7. One must remember, however, that this is not a correct method of finding the critical path.

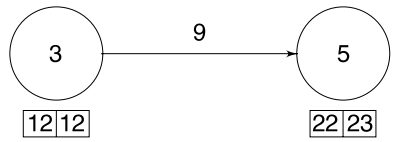


Figure 36.2 Calculation of Floats—an Example

Activity Slacks or 'Floats'

In order to find the critical path, strictly speaking, we need to find the slacks of the different activities and identify those activities which have no slack at all. These activities will be the critical activities and will comprise the critical path. The slacks are called, in CPM language, the 'floats'. Let us try to calculate the floats for the activities and illustrate them by means of Fig. 36.2.

Total Float Activity (3, 5) and the early and late times of nodes 3 and 5 are shown in Fig. 36.2. This activity can start at its earliest at the end of time period 12 and can be completed at the end of the time period 23. The start of activity (3, 5) is governed by the completion of the immediately preceding activities. If these preceding activities allow activity (3, 5) to start at its earliest, viz. time 12, and if the activity/activities down stream to (3, 5), viz. (5, 6) allow activity (3, 5) to end at the latest possible time, then activity (3, 5) has a slack or free play or float of 23 – 12 – 9 = 2. (Note that 9 is the duration of (3, 5).) The project duration will not be affected even if (3, 5) were to use this entire float. Of course, the downstream activities such as activity (5, 6) can now start only at their latest allowable time which is 23 and, therefore, activity (5, 6) may not have the liberty of starting at its earliest possible time and having a certain amount of slack for itself.

The slack or float for activity (3, 5) which we indicated above is called the 'total float'.

Free Float If we do not want the downstream activities to be affected by any permitted delays in the conduct of activity (3, 5), we shall have to see that activity (3, 5) ends by time period 22 which is the early time of event 5. In such a case, the float that is available to this activity is that of the difference between the early times of the two events minus the duration of the activity. This float is, therefore, 22 – 12 – 9 = 1. This kind of a float is called a 'free float.'. In calculating the free floats, the activities start at the early times and end at the early times of their respective nodes or events.

Independent Float There is another kind of a float which is called the 'independent float'. Here the activity is allowed to start at the late time, so as to allow the upstream activities to finish at their latest; and the activities are supposed to end at the early times of the end nodes, so as to allow the downstream activities a maximum amount of slack. Such a calculation of the float for an activity, will be independent of any effects either on the upstream-side or on the downstream-side and this is probably the reason for its name. The independent float for activity (3, 5) is 22 – 12 – 9 = 1.

The activities which are on the critical path have their total and free floats equal to zero. In *determining the critical path one may note the activities that have zero total floats.*

As an exercise, the reader may calculate the different floats for Fig. 36.1. As the definition of each of these categories of floats is different, the uses to which they can be put, will also be different.

Figure 36.3 illustrates the calculation of floats.

USES OF DIFFERENT FLOATS

The total float, if used completely, would make the succeeding activities critical. For this reason, it is not desirable to utilise this float completely, although the information that so much float is there is helpful. Whereas, free float can be utilised completely without disturbing the succeeding

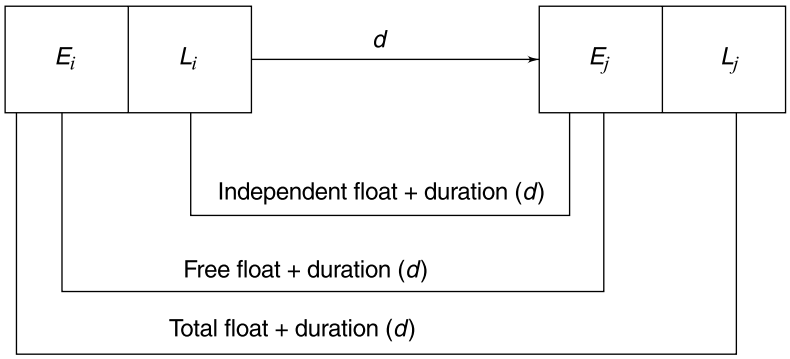


Figure 36.3 Different Floats

activities. Therefore, in case of slippages in time, Free Float is first made use of before resorting to total float. Still, the use of free float has an underlying assumption that the activity can start at its earliest which, in turns, means that the preceding activities should have been finished by this time. Thus, the use of free float is somewhat conditional, whereas independent float has no such strings attached either to the preceding or to the succeeding activities. It can be freely used.

One may use the floats judiciously while managing a project. The person responsible for only one activity, such as a chargeman or first level supervisor can be given only the independent float or at the most the free float information. The information regarding total float is liable not to be understood properly and may generate unnecessary complacency. At other levels of management also only the free float may be used first, and the total float may be used only exceptionally.

Resource Allocation

Free float and Total Float are extremely useful in the allocation of resources, particularly when there are constraints on their availability and usage. In the developing countries, shortage of commodities such as cement, steel, or explosives at one time or another is common. Also capital shortage is not unusual. Under such conditions it may not always be possible to complete the project in the planned time. Rescheduling the start of various activities, taking advantage of their floats, might relieve the pressure on the requirement of the resources at different points of time.

RESOURCE ANALYSIS

With the pattern of availability of resources being constrained, with the best of reallocation we may not be able to complete the project in the planned time, but at least the delay will be minimized. Such an exercise of rearranging activities, by taking advantage of their floats, in order to cause minimum delay to the project from availability-and-usage constraints on resources is called "Resource Analysis". This is a very important component of network analysis.

There are two types of resource problems:

(i) There may be a ceiling on the availability of a resource in a particular period of time. For instance, only Rs. 125 lakh per annum may be available to the project and, if unutilised during the year the remaining amount lapses. The particular resource analysis used, for this case, is termed as *Resource Smoothing*.

(ii) A resource may be required to be used in a uniform manner. For instance, in the present day labour situation, one cannot have 100 labourers yesterday, 30 today and 80 tomorrow. Once a labourer is hired, it is difficult to fire him. The rate of usage of labour has to be uniform. Resource Analysis used for this category of problem is called *Resource Levelling*.

In order to illustrate the resource smoothing problem, let us consider Fig. 36.4. It is a time-scaled network, which means, the length of the arrow is proportional to the duration of that activity and the entire network is squared without any oblique arrows. Moreover, the network is drawn with all activities starting at their earliest. The broken part of the arrow represents the float (in this case, Free Float). In Fig. 36.4, the number on top of an arrow represents not only the duration of the activity in days, but also the requirement of unskilled workers on any day for that activity. The requirement of the workers on different days can be easily computed as shown in the figure. This is the early start requirement of workers. It has a peak requirement of 12 workers on days 3, 4 and 5.

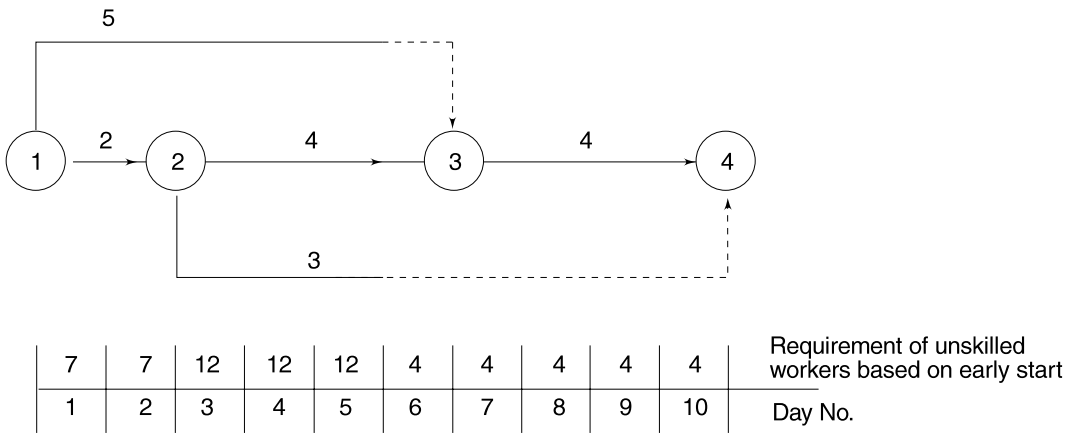


Figure 36.4 Time scaled Network, Depicting Floats, Accompanied by Calculations on the Minimum Requirment of the Unskilled Workers on Different Days

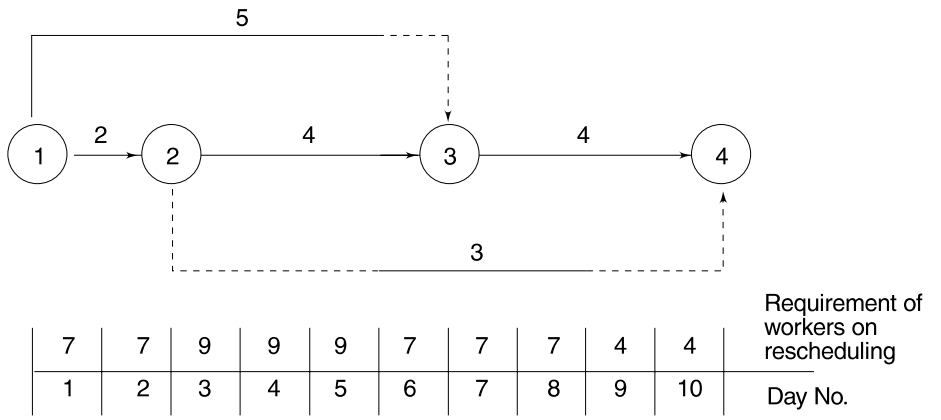
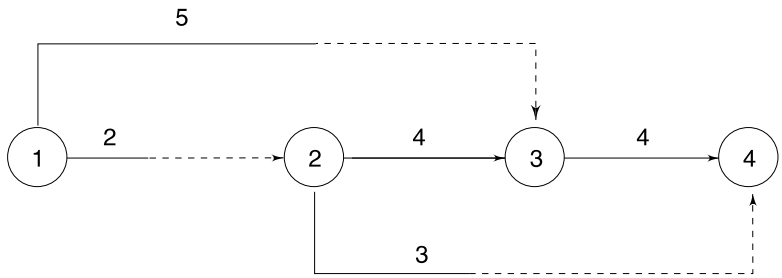


Figure 36.5 Network Rescheduling for the Availability of Maximum 9 Workers on Any Day

The McGraw·Hill Companies



Requirement of workers on rescheduling	7	7	5	5	5	7	7	7	4	4	4	4	4
Day No.	1	2	3	4	5	6	7	8	9	10	11	12	13

Figure 36.6 Network Rescheduling for the Availability of Maximum 7 Workers on Any Day

Now, if there is a constraint on the availability of labourers, the maximum available on any day being 9, can the project still be completed on time (i.e. in 10 days)?

As Fig. 36.5 shows, the project can still be completed in 10 days, by rescheduling activity (2, 4) to start on the 6th day and curtailing its float to 2 days (from the original 5 days). Thus, the 'floats' of the activities are useful in rescheduling and in the reallocation of resources.

Figure 36.6 shows rescheduling when the resources are constrained to the level of 7 workers (maximum) available on any day. Under such a drastic constraint, the project has to be delayed by at least 3 days.

(Note: In Figs. 36.4 to 36.6 it has been assumed that the activities, once started, cannot be interrupted; moreover, higher or lower amount of application of resources does not reduce or enhance the time duration of the activities.)

Use of Heuristics in Resource Analysis

We see from the above example that making use of floats available and shifting activities (rescheduling them) to correspond to resource availability in such a way as not to delay the project, or in cases where it is impossible not to delay the project, to delay the project as little as possible is the crux of Resource Analysis. There is no formula or an easy analytical or mathematical model to indicate the optimal shifting of activities from the early start schedule, taking advantage of the total and free floats.* What we have are certain thumb-rules or a set of thumb-rules. These thumb-rules or 'heuristics' do give, if not optimal, near-optimal results. One of the heuristic procedures for 'levelling of resources' is by Burgess; a modified version of the same is given below:**

Levelling of Resources *Step 1* List the project activities in order of precedence by arranging the arrow head numbers in ascending order, and when two or more activities have the same

* Linear Progamming models are available for resource allocation but these are too comber same even to solve on a computer.

** A.R. Burgess and J.B. Killebrew, 'Variation in Activity Level on a Cyclical Arrow Diagram', *Journal of Industrial Engineering*, Vol. 13, No. 2, March–April 1962. Also refer to: J.J. Moder and C.R. Phillips, Project *Management with CPM and PERT*, Reinhold Corporation, New York, 1964.

head number, list them so that the arrow tail numbers are also in ascending order. Next prepare a bar-chart for the activities showing their total and free slack and their current schedule which should be as early as possible. If certain activities have schedules fixed by previous resource allocations or total project duration time constraints, they should be drawn on the chart with no slack.

Step 2 Starting with the last activity (the one at the bottom of the diagram), schedule it to give the lowest total sum of squares of resource requirements for each time unit. If more than one schedule gives the same total sum of squares, then schedule the activity as late as possible to get as much slack as possible in all preceding activities.

Step 3 Holding the last activity fixed, repeat Step 2 on the next to the last activity in the network, taking advantage of any slack that may have been made available to it by the rescheduling in Step 2. In general, this slack availability check is made by observing the scheduled start times of all activities having a tail number equal to the head number of the activity in question; these activities will always be found below the one in question. The earliest of these observed scheduled start times is then the latest allowable finish time of the activity in question.

Step 4 Continue Step 3 until the first activity in the list has been considered; this completes the first rescheduling cycle.

Step 5 Carry out additional rescheduling cycles by repeating Steps 2 through 4 until no further reduction in the total sum of squares of resource requirements is possible, noting that only movement of an activity to the right (schedule later) is permissible under this scheme.

Step 6 Make final adjustments to the schedule taking into account factors not considered in the basic scheduling procedure.

The above procedure was for ensuring, as far as possible, a constant rate of usage of resources and hence the concept of the least sum of squares was quite appropriate. But when there are constraints or ceilings on the availability of resources, a very different kind of heuristic or algorithm is to be used. Most of the resources allocation algorithms schedule the job in each period (day or week, etc.) only up to the limit of resources, and then postpone any remaining jobs until resources are sufficient for scheduling them. The resources are allocated on a period by period basis to some subset of the available jobs—those whose predecessors have been completed. The approach is to use the jobs which are most critical. One of the heuristics presented by Wiest and Levy* is given below:

Resource Smoothing

1. Allocate the resources serially in time, i.e. start on the first day and schedule all the jobs that are possible, then do the same for the second day, and so on.
2. When a number of jobs compete for the same resources, give preference to the jobs that have the least slack.
3. Re-schedule non-critical jobs, if possible, and free resources for scheduling critical or non-slack jobs.

It should be emphasised once again that this heuristic, or any heuristic for that matter, may not produce optimal results; but definitely, near-optimal results can be achieved with the expenditure of less energy and time. Analytical procedures are to some extent available and they can guarantee optimality. Analytical procedures might involve linear programming, integer programming, etc.

* J.D. Wiest and F.K. Levy, A Management Guide to PERT/CPM, Prentice-Hall of India, New Delhi, 1977.

but again, these analytical methods are feasible for only very small projects. For the present, heuristic programmes are the only possible procedure for dealing with the problem of large projects and multiple constrained resources.

To sum up, resource allocation is a way of utilising the available floats of the activities and rescheduling the activities in such a way as not to exceed the given ceiling on the resources (or to achieve as much constant rate of usage of the resources as possible if that is what is needed) and to do this with limited delay in project completion. Resource allocation/analysis is also a very valuable planning exercise. It can provide alternative schedules by trying out different resource patterns. Various assumed conditions can provide different scenarios for the project manager's decision-making.

Use of a Computer for Resource Analysis

Another important point which needs to be made regarding resource analysis is that projects in real life comprise thousands of activities in the network. Manually one may be able to do the time analysis, but it is almost impossible to do the resource analysis. The help of a computer is essential in carrying out resource analysis. If multiple resource constraints exist, resource analysis may become a herculian task for any human being. When one resource has been optimised, the other resource may go out of bounds. Keeping track of a number of critical resources simultaneously and re-arranging activities to suit the availability of the different resources is next to impossible if the analysis were to be done manually. With the availability of computers nowadays, even in developing countries such as India, it takes only a few hours of computer time to do complex resource analysis for a considerably large project. Computer software packages are available which can do the resource analysis for networks having thousands of jobs and hundreds of resources. Microsoft Project and ICL-PERT are amongst the several comprehensive software packages for Project Management. These computer programs can also handle any other tricky situations in projects, such as when certain jobs can be split, i.e. where interruption in the activity is possible. Many Indian Software companies have also come out with software packages for project management.

APPLICATION OF NETWORK TECHNIQUE IN PRACTICE

For the better use of the PERT/CPM network technique some tips are given below:

Clarity

The project objectives, goals and scope should be clearly understood or defined right in the beginning. Without such an understanding, the various sub-projects and activities which need to go into the project, the various inter-relationships between the different internal and external agencies responsible for the success of the project, the time relationships and the time-to-cost relationships may not be clear during the implementation of the project and therefore, might lead to large errors that may not be fully rectified during the implementation of the project.

Control Related Organisation Structure

A proper organization structure for the execution of the project should be envisaged right in the beginning of the project after clearly defining the objectives and scope of the project. The Work Breakdown Structure as outlined in the earlier discussion is an important step. Without a clear

delineation of the authority structure, and without clarity in spelling out the responsibilities of the different executives within the organisation and the responsibilities of various agencies contributing inputs in the project, it is almost impossible to properly coordinate the project in order to finish it within the time and cost targets. The very purpose of the PERT/CPM charts is to 'control' the project and 'control' implies that somebody (executive or agency) should be clearly held accountable for his part of the project.

Details

After this responsibility delineation for the different elements of the project, it is advisable to make smaller PERT/CPM charts for these sub-projects including their activities and related activities and supply the same to the persons (or agencies) responsible for the execution of these sub-projects. The master-network which includes all the thousands of activities may be subdivided into a number of sub-networks.

Estimation of Time, Costs, Other Resources

It is important to bear in mind that time and cost estimates play a very significant role in successful implementation of the project. Since these estimates are, in the majority of cases, judgemental values, care should be taken to involve a number of concerned technical experts. Not only should the person entrusted with the job be involved in the estimation process, but also his boss and his peers. Moreover, such estimation should be done after a number of sittings so that factors not considered in one sitting may be considered in another sitting. These estimates are at the heart of the 'management by network analysis' and therefore, much care needs to be exercised. Whenever in the course of the execution of the project the time estimates prove to be wrong due to wrong assumptions made in the beginning, such modifications ought to be incorporated at the review stages of the project.

Work Breakdown

It is important to note that while identifying the activities, the work breakdown should be done to the maximum extent possible. An activity should be the smallest work component possible which makes sense for project control. The activity should not be broad like "digging the tunnel for a water conductor system". Such a broad activity would not be amenable to management control. Instead, the various small elemental jobs comprising this activity should be clearly visualized in the initial planning stages. An activity should be a micro-level work component. A Chief Engineer of one of the State's Power Boards attributes his success, in using network analysis for his power projects, to the micro-level subdivision of the projects' work components. He claims that this gave him an excellent control over the projects. This is an important point which many professional management consultants forget while formulating a network for the implementation of a project. Without such subdivision many inter-relationships between different activities may never be brought to light until that part of the job presents itself; by then it is quite late to do much.

User Orientation

While drawing the initial network, various persons from different levels of the organisational hierarchy should be involved in the network design process. It is a dictum of any management process

that it should be 'user-oriented'. This 'user-orientation' is a must even in the network design and planning for project management. The 'acceptability' of the people who are going to use the CPM chart or the plan of action is essential, and therefore, their involvement right from the beginning of the planning process is a must. The user should be convinced of the usefulness of the network which is being drawn for the implementation and monitoring of the project. Many of the government officers in our country are sceptical about the use of PERT/CPM techniques in general, leave alone the particular network design. So, while contemplating the use of network techniques for government projects, the job of getting acceptance is two-fold:

(i) to convince the users regarding the usefulness of the network technique *per se*; and

(ii) to get their approval in the identification of the sub-projects, work elements, listing of activities, estimation of cost and time for different activities, and the inter-relationships between different activities.

Periodic Reviews

The network drawn in the beginning of the project is only a tentative plan of action. The same network cannot be used for the entire duration of the project because as the project progresses there may be many slippages and unforeseen events that take place which may delay the project or overshoot the cost estimates. Such deviations have to be corrected and therefore the initial plan of work (the initial CPM chart) needs to be updated and modified periodically. An activity may be expedited by supplying more resources; or an activity may be put in parallel, changing the logic of the network where required. A periodic review of the work done and the corresponding rectification is essential for the proper execution of a project. A network may keep on changing at successive review periods but the basic objectives and the scope of the project properly defined earlier keep the basic skeleton or structure of the network intact. Updating, monitoring and control of the project are essential prerequisites for the successful management of the project. After modifying the network, the revised time analysis and the revised resource analysis have to be performed at each review period. For this purpose, wherever desirable, monitoring cells may be established with the express purpose of pooling the information from all works involved in the project and performing the centralised project analysis.

Information System

Updating and monitoring require a proper information system for project management. All the aspects of the project such as time, money, physical work done, and resources consumed, etc. should be kept track of. Information should flow rapidly from bottom to top and from top to bottom of the management hierarchy, and between external agencies and the project executives. Without a proper information system and a two-way feedback, the purpose of controlling the project will not be served.

Uncertainties

In the latter two points we spoke of uncertainties and therefore the required control action. Uncertainties are everywhere: in any sector of the economy, and in any job that we do. In fact, because there are uncertainties we need to do a good planning job right in the beginning itself, and provide for flexibilities as such uncertainties present themselves during the implementation

of the project.Sometimes it is observed that some of the uncertainties are not really 'uncertainties'. A supplier may say that he can deliver a raw material in a period of three months. But, in fact he may deliver it only after five or six months. We can visualise such 'uncertainties' by studying the supplier's jobs and drawing his CPM chart ourselves, so as to make our own estimate as to when he could realistically supply the raw materials. In such a case the delay in the supply of raw materials will not be an uncertainty, but an expected event which has already been calculated. Of course, wherever it is possible, the suppliers or the external agencies should be given their part of the CPM chart and it should be insisted that they follow the same. Where it is not feasible to do so, the external agencies' charts should be drawn for one's own guidance.

Contingency Plans

In addition to the master-plan, it may be necessary, many a time, to prepare 'contingency plans in the beginning itself. Contingencies may present themselves as follows:

(a) The geological soil structure may not be very clear in the beginning, and therefore there may be a possibility of delay in operations such as digging tunnels, bore wells, etc.

(b) It may not be possible to predict exactly when the monsoon will begin and therefore hamper with the progress of the project.

(c) Due to political problems part of the international loan such as the World Bank loan or aid from other countries may not come through or may be delayed.

(d) Governmental approval and/or licenses may get delayed.

To handle such uncertainties, if anticipated, contingency plans should be made at the beginning along with the master-plan.

The network can be compared with the time-table of the railways. Unless we have the timetable, we shall not know whether trains are on time or are delayed. The network schedule, of course, is not only for time but also for the cost and use of different resources. It is only a tool in the hands of the management, and much depends upon how it is used and whether it is sharpened from time to time. Unless this is done, the desired results will not be produced.

TECHNICAL LIMITATION OF PERT/CPM

The PERT/CPM technique has an inherent technological draw back (although this should not constitute a problem to project management). It is that, this technique basically uses the finish-to-start relationship exclusively. There are four kinds of relationships possible between two different activities:

1. Start-to-start
2. Start-to-finish
3. Finish-to-start
4. Finish-to-finish

For instance, drain-pipes can be laid as soon as a certain portion of channels are dug. The start of the laying of the drain-pipes lags behind the start of the digging of the channel by a small amount of time. But, it need not wait for the completion of the digging of the channel. This is a start-to-start relationship with a certain lag between the two activities. The covering of the channel after laying the drain pipes can begin as soon as the drain-pipes are laid to some extent, but cannot be completed unless all the drain-pipes have been laid. Therefore the finish of the covering activity depends on the finish of the drain-pipes laying activity. This is finish-to-finish relationship. Such

relationships are shown diagrammatically in Fig. 36.7. The Precedence Network is an *activity on node diagram*, as against CPM which is an *activity on arrow* diagram.

Ladder Activities

The conventional CPM chart can surmount such difficulties by dividing the activities into smaller elements and showing the usual finish-to-start relationships between the sub-elements of the activities on the chart. Alternatively, it may also be shown by means of what is known as 'ladder activities' where the relationship between the start-to-start or finish-to-finish or start-to-finish is shown by means of the lag or lead times.

Figures 36.8 and 36.9 illustrate these two methods.

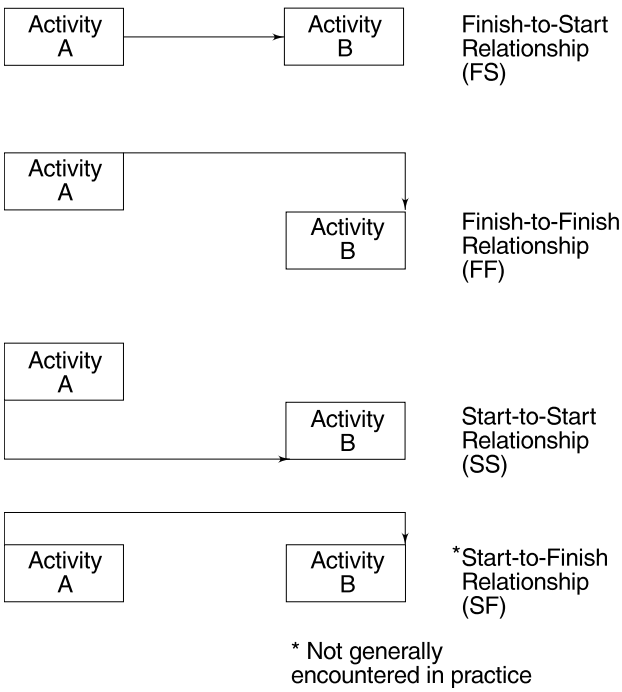


Figure 36.7 Precedence Networking

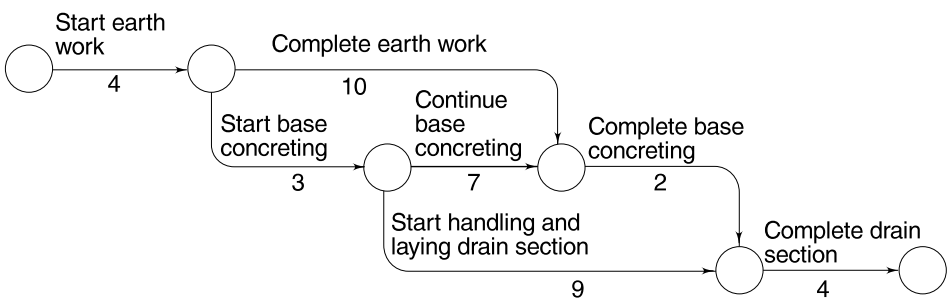


Figure 36.8 Using Conventional CPM to Depict Start-to-Start and Finish-to-Finish Relationships

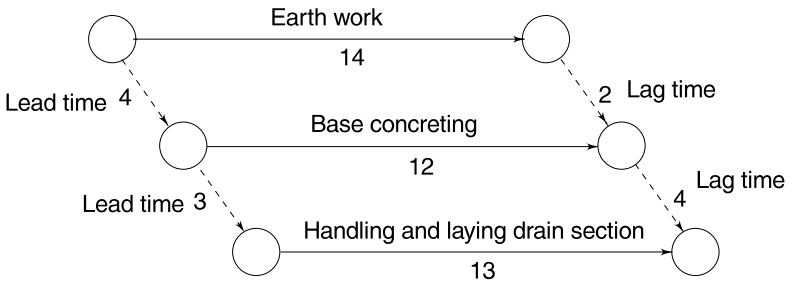


Figure 36.9 'Ladder' Representation

Note: Broken arrows flowing downwards show the lead and lag time relationship

PRECEDENCE NETWORKING

Civil works or public works activities may, quite often, present a considerable number of 'ladder activities'. But such problems can be circumvented by the suggestion made earlier, that of subdividing the activity into small elements and using the conventional CPM principles to show the relationships between the sub-elements.

Such relationships can also be shown and analyzed by means of the relatively more accurate but more cumbersome technique of Precedence Networking. This is an extension of the idea of PERT charts and the above mentioned four relationships are shown directly on the network itself. An example of a Precedence Network is shown below in Fig. 36.10.

The time analysis for the Precedence Network, naturally, is more complex than for the PERT/CPM chart. While doing the backward and forward passes the various times arrived at because of the different SF, SS, FF, and FS relationships should all be taken into account. As one might see for oneself, time analysis itself is quite complex, leave alone resource analysis. This complexity very much limits the use of the Precedence Network technique in practice. Moreover, the PERT or CPM is able to take care of such complexity provided some modifications are done to the charts as earlier indicated. Therefore, the new and specialised techniques have not been of much practical interest so far.

Project management involves not only feasibility studies, implementation and monitoring, but also includes organisational aspects, governmental regulations, and many other questions such as how to present the information to different financing agencies, the licensing policies of the government, tendering and contracting procedures, etc. But these are all beyond the scope of this book.

PROJECT EVALUATION AND POST-IMPLEMENTATION ANALYSIS

The last aspect of project management, but certainly not the least important, is the evaluation of the project which is usually conducted after the project is complete and has started yielding results. At this stage our analysis should address itself to questions such as:

(a) Have the objectives of the project as they had been set out initially, been achieved or are they being achieved? Is the achievement partial or complete?

(b) What are the reasons for the non-achievement of the objectives?

(c) Were the objectives realistic enough to start with? If the objectives are only partially achievable, should future projects, with similar objectives, be modified?

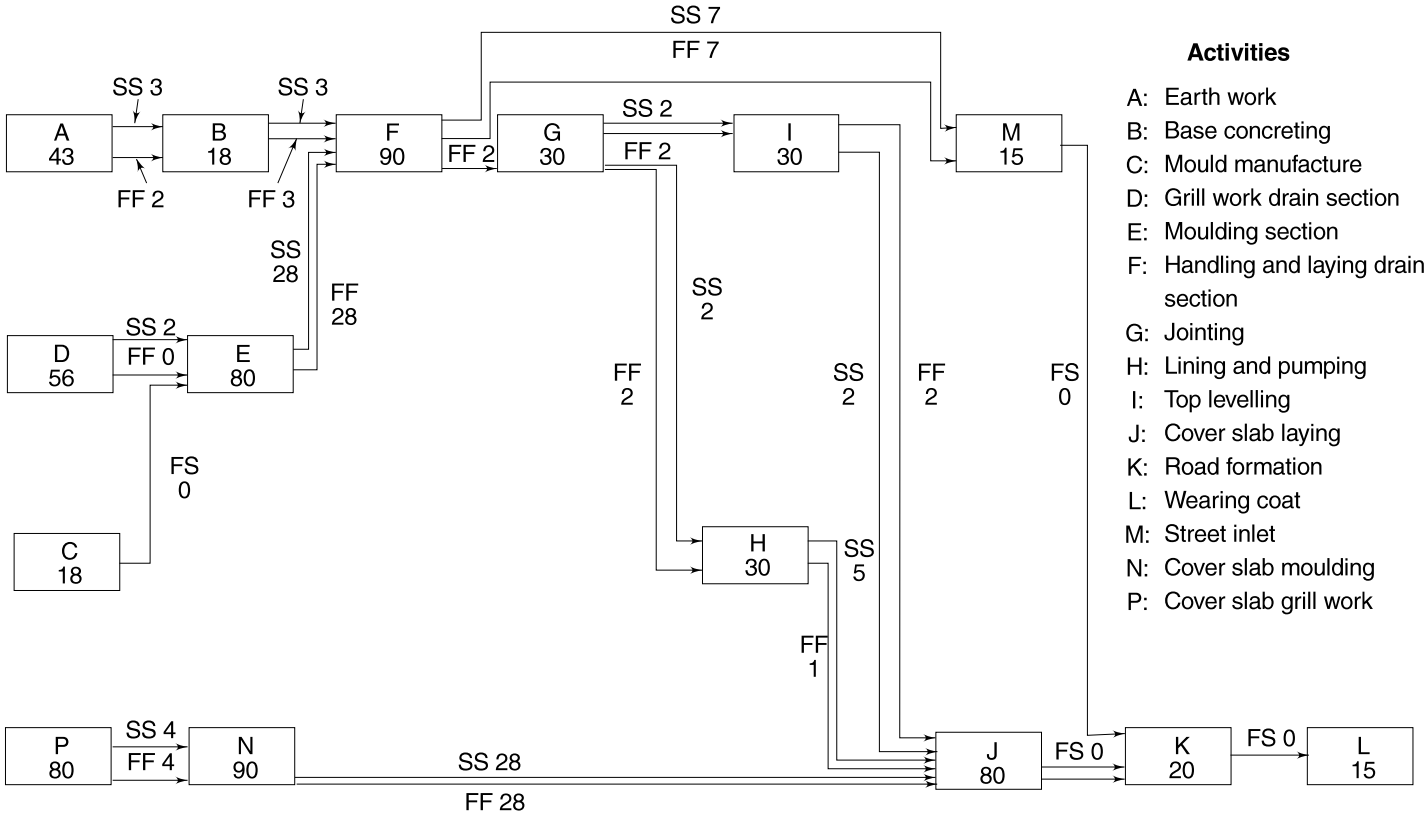


Figure 36.10 Precedence Network (Canal for Storm-Water Drainage)

(d) Were the time-and-cost targets achieved or partially achieved? What are the reasons for the deviations? What lessons might be learnt for future projects in terms of the time-and-cost behaviour?

(e) What were the technical problems faced in the execution of the project and what were the lessons learnt for future projects?

(f) How have the various assumptions regarding the social benefits and costs proved right or wrong for the present project? How might future projects be analyzed for social cost-benefit, with the new information available from the presently implemented project?

(g) What has the experience of the project been in terms of organising it internally and with external agencies? How should the future projects be organised? What kind of external agencies should be relied upon in the execution of future projects and what precautions should be taken in taking their help in future?

(h) What lessons can be learnt in terms of monitoring and controlling future projects?

Such critical examination will help in preventing the same errors for other projects in the future. Such an examination becomes imperative for projects where immense funds have to be invested, such as various governmental projects. Project management is thus a continuous learning experience.

Many governmental projects are multiple projects where different projects are interlinked. Building a cement industry may have effect on the building of dams, irrigation and power projects. What happens with the power projects may have ramifications for irrigation, agriculture and industrial development. Of course, the various sectors of the economy have input-output interlinkages; but, this is not the point which is being made. What is being said is that at the micro-level there may be much inter-dependence between different projects (handled by one Department of Government or an organisation) and such dependencies will cause one project to lag behind the scheduled date if another project goes off its own schedule. Such dependencies should be depicted on the PERT/CPM charts to account for difficulties in the execution of projects.

Project management is a vast field and only the basics have been covered in Chapters 35 and 36. For further reading refer to the bibliography to this chapter.

Highlight — RELIANCE PETROLEUM REFINERY AT JAMNAGAR

The experiences in creating the Reliance complex at Jamnagar, that has 4,500 engineers, managers and 80,000 other workers today, form an exemplary study in project management. The project was conceptualised at a time when it was thought unimaginable. In December 1996, Reliance started to build this integrated petroleum, petrochemical and power complex involving an investment of Rs 25,000 crore. It was spread over 7,500 acres of land—a third of Mumbai's land area. With optimism, confidence and professionalism, the company set about chalking out a meticulous strategy—in project planning, design, implementation and business strategy.

The refinery was built in a record 36 months. After completing construction in a record time, the project was commissioned in 60 to 90 days as against the normal 6 to 18 months. Perhaps nowhere in the world had such a refinery been built in this time frame. It is the largest single investment ever in Indian corporate history. It is the largest investment ever made at any single location

in India. In one step, it represents 29% of the total refining capacity in India. It represents 4% of all investments under implementation in India. It is 5% of the gross assets of the entire corporate sector in India. At the international level, it demonstrates that a mega project of this size and complexity can be implemented in India in less than 36 months.

Reliance viewed time as a critical and scarce resource. As its Vice-Chairman Mukesh Ambani (now Chairman) would say, "Lost money can be regained. Lost time is lost forever." This was a tenet guiding this project. Also, from the outset, the company was acutely conscious that the people in the area must see the project as being community friendly. The company was, therefore, keen to build a refinery that shared social concerns for the protection of ecology and environment.

The mammoth project followed carefully and consistently, the Reliance philosophy of trusting people. "Trust is the cornerstone of all our initiatives. We believe that trusting our people results in superior performance", says the Chairman of Reliance.

The Jamnagar Refinery project seems to illustrate the high level of applicability of certain general principles in the management of projects.

'Out of the box' thinking while conceptualising the project

Thinking out of the box, the company saw value creation opportunities at the convergence of petroleum refining, petrochemical and power generation businesses. Reliance designed the refinery to integrate with petrochemicals and power generation. This would enable it to capture the highest value from every barrel of crude oil processed, to get maximum value per investment rupee. It built a refinery that was large in scale, technically complex, integrated with petrochemicals and power generation and environment friendly. Reliance had redefined an industry.

The refinery was designed to process a whole range—virtually every type of crude oil in the world. This increased the capital cost, no doubt. But it enabled the company to quickly capitalise price differentials in crude oils and earn superior returns. The right choice of technologies and product configuration yielded significant value. They planned for the refinery to give a high proportion of lighter fractions that are more valuable.Consequently, Reliance could have superior rates of return on invested capital.

Thus, while older refineries produced 2% of their product slate as high value LPG, Reliance could produce 12%. While the older refineries produced 15% low value fuel oil products, Reliance would not produce any. While the other older refineries had a narrow crude oil input capability, Reliance had the ability to process all types of crude oil. Reliance had redefined technology integration.

Investments in people and technology

About five million man-hours of engineering had to be expended in just 18 months. This was to be the largest engineering effort in India and one of the largest in the world. So, Reliance project managers resorted to simultaneous engineering at several locations—London, Chicago, Houston, Mumbai, Delhi and Jamnagar. It involved over one thousand engineers. All these locations were interconnected.

Recruiting skilled manpower for construction was a big bottleneck. Trained people in sufficient numbers were just not available. The problem was overcome by a massive skill development pro-

gramme through intensive training of raw people.

The project management reckoned that for every single skilled person required, it would be necessary to train four people. A crafts training centre was set up on the basis of this ratio. This means that Reliance trained 320,000 individuals in base skills of carpentry, welding, electrical and instrumentation. This was essential to maintain a work force of 80,000.

Automated welding was used for the first time in India. Induction bending technology was used to reduce volume of work by 30% to 40%. Automated engineering integration was done by virtual transfer of drawings from engineering offices directly to the production machines. Above all, the Reliance project invested Rs 700 crore in their own construction equipment to have full control over construction schedules. All these measures saved many months in project schedule.

Getting ordinary people to do extraordinary things

The project management at Reliance institutionalised a concept of systemwise ownership. The project was broken into eight major sections, 42 different units and thousands of systems. Each system head was vested with ownership. The system heads were motivated to act as owner managers rather than mere employees. About 80,000 activities were tracked and performance monitored daily in a 'war' room.

The project was completed at a cost that was 30% to 50% lower than similar refineries in other parts of the world. Thus, getting ordinary people to do extraordinary things is a function of setting challenging tasks, placing trust, underlining managing processes and devolving ownership. This is an important lesson in project management.

Investing in infrastructure: for project execution and future operations

Reliance decided to invest in their own infrastructure. It saw that as the key to productivity. It was also, in a sense, an insurance for the company, given the magnitude of the project.

A 50 million tonnes per year port terminal was planned to be an integral component of the project. It is today the largest port terminal in India, representing a quarter of India's port capacity. Equally massive infrastructure was created on other fronts—500 MW captive power plant, a 12 million gallons per day sea water desalination plant, 4 million tonnes of tankage capacity, 10 million tonnes per year product despatch road and rail terminals, 150 kilometres of road network, giga byte Ethernet network and a state-of-the-art 200 kilometre optic fibre communications network. It was the equivalent of creating infrastructure for a city with a population of a million people.

Embracing ecology

The project team at Reliance decided to go beyond the normal call of creating green belts. They decided to develop new ecosystems. Two million trees were planted representing 200 species over 2,000 acres of arid land. About one million mangroves were developed in ten species over 100 acres in the inter-tidal region. This is now helping the creation of a new coastal ecosystem. Four large artificial ponds were created. Apart from helping water management, it has now created a water body for birds. Reliance designed the refinery to be a zero effluent refinery. In a few years from now, one would see more of greenery than a refinery in that arid region. It shows that social concerns and profitability are not necessarily in conflict with each other.

Creating confidence in constituencies

The constituencies include the consumers, the shareholders, the government and the community where the refinery is located.

The consumer expects that the fuels are priced reasonably and are of a quality that meets international levels. Reliance refinery's products meet stringent Californian standards. As for the constituency of shareholders, Reliance had always enjoyed their confidence.

Since the petroleum sector in India is still controlled by the Government, the Government is a major constituency. Reliance Petroleum aligned its business and planning processes so that the Government has the confidence that the project—on completion—could deliver international quality products at international prices.

The community and the neighborhood are of tremendous importance for a project. Recently, when drought stalked the region, Reliance Refinery supplied Jamnagar city with drinking water. By 2002, they had supplied 36 crore litres of drinking water to Jamnagar city.

Building competence around people

Reliance does not subscribe to conventional theory of sticking to one's core competence and getting out of businesses that are termed 'non-core'. Such a theory does not recognise the fact that competencies are built around people. Fluid catalytic cracker unit start-up is normally the nemesis of most refineries. Reliance imported talent and knowledge, and trained its young people.

In order to start up the world's largest unit, the Reliance project management hired an expert team that had started 15 such units in other parts of the world. The expert team was supplemented with local bright young engineers. The result was that Reliance had a dream start-up.

A cyclone struck Jamnagar in June 1998 in the midst of this refinery construction. It was a devastating cyclone, with a once in 500-year return probability. Despite such calamity, the project was completed in a record time.

(Adapted from the lecture of Mukesh D. Ambani, Chairman, Reliance Industries Limited, in the Lecture Series 'Ideas that have worked', organised by the Department of Administrative Reforms and Public Grievances, Ministry of Personnel, Public Grievances and Pensions, Government of India, New Delhi, September 16, 2000) *Courtesy*: Reliance Industries Ltd., Mumbai.

SOLVED PROBLEMS

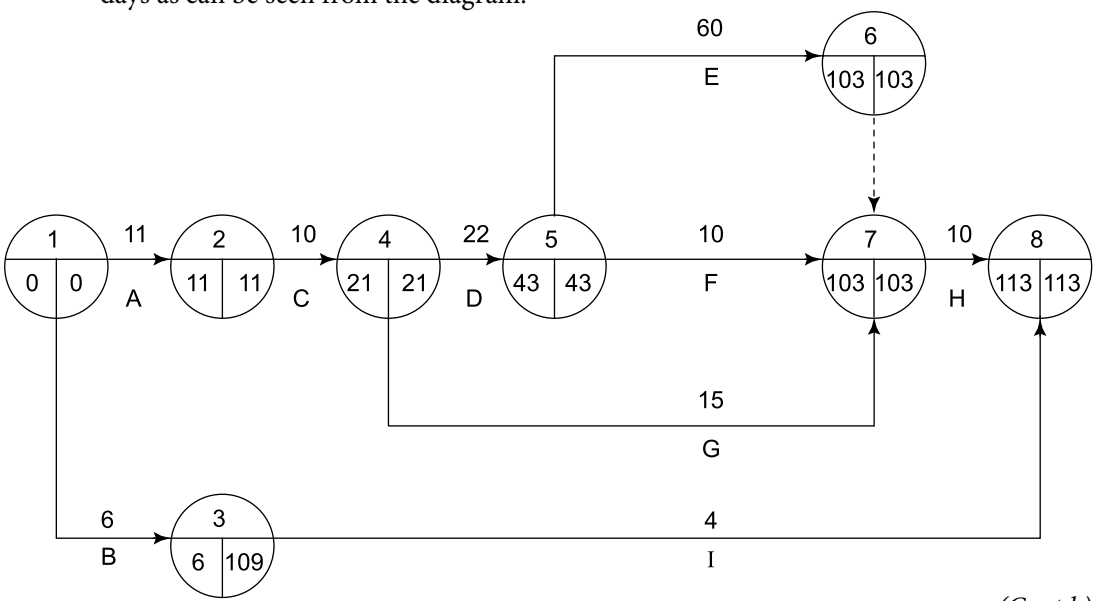
1. Santosh Saikia, Product Manager of Sai 'Tiger Cubs', a new brand of motorcycles, has planned a list of activities culminating in the inaugural launch of the new product. Saikia is using CPM network techniques to plan, monitor and control the project to launch these motorcycles. The estimated time durations for the activities and the sequencing relationships are given in the table below.

Activity	*Estimated Time Duration*	*Immediate Predecessor/s*
A. Performing production tests	11	–
B. Toning up quality testing	6	–
C. Conducting meeting on marketing strategy	10	A
D. Arranging and executing dealer meetings	22	C
E. Promoting dealers	60	D
F. Advertising in the newspapers	10	D
G. Releasing commercials on the TV	15	C
H. Participating in a marketing tactics meet	10	E, F, G
I. Production run	4	B

(a) What is the 'critical path'? What is the time needed to complete the project?
(b) What are the Total Float, Free Float and Independent Float for all the activities?
(c) If each activity needs Rs. 10,000 per day of the activity, what are the funds needed in each of the different months of the project? Consider that each activity is allowed to start at its earliest start time and a month has 30 days.
(d) If Saikia has been allowed only Rs. 400,000 per month, will he be able to complete the project on time? How would he manage to complete the project on time?

Answer

(a)& (b) The CPM diagram with the time estimates for each activity is drawn as per the sequencing relationship given. A dummy activity is needed here, so that all activities have a unique number. Also, note the numbering of the events – top to down and then left to right as each node is encountered from the start of the project to its completion. The time estimates for each of the activities have also been indicated on the activity arrows.
The forward and backward passes have also been done and the early and late times for the events have been shown in the diagram. The estimated time to complete the project is 113 days as can be seen from the diagram.



(Contd.)

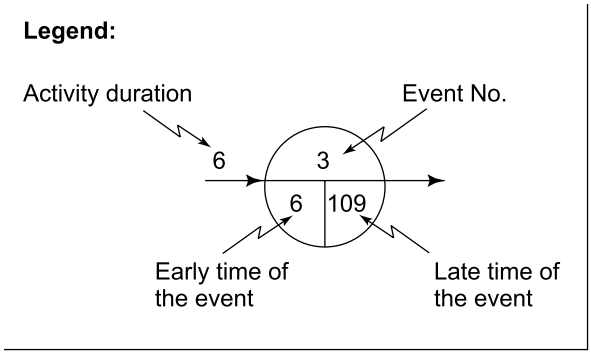


Figure 36.11 Network Diagram for the Project (not drawn to scale)

Various floats – total floats, free floats and independent floats – are computed and the values of these floats are given in the table below.

Activity					
Name	*Number*	*Duration*	*TF*	*FF*	*IF*
A	(1,2)	11	0	0	0
B	(1,3)	6	103	0	0
C	(2,4)	10	0	0	0
D	(4,5)	22	0	0	0
E	(5,6)	60	0	0	0
F	(5,7)	10	50	50	50
G	(4,7)	15	67	67	67
Dummy	(6,7)	0	0	0	0
H	(7,8)	10	0	0	0
I	(3,8)	4	103	103	0

Note: TF ≡ Total Float, FF ≡ Free Float and IF ≡ Independent Float. The critical activities have been underlined.

Critical activities are those that have zero 'total float'. The critical activities have been underlined in the above table. These are A, C, D, E, and H. That a dummy activity is critical has no particular significance. The critical path for the above project is A-C-D-E-H. In terms of numerical nomenclature, the critical path is: 1-2-4-5-6-7-8. Its time duration is 113 days and this is the duration of the project.

(c)& (d) *Schedule with a resource constraint of Rs. 400,000 per month*

In order to compute the funds requirement every month, one needs to add up the funds needed to run the activities during that month. To facilitate the visual computation, we draw the network to time-scale. If all activities were to start at their earliest, the funds requirement during each of the first and second months would exceed the ceiling of Rs. 400,000.

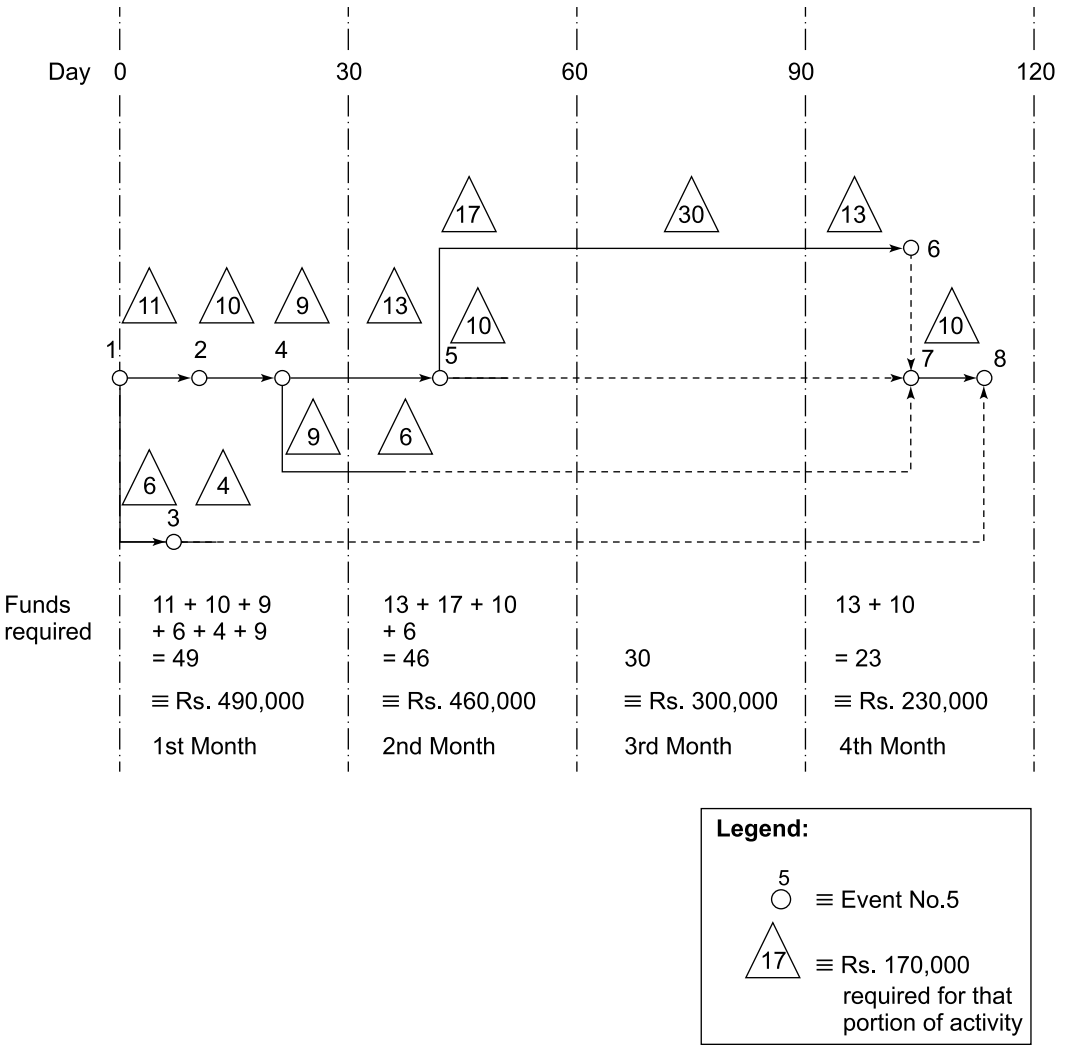


Figure 36.12 Requirement of Funds when all Activities Start at their earliest.

Requirement of funds during each month is as follows.

Month	*Funds requirement (Rs.)*
1	4,90,000
2	4,60,000
3	3,00,000
4	2,30,000
	Total: 14,80,000

But, if the activity G, i.e. (4,7) is shifted to its end so that it starts on day 89, the constraint (of funds being restricted to Rs. 400,000 per month) is met over each of the months of the project. All other activities can start at their earliest. The project completion date remains unaffected. Refer to the network drawn to time-scale below with the activity (4,7) rescheduled (it is pushed to its end).

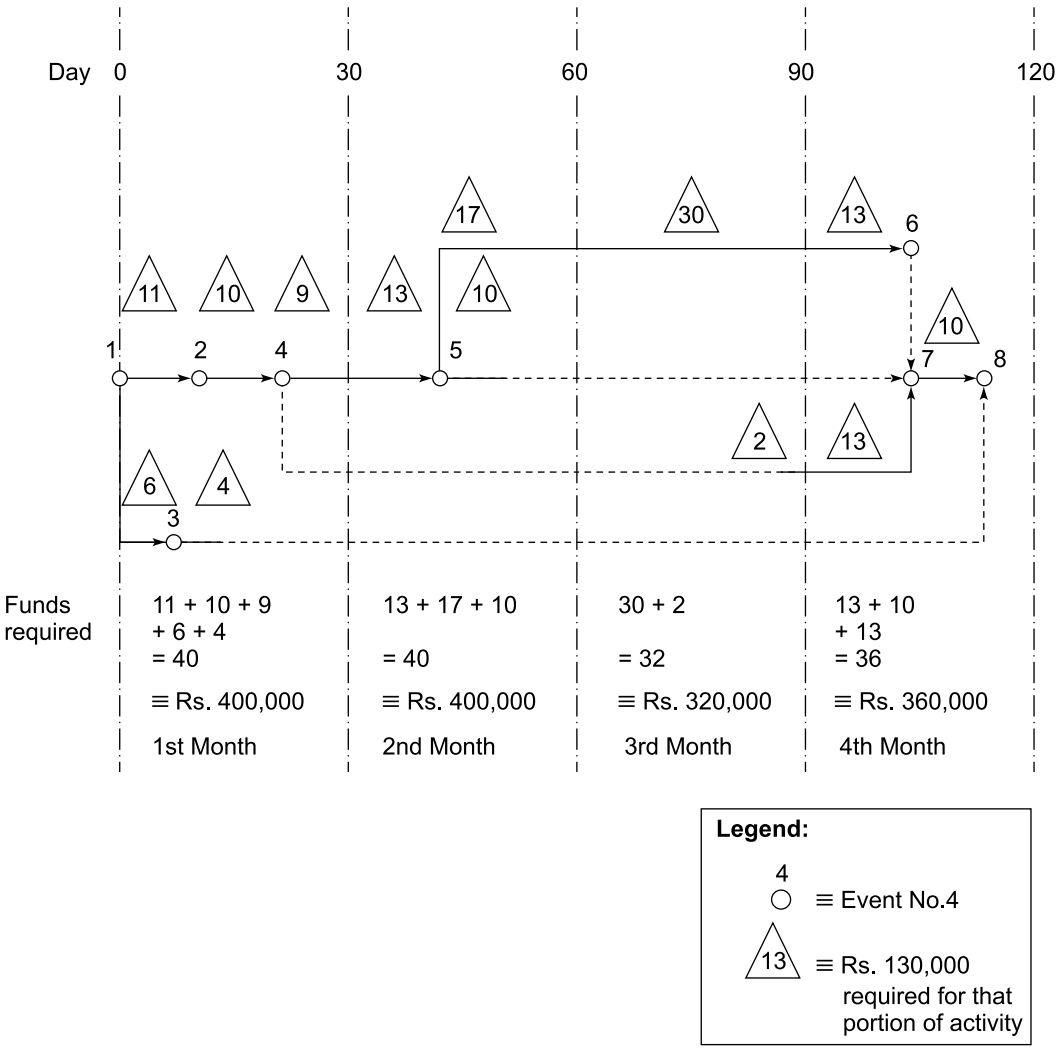


Figure 36.13 Requirement of Funds after Rescheduling of Activity in order to meet the Limitation on the Funds Availability per Month.

The requirement of funds, with this rescheduling of activity (4,7) is as follows:

Month	*Funds requirement (Rs.)*
1	4,00,000
2	4,00,000
3	3,20,000
4	3,60,000
	Total: 14,80,000

2. Let the network diagram, i.e. the activities and their sequencing relationships, be the same as in the earlier problem. However, let the activity time estimates be the 3 time estimates for PERT. These probabilistic time estimates made by Santosh Saikia, the Project Manager, are given in the table below.

Activity		*Time Estimates*		
Name	*Number*	*Pessimistic*	*Most Likely*	*Optimistic*
A	1, 2	20	10	6
B	1, 3	9	6	3
C	2, 4	12	10	8
D	4, 5	40	20	12
E	5, 6	90	60	30
F	5, 7	14	10	6
G	4, 7	25	15	5
H	7, 8	12	10	8
I	3, 8	5	4	3

Compute the probabilities that the project – to launch the new product – completes by:

(a) 93 days and

(b) 123 days.

Answer

In PERT system, the expected time of an activity is given by: $(t_o + 4t_{ml} + t_p)/6$.

These times are calculated and we find that by clever design they happen to be the same as in the CPM's single time estimates. Hence, our network remains the same as in the earlier solved problem.

The critical path is comprised of activities A, C, D, E and H. In order to find the probability of completion of the project, as a first step, we need to compute the standard deviation of the duration of the critical path. For this, we need to know the standard deviation of each of the activities.

The standard deviation of an activity is given by: $(t_p - t_o)/6$

The expected times and standard deviations of all the activities are listed in the table below.

Activity		Time Estimates				
Name	*Number*	*Pessimistic (days)*	*Most Likely (days)*	*Optimistic (days)*	*Expected time (days)*	*Standard Deviation (days)*
A	1, 2	20	10	6	11	14/6
B	1, 3	9	6	3	6	6/6
C	2, 4	12	10	8	10	4/6
D	4, 5	40	20	12	22	28/6
E	5, 6	90	60	30	60	60/6
F	5, 7	14	10	6	10	8/6
G	4, 7	25	15	5	15	20/6
H	7, 8	12	10	8	10	4/6
I	3, 8	5	4	3	4	2/6

Note: Critical activities have been underlined.

Standard deviation (σ) of the critical path

= Square root of the 'Sum of the variances of all activities on a critical path'

$$= \sqrt{(14/6)^2 + (4/6)^2 + (28/6)^2 + (60/6)^2 + (4/6)^2} = 11.319$$

(a) Probability of completing the project by 93 days is found by referring to the standard normal distribution table. Of course, the standard normal distribution applies is an assumption. We compute the Z value and then refer to the table.

$Z = (x - \mu)/\sigma$ where $\mu \equiv$ expected time for project completion and $\sigma \equiv$ standard deviation of the critical path.

Thus, $Z = (93 - 113)/(11.319) = -1.767$

Therefore, the probability of completion by 93 days is: (0.5 – 0.4611) = 0.0389

(b) Probability of completing the project by 123 days is found in a similar manner.

$Z = (123 - 113) / / (11.319) = 0.8835$

Therefore, the probability of completion by 123 days is: (0.5 + 0.2981) = 0.7981

It may be noted that the path next longest (in terms of expected time needed to complete the path) to the critical path is A-C-D-F-H. The sum of expected times of all the activities on this path is 63 days. However, this is considerably smaller than the duration of the critical path and even under a pessimistic scenario, it does not exceed the duration of the critical path A-C-D-E-H. Same is true of the other paths. Therefore, the above calculated probabilities of completion of the project hold good.

QUESTIONS FOR DISCUSSION

1. Would a project management organisation be different from an organisation for regular manufacturing? In what ways?
2. How are organisational considerations important in the network development?
3. How are projects identified? Discuss the process.
4. What are the similarities, if any, between the corporate planning process and the project identification and appraisal process?

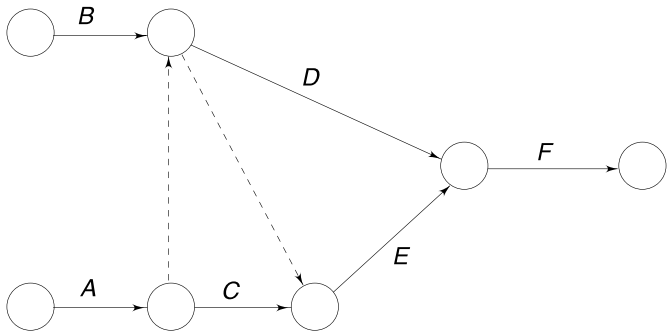
5. What is the relevance of 'objectives' in project management? Where is the effect of this consideration felt during the project management process? Give examples and explain.
6. Discuss the uses of:
   (i) Social Cost Benefit Analysis;
   (ii) Impact Analysis in project management.
7. How is project evaluation (as described in this book) different from project appraisal?
8. What is an 'activity'? How is a proper concept of 'activity' important in the implementation of the project?
9. Discuss the importance of 'time estimation' in the application of network analysis to projects.
10. What are the merits and demerits of 3-time estimates versus a single time estimate?
11. What is the significance of Critical path? Can there be multiple Critical Paths in a network?
12. Explain the managerial significance and use of total and free floats.
13. Does time analysis give us the final schedule of activities? Explain your answer.
14. What are the limitations of CPM?
15. A group of students wanted to visit a project to study the use of Network Analysis. "Our CPM Charts are not yet stable" came the reply from the project manager. What are your comments on this?
16. Given the following

Activity	*Immediate predecessor*	*Duration, in days*
A	–	9
B	–	20
C	–	10
D	A	11
E	C	10
F	B, C	4
G	F	2
H	D, F	5
I	E, F, K	18
J	G, H	14
K	–	24
L	K	6

   (a) Draw the CPM diagram.
   (b) Find out the critical activities.
   (c) Compute the total, free and independent floats for activities E, D, G, H and L.
17. Consider the following project:

Activity	*Immediate predecessor/s*
A	–
B	–
C	A
D	A, B
E	B, C
F	D, E

For the above project, the following arrow diagram is drawn:



Is there any flaw in the above diagram? If so, draw an improved arrow diagram.

18. Refer to the example on Resource Analysis given in this chapter. If, in addition to the unskilled workers, skilled workers are also required to accomplish the activities as given below,
Do the re-scheduling for a restriction that:
(i) not more than 9 unskilled and 6 skilled workers will be available on any day,
(ii) not more than 7 unskilled and 6 skilled workers will be available on any day.
(Note: (a) The activities once started, cannot be discontinued; (b) It is neither possible to shorten nor to lengthen the duration of the activities by applying more or less labour.)

Activity	*No. of skilled workers required on any day*
(1, 2)	4
(1, 3)	2
(2, 3)	2
(2, 4)	4
(3, 4)	3

19. For the Precedence Network (Canal for Storm-Water Drainage) given in this chapter, work out the
(i) Early Start Schedule, and
(ii) Late Start Schedule.
(Note: Activities cannot be interrupted once started.)

ASSIGNMENT QUESTION

1. Study an ongoing project of any size. Applying project management principles, present your observations and recommendations for possible improvements.

APPENDIX

PERT SYSTEM OF NETWORKING

PERT, just like CPM, is an Activity-on-Arrow diagram. In fact, the network diagram for PERT and CPM are exactly the same. Where PERT differs from CPM is in its stochastic considerations as against CPM which is deterministic.

For every activity in PERT, three different time estimates are obtained;

Optimistic time (t_o) : If everything goes smoothly while performing the activity

Pessimistic time (p_t) : If everything goes wrong, short of natural calamities, while performing the activity

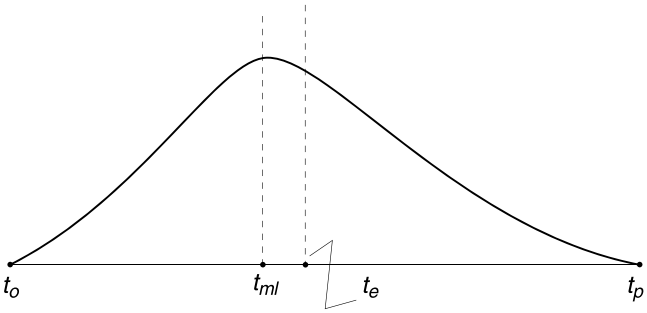
Most Likely time (t_{ml}) : The time which occurs most frequently

The actual time taken by the activity could fall anywhere between t_o and t_p; and if, hypothetically, the same activity was performed a number of times, it will be complete at t_{ml} most number of times.

It is thought that a β-distribution would adequately represent this situation. With some approximation, the values of the mean and standard deviation are given as follows:

$$\text{Mean (i.e. expected) time for the activity, } t_e = \frac{t_0 + 4t_{ml} + t_p}{6}$$

$$\text{Standard deviation, } \sigma = \frac{t_p - t_0}{6}$$



The probability of the completion of a project within a certain time duration can be computed with the help of these data on individual activities. Generally, the probability of the completion of the critical path is taken as the probability of completion of the project within any given time. If the number of activities on the critical path is large then one can use the Central Limit Theorem and accordingly assume a Normal distribution for the path with:

T_e (i.e. expected time for the path) = $\sum$ t_e of all activities on the path

and variance (i.e. σ^2) for the path = $\sum$ activity variance for all activities on the path

Supposing the following are the network and other activity details:

	Estimated times, days			Therefore, Calculated	
Activity	t_o	t_{ml}	t_p	t_e	std. deviation
1, 2	1	4	7	4	1
1, 3	5	11	17	11	2
2, 4	4	7	28	10	4
2, 3	1	2.5	7	3	1
3, 4	1	4	7	4	1

The critical path is 1-3-4 and the expected project duration is 15 days. Draw the diagram and verify.

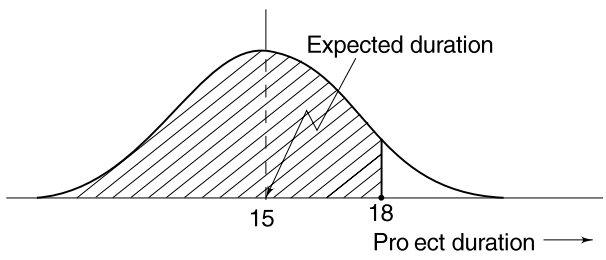
Note, that the probability of completing the project in 15 days is 0.50 only. The probability is higher for longer (than 15) project completion times.

Let us compute chances of completing the project in 18 days. The standard deviation for the critical path is $\sqrt{4+1} = \sqrt{5}$

Therefore, $$Z = \frac{X-\mu}{\sigma} = \frac{18-5}{\sqrt{5}} = +1.34$$

and the probability of completion of the project = 0.91

Likewise, the various probabilities of the completion of the project within different time durations can be computed. PERT system provides this additional dimension.



Note: Hatched area represents probability of completion within 18 days.

However, we should be careful about any false sense of sophistication because even the above computations could be erroneous. We have assumed that for all such computations, considering the (so-called) critical path is enough. In fact, in our example, path 1-2-4 is near-critical (expected duration 14 days) and has a variance much higher (17) than that of the 'critical path' (5).

Let us compute the probability of completing the path 1-2-4 within 18 days:

$$Z = \frac{18-14}{\sqrt{17}} = +0.971$$

and Probability = 0.835

This is lower than that for the path 1-3-4. So, which path is critical? What could be the definition of 'critical path' in such probabilistic situations?

It would also be worth noting that for a project to be completed, all the activities in the network have to be completed. So, really, for computing the probability of completion of the given project within 18 days, one has to consider the joint probability of completion of all the paths, which would be significantly less than the probability calculated for the so-called critical path.

Although one can analytically arrive at a probability figure for the entire network by combining the statistical distributions of all activities, this analytical procedure is too cumbersome and complex particularly for networks with a large number of activities.

In most cases, therefore, a Simulation method helps. It generates thousands of combinations of activity times and computes corresponding criticalg path lengths. An Index of Criticality could be attached to the different paths according to the number of times, during the simulation run, these paths went critical. For instance if path 1-3-4 became critical 400 out of 1000 runs, then the Index of Criticality for 1-3-4 is 0.40.

Thus, one may say that there is no one path critical, but each path has an index of criticality attached to it according to its propensity to go critical. There are no critical activities, instead each activity has a probability of being on a critical path.

Although the PERT system appears computationally very precise, it has some serious drawbacks.

1. First of all, the choice of β-distribution is not based upon any empirical data. Perhaps, it was chosen because it is unimodal, has finite non-negative end-points, and it need not be symmetrical. That seems all.

   Also, the jobs do not occur so many times as to provide data to fit a β or any other distribution. Many activities occur only once.
2. The formula to calculate the expected times and standard deviations is again an approximation.
3. Moreover, it is difficult in practice to get three time estimates giving a true-enough picture of the optimistic, pessimistic and modal happenings for the number of activities in a project. The entire probabilistic analysis depends upon these estimates.

37 Just-In-Time Production

Having discussed conventional production planning, scheduling and inventory control systems in the earlier chapters, let us now take a look at a revolutionary concept in operations that is fast catching up in the industrialised world.

Think of a situation where we produce the required goods only at the time when they are needed and in the quantity that is needed; and where this holds good for finished products and semi-finished products, both. If such a situation materialises, the inventories of the finished goods and work-in-progress would be almost nil. Now, if we make our raw materials suppliers agree that they should deliver their goods only at the time and in the quantities we need them to, then we are almost eliminating raw materials inventories as well. We shall then have virtually zero inventories (or near about zero). This is called the Just-In-Time (J-I-T) production system founded by Taiichi Ohno (a Vice-President at Toyota) and first successfully implemented at the Toyota Motor Company's plants in Japan and now being tried at various manufacturing industries all over the world (Fig. 37.1).

SINGLE UNIT PRODUCTION AND CONVEYANCE

The J-I-T concept may have been borrowed from the inventory systems of American Supermarkets, i.e. only the units that are sold are replaced. It is actually a production-and-materials planning system where the production and procurement closely follow the actual demand. And this system is carried down the line from the final product to the basic component. It can be perceived as a Job-order production carried to the extreme of single unit job ordering yet retaining the conveyor line system and its advantages. There are no lot-size productions anywhere (if inevitable, they are minimised). As and when the item is produced it is conveyed to the next process so that there is no 'waiting' involved at any place. Of course, the operation times at each workplace are also equalised. In short, in J-I-T we have: (i) no delay—either due to lot-size production or due to unequal production times of different work places; and (ii) conveyance times are also balanced. J-I-T is a combination of single-unit production and the conveyor system and is called 'Ikko Nagare' in Japanese meaning Single Unit Production and Conveyance.

It is obvious that J-I-T can be more easily used for continuous mass production of a variety of finished products. It may not be that easy to apply it to the totally customised intermittent production.

YO – I – DON AND STANDARDISATION

Since the pacing of the line is very important, a Ready-Set-Go (Y ō-i-don, in Japanese) type of procedure is used on the line. If anything gets delayed anywhere, the whole line comes to a halt. It is like every work place going through exactly the same cycle; all have the same preplanned cycle time or all of them get delayed to the same extent. Every operator, when he finishes his job, is required to press a button. By the cycle time if all have not pressed their buttons, a red light comes on the 'Andon' indicating to everybody which work place is having problem, so that the neighbouring worker can come and help and get the whole line started again. Note, that this procedure puts a psychological pressure on the workers to maintain the required cycle time. Since defective work anywhere on the line holds up the entire line, there is group pressure to produce good quality at all work places. J-I-T thus promotes production of good quality.

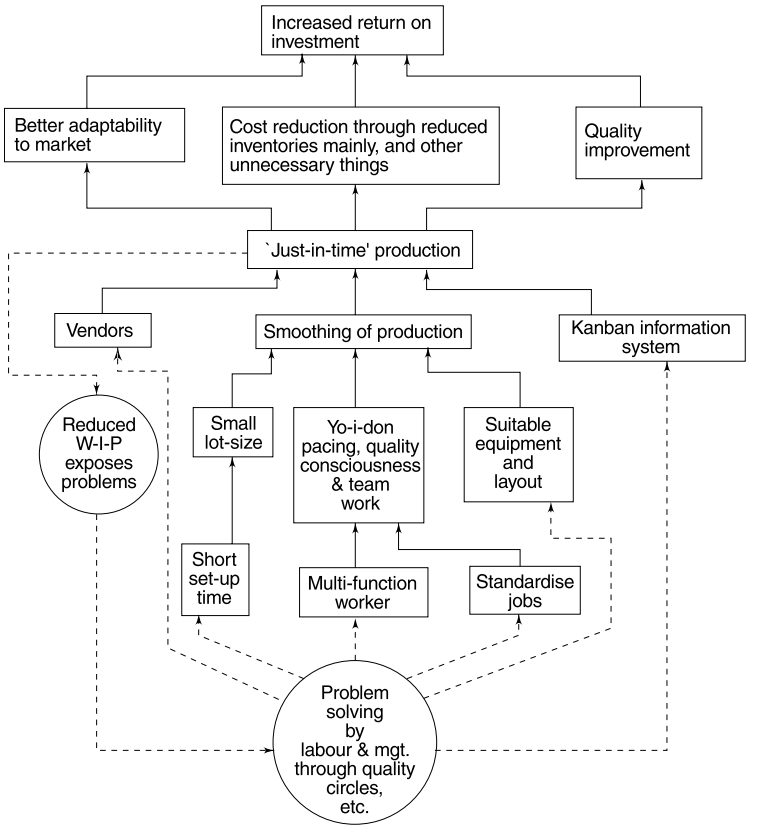


Figure 37.1 'Just-In-Time' Production System

The McGraw·Hill Companies

In order to produce the required quantity by a given time at all the work places, it is very necessary to standardise the operations in terms of machines, materials and methods.

Smoothing

The other important aspect of J-I-T is the 'smoothing of production'. Since inventories are to be avoided at all places including the finished goods and to have uniform workload at all work places, it is essential to convert the demands for the final products into a sequence of single unit productions, the sequence repeating itself in time. For instance, if the monthly demand for Maruti vans is: 1000 flat-tops, 500 dome-tops, and 500 'tops' (at this juncture imaginary), then under J-I-T we need to reduce it equi-proportionately to the daily demand of 40 flats, 20 domes and 20 tops (assuming 25 days per month). This demand needs to be further micronised to the single unit production sequence of Flat-Flat-Dome-Tops/Flat-Flat-Dome-Tops/Flat-Flat-Dome-Tops/. This type of sequencing at the single unit of product level helps in eliminating the lot sizes, in facilitating smooth withdrawals from preceding processes and in the even-balancing of the work flow through the various workspots.

It may be noted that for such smooth production flow, a monthly (depending upon various lead times) fairly stable production plan is necessary.

Short Setup Times

However, what such a 'smoothed production' needs is short setup times because it assumes that there is very little time lost between the different changeovers. The reader may easily understand that the single-unitisation (or at the worst, small lot production) implies that the setup times be small. For cost economy, the smaller the lot size the smaller the setup time should be; otherwise, what is saved on the waiting time between processes will be wasted on the increased production time. It may be easily understood that if the setup time is lowered to, say, 10% of its earlier value, then the lot-size can also be lowered proportionately; because for optimal costs, the setup and carrying costs have to balance.

In the Toyota Motor Company in Japan there have been continuous efforts to reduce the setup times. For example, the setup time of the pressing department which was 2–3 hours during 1945–64 was reduced to 3 minutes after 1965.* Such setups which have single digit (in minutes) setup times are called *single setups*. Through the use of Quality Circles, setup times of even less than a minute have been achieved in some cases at the Toyota Motor Company, Japan. These may be appropriately called *One Touch Setups*. This kind of reduction in setup times has been achieved by (i) recognising the internal portion of the setup as being different from the external portion, i.e. activities that can be done while the machine is running, (ii) by converting internal setup to external setup as much as possible, and (iii) by eliminating the 'adjustment' aspects in the setup.**

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* Yasuhiro Monden, 'What Makes the Toyota Production System Really Tick?' *Industrial Engineering*, Jan. 1981.

** Yasuhiro Monden, 'How Toyota Shortened Supply Lot Production Time, Waiting Time and Conveyance Time', *Industrial Engineering*, Sept. 1981.

Need for Multi-skilled Worker

In order to ensure a smooth production process, it is necessary that the workers be skilled in a number of functions. The worker should be able to operate different types of machines required for different jobs, be of help to his neighbour in times of trouble, carry out routine maintenance and be his own quality inspector. The use of mono-skilled and mono-function workers in industry, which is the case in India and also in countries like the U.S.A. leads to much under-utilisation of labour/machinery and an increase in the wasteful conveyance time if J-I-T were to be used.

Small fluctuations in the demand can be taken care of by J-I-T, through the use of elongated shift-working and deployment of temporary (skilled) workers. However, if the demand is slightly lower, the work is finished early and the rest of the period is used for either workers'rest, or activities such as practicing set-ups, Quality Circle meetings, preventive maintenance, etc. J-I-T does not believe in over-production. Rather, over-production is thought to be much worse than under-utilisation of machines and manpower.

Since J-I-T stipulates strictness in adherence to standard process times, naturally more and more automation is preferred.

KANBAN PRODUCTION INFORMATION SYSTEM

A J-I-T production system uses a peculiar material withdrawal and work ordering system. This is called the Kanban (or marker) system. As we have so far noted, the J-I-T system works based on the requirement at the final product level. Basically, it believes in producing at a time only that many items as have been withdrawn. This chain of withdrawal-and-production is continuous from the end product to the beginning process. This is the way the work-in-process inventory is kept very very low. (In the J-I-T system, in fact, the inventories are not kept in the store but on the shop-floor, right in between two preceding and succeeding processes.) The withdrawal of material from the preceding process and the production of items to replace this is ordered through a withdrawal and production Kanban (or marker card). It is a physical control system, and is visual in nature which is an advantage over the conventional production control paper work which could be quite confusing at times. The Kanban system is illustrated in Fig. 37.2.

As indicated in Fig. 37.2 the withdrawal Kanban (WK card) and the Production-ordering Kanban (POK) card keep shuffling back and forth. Whenever withdrawals take place from a work centre, the POKs from the full containers are removed and replaced by WKs. The POKs indicate that much of production output from the process (work centre). They are picked up from their collection posts, the designated production quantity is manufactured and the POKs are returned tagged to the respective (full containers) once again. The WK, which accompanies the withdrawn container proceeding to the next production process, is again returned to the WK post when the containers get empty. When the material is to be drawn from the preceding process, these WKs are collected along with the empty containers and the cycle starts afresh. By this simple physical and visual method, the requirements of the type of product are conveyed down the line from the final process to the beginning process. The Kanban system connects successive pairs of work centres such that, a 'conveyor line' effect is realised.

The containers for the material are of fixed size, and the production lot-size is that which a container can contain. The number of containers used depends upon: (i) the cycle time for a container to go the next work centre and return, (ii) the rate at which the material is getting consumed, and

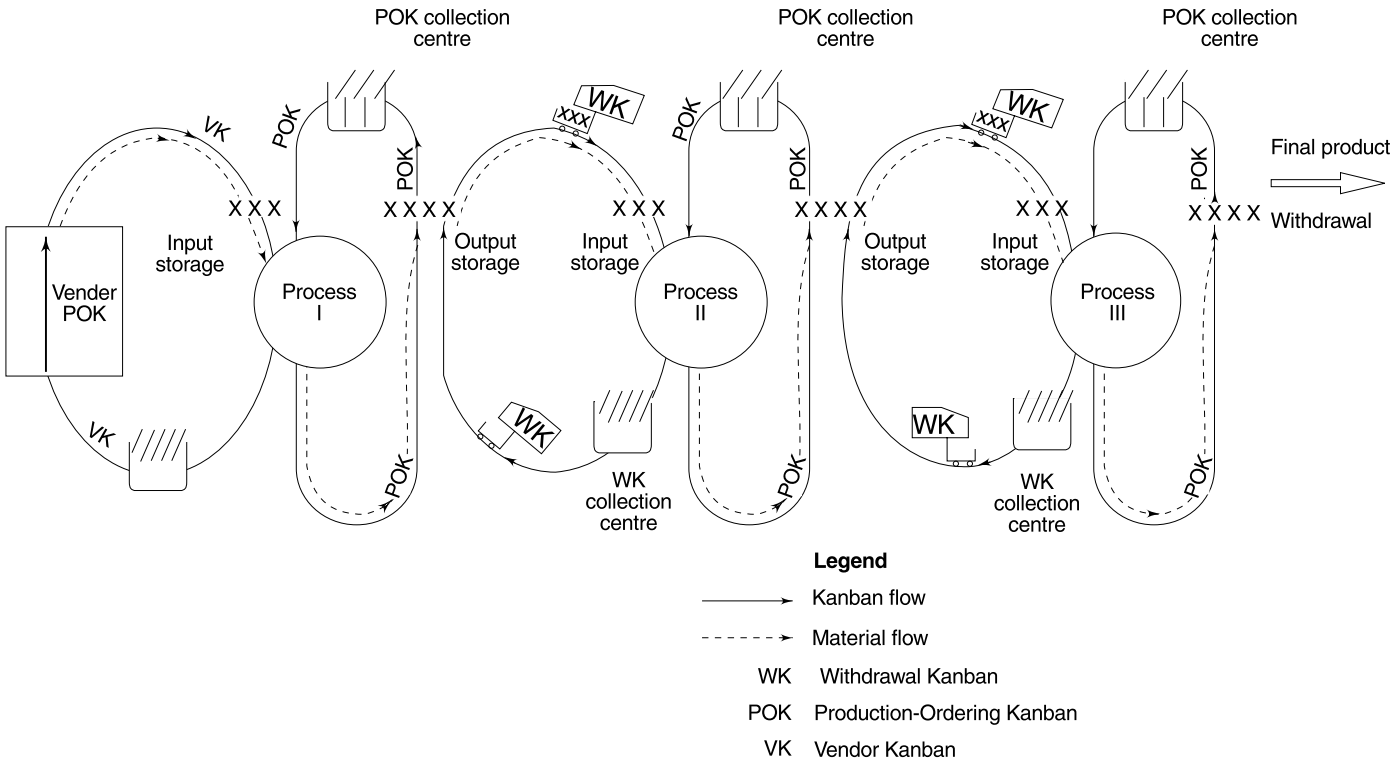


Figure 37.2 Kanban System (Including Vendor Participation)

(iii) the size of the container. Needless to say, the number of containers (i.e. the work-in-process inventory) should be small. This can be achieved by reducing the cycle time. This means a reduction in the setup and conveyance times.

IMPETUS TO QUALITY PRODUCTION

Due to the Kanban system, a work centre will withdraw the required type and number of output items from the previous work centre at a required time. The previous work centre will then produce only that many items which have been withdrawn. It may be noted that defective production at any one work centre will create chaos in the succeeding work centres, particularly because of the mechanical (physical) nature of the Kanban information system. Therefore, the production of good quality cannot be any better emphasised. Moreover, this system itself reveals such problems immediately and glaringly on the production floor for all to notice. This puts much peer pressure on the defaulter, if the problem of quality is the person producing it. For an example of Kanbans see Fig. 37.3.

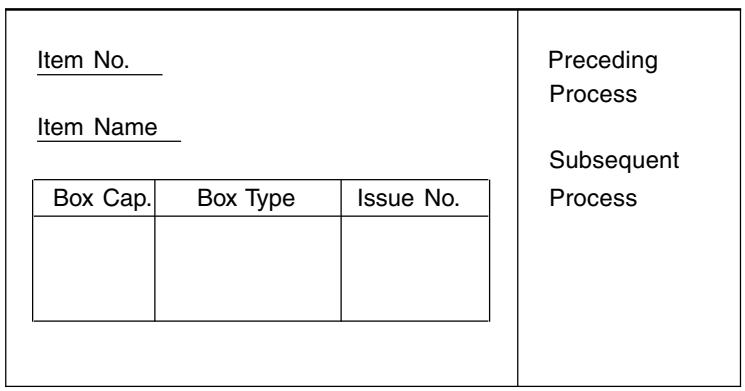


Figure 37.3 The Kanbans

Cooperation of Company Vendors

To be successful, J-I-T needs the cooperation of the company's vendors. The latter should also participate fully in the J-I-T system and become, so to say, an extension of the company (refer Fig. 37.2). Otherwise, because of the problems in the raw material/bought-out parts supply, the whole 'conveyor' of production processes linked with Kanbans may break down. In J-I-T, the vendor is not an adversary as in conventional purchasing, rather he is to be viewed by the company as a partner. One does not think of alternative sources and multiple sources of supply; rather one thinks in terms of having one good supplier and of developing him. Multiplicity of sources will create confusion under J-I-T. Also note that the J-I-T 'conveyor' extends to the vendor plant, and therefore the vendor is required to deliver good quality, always. There is little time in J-I-T for post-mortem analysis or for waiting, and therefore the vendor himself has to take the responsibility for the quality of the goods he is supplying. This is similar to the situation in J-I-T where the production worker himself assumes responsibility for the quality he produces and sees to it that no bad quality item ever enters the succeeding process. This is, indeed, a totally different philosophy in quality management—very similar to the 'zero defects' concept. J-I-T, therefore relies much on positive motivation—whether it be workers or vendors—so that the best of everyone is brought out and a symbiotic relationship is established. The emphasis is on long-term relationships, amicable settlement of any points of dispute and cutting down on the mutual-belief-destroying and constraining bureaucratic lines of communication. The vendor may be given a life time (of the item) contract, perhaps for a number of items, with the price negotiations expressing concern for one another's problems and prospects.

In J-I-T, the vendors have to deliver goods to the production line at the required time-which may be quite frequently—for instance every 3 or 4 hours. Therefore, it is necessary that the vendors be near the company, perhaps in the same town. Otherwise, it is physically not possible to deliver so frequently. Even so, the transportation costs of very frequent deliveries are high and it may be worthwhile for 3–4 vendors in the area to pool vehicles and make round-robin deliveries.

Need for Self-discipline

As mentioned earlier, positive human relations is the basic pre-requisite of the J-I-T system. Here, each individual worker is his own boss. The entire J-I-T conveyor is dependent on him. The strength and necessity of this system is discipline or self-discipline and not one that is imposed. The system is quite fragile for an imposition of discipline. The worker produces, paces himself appropriately, checks his own work and ensures zero defectives in his output that is sent to the next process in line. The worker is a whole time partner in the plant's operations and not just a wage-earner. This kind of a thinking should govern the relations between the company and him. This philosophy goes even beyond participative management; what is required is not just equality in the availability of benefits and power but an attachment and a commitment similar to that in a family.

Commitment of Top Management

It needs no elaboration that for the success of J-I-T the solid support and commitment of top management is a must; because, J-I-T requires radical changes—physical and mental. It needs vision and good leadership to manage this tremendously human-oriented system.

DIFFERENCES BETWEEN J-I-T AND MRP

J-I-T is, many a time, compared to Materials Requirement Planning (MRP), perhaps because both lay emphasis on the question: 'When is a material required?' Firstly, the two systems are used for different types of demand. While MRP can be used for a dynamic situation, that is, when the demand could change significantly in the future, J-I-T is incapable of taking large and sudden variations. J-I-T is basically, for a repetitive manufacturing system. Secondly, and somewhat paradoxically, J-I-T is single unit production, whereas MRP involves lot sizes at all levels of the product. The rigour of J-I-T in eliminating inventories is in no way comparable to the rather limited MRP intentions. In fact, MRP is prepared to make some compromises and even keep safety stocks to insure against demand and supply variations. Thirdly, MRP does not require human-orientation as a pre-requisite as in J-I-T. Fourthly, in MRP, there is not as much stress on vendor relations as in J-I-T. In short, MRP, can work with all the conventional beliefs about and approaches to people; whereas, J-I-T is a system requiring radical re-orientation in our approach to people within and outside the company. To repeat, in their common focus of attack—the inventories of material—they differ in their intensity: J-I-T tries to make the ideal of no inventories come true, while MPR is only interested in low levels of inventories. Another difference is that J-I-T has to be bothered about quality unlike MRP. Finally planning in J-I-T is simple—one needs to plan only the smoothened production of the finished products; whereas, in MRP one needs to plan for every intermediate product and process as well.

J-I-T AS A BUSINESS PHILOSOPHY

J-I-T should not be viewed as a mere production system. It expresses, in fact, an organisation's philosophy of customer-orientation. Service to the customer is the focus of J-I-T. The production system is a consequence of this business philosophy. Service includes providing to the customer the product (necessary service) in time, providing him variety of products, allowing him to choose as per his preferences, providing him with quality products, providing him service/ product close to him (space utility), and communicating with him more intensely than before–almost including him in your own facility or vice versa and above all providing product/service at a price affordable and perceived as reasonable by the customer. Such service-orientation generates the need for an appropriately responsive production system such as a J-I-T system.

As the customers are to be provided a variety of products and in time, the production of the finished goods should be in very small lots. For the same reason, the upstream production processes should also produce equally small lots just to meet the downstream needs. Going upstream in this manner, it is obvious that the vendors too have to supply items in small numbers and just–in–time.

In order to produce a very small lot, almost a single unit at a time, the prerequisites are that there are no defective items produced, which further means:

(i) the workers are motivated to produce defect-free items; they feel more responsible;

(ii) the worker, therefore, should be empowered to take his own decisions with respect to the item; that he inspects his own produce; that there should be minimum supervision, limited to guidance and counsel when required;

(iii) the workers should be multi-skilled, so that in case of problems they could help each other; and

(iv) the vendors also produce defect-free, perform self-inspection and certify.

Human relations is, therefore, at the core of J-I-T; and these human relations include vendors, employees, dealers and customers, i.e. the entire value chain. Thus, J-I-T is about the 'Time' dimension because the organisation respects and cares for the customer. This 'care' is shown in several ways including the timely service.

Figure 37.4 depicts that the focus of the JIT system is on providing service to the customer, i.e. what the customer wants is to be provided just when the customer wants. Quality product at low price is to be delivered in time. This means zero defects, zero inventory and small lot production. Entire system is built around manageable small lot production because lower costs and lower response times can be better achieved, if the production is in small lots. This, in turn, necessitates smaller sizes of consignments from vendors that require supplies with certified zero defects. In order that zero defects become a reality, the firm's employees and those of its vendor/s need to be trained (in requisite skills, knowledge and orientation) with a focus on providing service to the

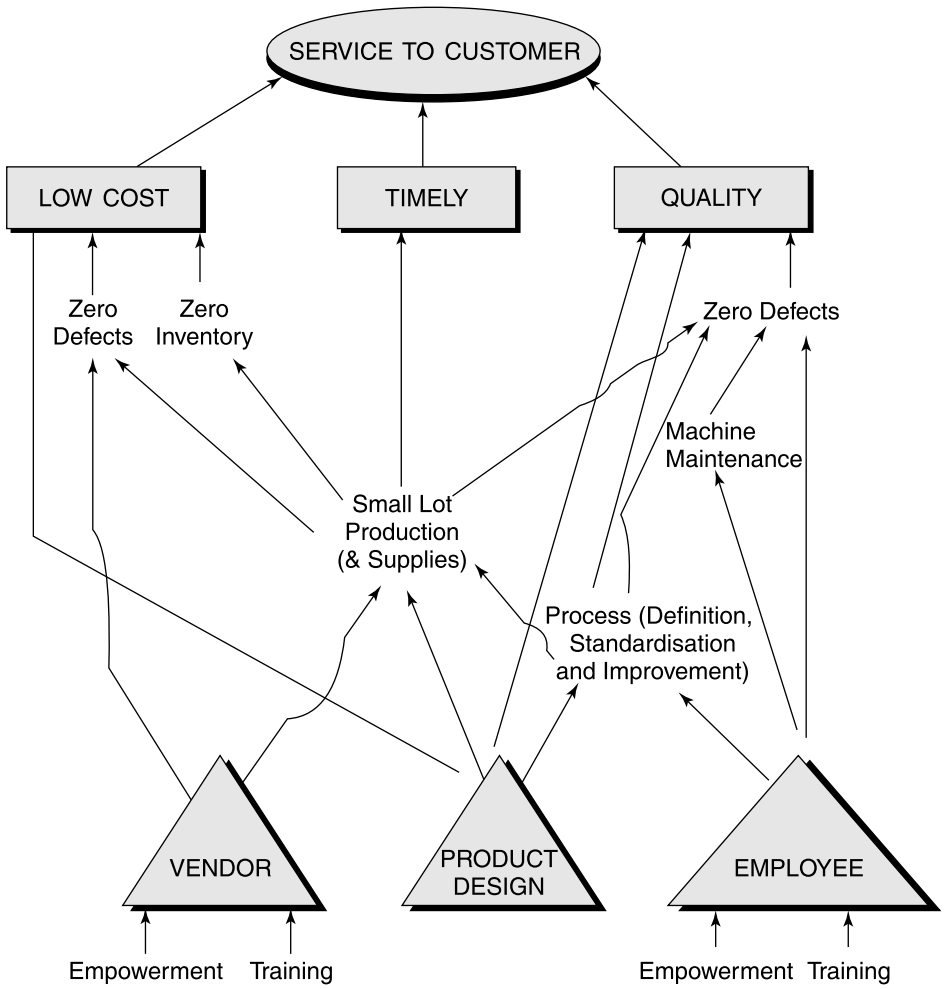


Figure 37.4 JIT Production–Foundation and Focus

customer. They need to be empowered because only empowered workforce can take right decisions when required and provide the required output with zero defects. Empowered and trained and, therefore, aligned employees and business associates are the foundation of this system. Product and service design also has a fundamental role to play in attaining the quality, time and cost parameters of service to the customer. Product/service design reflects the fundamental value proposition of the organisation.

THE INDIAN RESPONSE

Of late, Indian businesses have also been increasingly realising the importance of time as a dominant dimension of global competition. Otherwise, the typical Indian reaction to any kind of competition has been to lower prices and not to compete based on quality and time as expected by the customer. It is somewhat heartening to see companies such as Dabur Group Foods Division introducing one new brand on every successive Monday during a span of six weeks. Coates, the Rs. 1,600 million inkmakers have set up an on-line computerised system linking every point from which information originates within the value chain: sales offices, depots, factories, transportation hubs and major suppliers. This real-time information infrastructure is visualised to be integrated further to include materials ordering, inventory management, production coordination, accounts and billing and also personnel management. Thus, Coates can have a large variety of products along with enhanced speed of order execution.* BPL Group designed its new models of colour televisions much before the market was ready for them, in anticipation of the customer demand. This gave them the head-start, much ahead of their competitors. Cadbury India, the more than Rs. 3,000 million confectionery company responded to the challenge of meeting the customer demand which is, generally, impulse-driven and hence difficult to predict, by streamlining the downstream and upstream activities in the entire value chain so that the system can respond quickly to the changes in customer requirements. Mysore Kirloskar Ltd. at their Hubli plant manufacturing machine tools have also streamlined their production facilities reducing their cycle times and reaction times.

It is true that the Indian industries/businesses, in general, have to go a long way before coming up close to a Just-In-Time philosophy. Since it is a different philosophy, one has to look into the two different socio-cultural systems viz. Japanese and Indian. It is always easier to translate the existing socio-cultural system into the business/industry culture. On that count, Indians may be considered luckier than the Westerners. Indians do have a tradition that is quite parallel to the requirements of a J-I-T; only thing is that the traditions/cultural patterns in an Indian family have not been transferred to the Indian industry/business due to historical reasons. For instance, there cannot be a better customer-orientation than the age-old custom of *Atithi Devo Bhava* (Treat any Unannounced Guest as God incarnate). The ideas of single-sourcing cannot be better exemplified than in the age-old Indian marriage system where divorce was very uncommon. It exemplifies the kind of commitment, the feeling of sharing and continuous learning about each other that one needs to bring about. Likewise, participative management and treating the employee as a member of a family can be best benchmarked against the typical Indian family, which has a hierarchy-grandfather, grandmother, parents, uncles, aunts, brothers, sisters, cousins, etc.–but, they all participate and live together. Western style of participative management with equal rights for each

* Ref. 'Competing On Time', *Business Today*, Sept. 7–21, 1997, pp. 64–75.

individual does not effectively bind the already amorphous group of individuals. Indians, if they could translate their age-old traditions into the industrial/business setting, have the potential to become world-class in their management styles. This is not to advocate to tread back; rather, it is only purported to mention the potential this country has if its citizens care to make use of it in the right manner. The guiding principles for world-class business today are care, concern, commitment and self-displine. The route for it could be the olden Indian way or the western way of fierce individualism leading indirectly to the good for all (Refer book: *Virtue of Selfishness* by Ayn Rand). Either route is alright as long as it achieves the noble objectives of world-class management.

QUESTIONS FOR DISCUSSION

1. What is Just-In-Time production? What are its aims?
2. Why is a multi-function worker required in J-I-T?
3. What difficulties might you perceive in meeting the above requirement? Answer in the context of Indian human resources and human relations.
4. What is the role of set-up times in J-I-T? How should they be reduced? Give an example.
5. How flexible is the J-I-T system? Explain.
6. In its simplest terms, Toyota Production system might be interpreted as a special case of MRP. Comment.
7. Does J-I-T bring in a reduction in the (a) machinery and (b) manpower cost? Explain.
8. How would one go about implementing J-I-T? Elaborate.
9. What is 'Smoothing Production'? Why is it done?
10. Do you see any commonalities between Quality Circles and J-I-T?
11. Explain the purpose of Y ō-i-don.
12. What is the role of automation in J-I-T?
13. Does J-I-T combine the benefits of job-order production and that of line production? Explain.
14. What would be the role of supervisors under J-I-T?
15. What is the role of 'empowerment' in JIT business philosophy? Discuss.

ASSIGNMENT QUESTION

1. Study organisations that have been practicing JIT. Present your observations on the benefits obtained by the organisation and/or problems faced. Present a detailed report on the application of JIT principles and your suggestions.

38 Lean Operations

If Just-in-Time was a phenomenon in operations, 'Lean Operations' has been an improvement over it. The basic thought underlying it or the philosophy behind it is the same: that of 'providing service to the customer'. However, as the adjective 'lean' indicates, the operations are to be shorn of any excess fat. 'No fat, only meat' or in other words 'no wasteful elements' in the operations is the goal. Lean operations do not tolerate any 'waste'.

VALUE AND WASTE

In lean operations, 'value' and 'waste' are central concepts. Importantly, these are defined with reference to the customer. At every step, lean methodology checks for value and waste. Waste is to be constantly shed. But, what is 'waste'?

Are We Providing Value to the Customer?

Since providing value to the customer is the ultimate goal of operations, 'lean' considers any operation, any storage, any effort, any time spent, any expenditure of material or other resources that is done for any purpose other than for providing 'value to the customer' as waste. Value to the customer is of paramount consideration. In Chapter 1, the criteria of performance for operations management were mentioned. These were: efficiency, effectiveness and customer satisfaction. 'Lean' is totally in line with those objectives and re-emphasises the importance of customer satisfaction. In fact, it reminds us that the entire exercise of enhancing efficiencies and fine-tuning of effectiveness is mainly for satisfying the customer. According to 'lean', operations management exists for customer satisfaction. If the customer considers a product or a part of a product or a service as of no 'value' to him/her then that product or part of the product or service becomes a waste irrespective of its goodness in the eyes of the manufacturer or service-provider.

In short, there is a difference between 'adding value to a product/service' and 'adding value to the customer'. If the customer wants a simple *masala dosa* that tastes good, there is no value to the customer whether you add mozzarella cheese in its masala or stick a thin silver varkha (wafer) or gold plating on its outer covering. All the latter actions may add value to the product, but do not add value for the customer. In the eyes of the restaurant owner/manager, the dosa may be worth a

five hundred bucks, but the customer does not care and does not want to pay for all these embellishments. All these trappings are a waste.

'Value' is What the Customer is 'Willing to Pay' for

What is 'value'? According to the 'lean' thinking, value exists only when the customer is willing to 'pay' for a product or service. Any operation or part of it has to be tested on the criterion of "Will the customer be willing to pay for it?" In fact, any part of the product or any element of the service has to prove against this test-stone. Sans customer's willingness to pay, value cannot independently exist. Those tasks that the customer is not willing to pay for are 'non-value added' or 'waste' and these tasks should be designed out of the process or operation, simplified or reduced.

Fig. 38.1 indicates that the real 'value adding' operations/activities are many a time just a small fraction of the total activities. A heavy chunk could be non-value adding and, therefore, 'waste'. Another heavy but smaller chunk could be non-value added activities which are necessary.

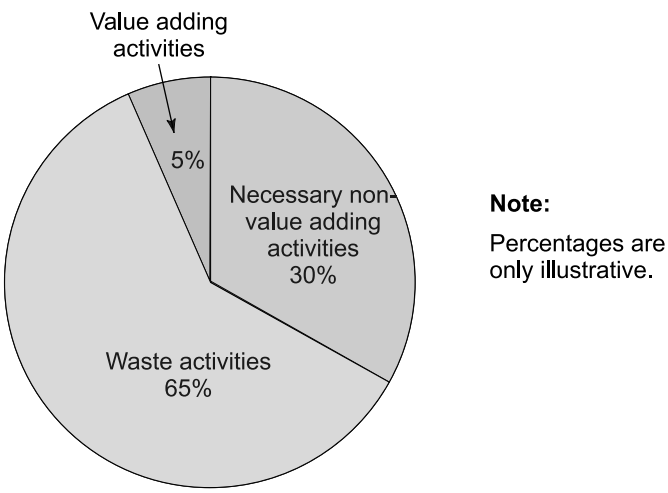


Figure 38.1 Value Adding Activities as a Small Fraction of Total Activities

An instance of necessary non-value added activity could be the inspection for quality. In the chapters on quality management, process control by means of various charts and acceptance sampling for material inputs into the processes were discussed. One has these control measures precisely because one is afraid that the machinery may wear out, the controls may drift, the workers/operators may make errors, and/or the vendors may slip in supplying quality materials. However, the customer actually cares little for any of these plausible reasons. S/he cares little whether the organisation has one quality inspection or multiple; s/he is least interested, if there is statistical process control with a p-chart or c-chart or none. S/he just wants a defect-free product or service and pays only for it. The customer does not care for and will certainly prefer not to pay for the quality control procedures or inspections.

Just because the customer is 'made to pay' (built into the price of the product or service) for the expenses on these quality controls, it does not mean s/he is 'willing' to pay for it. In fact, s/he would want the organisation never to make any errors if they could. The organisation may think

of the tough multiple quality control measures as a testimony to its commitment to quality. But, the customer is interested in only a quality product or service being delivered to him/her and not in what the organisation does in order to get that product or service. In short, the quality-related explicit costs are a 'waste'.

Learn to Separate Value and Waste

In some cases, the customer (a company in a supply chain) may specify a quality inspection or other procedure. Does that mean the customer is 'willing' to pay for it? No. In reality, the customer would like the supplying organisation to eliminate or 'design out' such inspection. Customer stipulates certain inspection only because s/he fears that the supplier is habituated to make errors and s/he would like to insulate her/himself from the effect of such undesirable errors as much as possible. Therefore, all quality control procedures, even if mandated by customers, are really nothing but 'wasteful'. Once a customer develops confidence that the supplier will not make errors, the customer will stop making those stipulations for quality inspections.

One may summarise the above discussion by saying that the amount of waste in our operations has no relation to the customer value. So, we must learn to separate 'waste' and 'value' in operations. That is the basic foundation of 'lean' operations.

Value-stream Mapping and Waste Visualisation

In order to pinpoint areas where there is 'waste', the present material and information flow or stream from the time the inputs are ordered to the receipt of the output/product by the customer has to be traced or 'mapped' in sufficient detail – but as a concise one-page picture - regarding the contribution to 'value' from each of the aspects given below.

- **(i)** All the processes
- **(ii)** All the material, energy, manpower and machinery inputs and/or efforts along with the times spent
- **(iii)** Stoppages/delays and storages
- **(iv)** Inventories (of raw material, work-in-process and finished goods as well as that of stand-by manpower and/or of stand-by equipment)
- **(v)** Production/operations control activities, scheduling methods, lot sizes
- **(vi)** Forecasts
- **(vii)** Purchase and work orders – quantity and frequency
- **(viii)** Cycle times and lead times
- **(ix)** Process control and other quality related inspections
- **(x)** Transports within and outside the plant or office (distance, frequency, loads, modes)
- **(xi)** Communications – the parties that are communicating, the information flows, the content, the channels and the frequency, etc.

For every one of the points above, the question is to be asked: "Does it provide 'value'? If so, 'what?' and 'how much?" We may call it 'waste visualisation'. Fig. 38.2 below provides a glimpse of this.

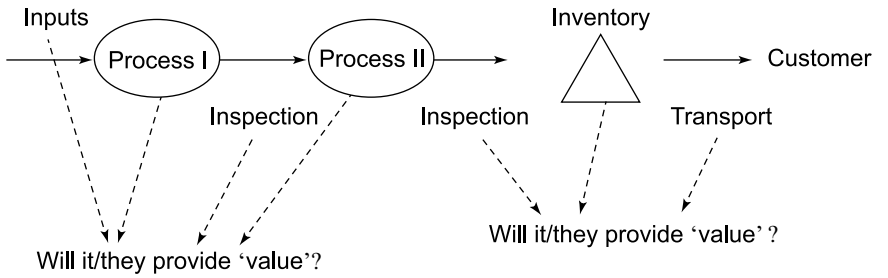


Figure 38.2 Touch-stone of 'Value'

The steps in Value Stream Mapping are indicated in Box No. 38.1 below.

38.1 STEPS IN VALUE STREAM MAPPING

(1) Understand the value desired by the customer
(2) Map the 'present' state (as indicated earlier in this section)
(3) Improve the flows and design a 'future' state that is 'lean', i.e. where fewer resources, less space, less time and less information are needed to provide the value desired by the customer.
It is recommended that this design of the 'lean value stream' should be a participative effort for better acceptance.
(4) Draw up a plan of implementation of this vision of a 'lean future'. This should be drawn with the agreement of all parties to the implementation.

Traditional Thinking Versus Lean Thinking

The basic difference between traditional thinking and lean thinking is the emphasis that 'Lean' puts on providing 'value to the customer'. Thus customer is at the forefront of the design of products, services and the processes/operations. Any resource spent – materials, machinery investment, money, manpower, management effort or time or information, and any operation or action done that does not contribute to value as perceived by the customer is 'waste'. Entire efficiency and effectiveness exercise is towards the supreme goal – 'customer satisfaction'. A company may save money, but if that does not contribute towards providing value as desired by the customer, then that saving is transitory. Enduring savings are those that help to provide customer value. In short, while the traditional thinking focused primarily on 'self', i.e. the company, the 'lean' thinking focuses primarily on the customer. The difference is one of inward and outward focus. The outside world matters to the firm more. That makes a world of difference. It calls for a change from a world of business pushing or shoving products/services onto the customer to a business world where the customer's requirements pull the products/services, processes and operations. The gains from a 'push' oriented business operation would be ephemeral. The present world is increasingly about sharing. Fig. 38.3 given below depicts these principles. One may work harder and faster as earlier, but it has to fit into improving value to the customer.

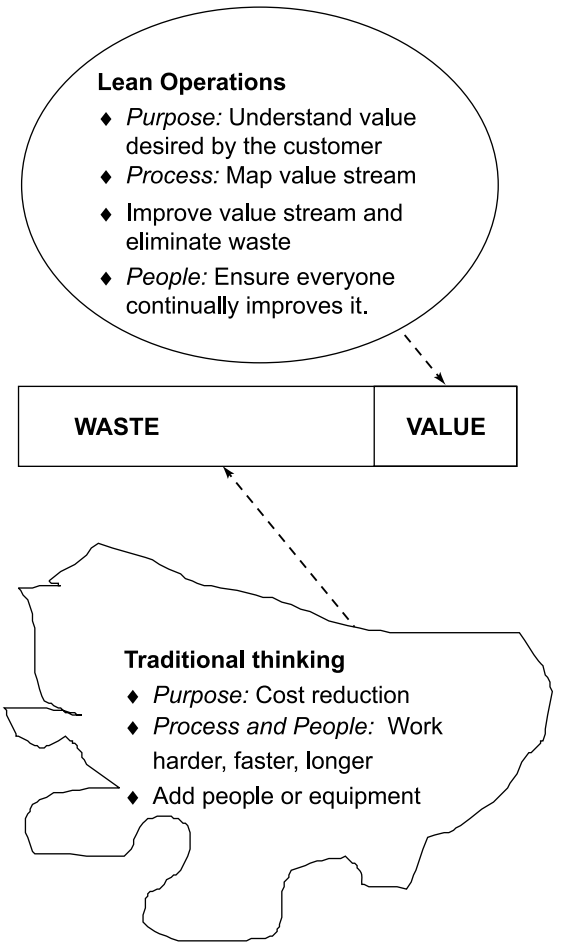


Figure 38.3 Traditional versus Lean Thinking

A Hint of Caution While Applying the Concept of 'Value'

However, product manufacturers and service providers must remember that 'value' is (1) contextual, (2) in relation to a bucket of needs and (3) many a time based on 'emotions'. If sold on the pavement, a cone of pop-corn may not sell for more than ten rupees, but the same customers would not hesitate to buy similar pop-corn in a cinema theatre for fifty rupees. Thus, the 'context' makes a huge difference to the value as perceived by the customers. Now, if the customer has already bought a burger or a pack of chips and a Pepsi or Coke, s/he is less likely to also buy the pop-corn. There is only so much the 'bucket' of needs can take. However, if munching pop-corn in a multiplex is the 'in thing', the customer will most likely buy the pop-corn at fifty rupees or even more and in preference over the burger or chips or other eatables. Thus, the value to the customer can be an evaluation based on 'emotional' factors – not based on real physical attributes. The point being made here is that while reducing/eliminating waste to make the operation 'lean', one must ensure that the attributes that add value to the customer are not being reduced in the process.

HISTORY OF LEAN OPERATIONS

The stress on 'lean operations' may be a recent development born out of globalisation of business and competition on an international level where goods and services are able to move and be available across national and regional boundaries with ever-increasing ease, speed and variety. With rapid developments in science and technology, new goods and services are giving a tough competition to the existing ones. In such a scenario, the importance of 'lean operations' cannot be over-emphasised.

While historically several visionary businessmen and scientists had understood the importance of keeping operations 'lean', the thought has evolved from 'cost minimisation' to 'improving value to the customer'. Box No. 38.2 offers a brief recount of some of these developments in 'lean operations'.

38.2 HISTORY OF 'LEAN' THINKING

- *Early 18th century:*
  Importance of Cost Reduction
  Benjamin Franklin mentions that avoiding unnecessary costs could be more profitable than increasing sales: "A penny saved is two pence clear." Regarding unnecessary inventories he says, "You call them goods; but if you do not take care, they will prove evils to some of you."[1]

Early 20th century:
Standardisation efforts

- Frederick W. Taylor (1911) enunciates the principles of time study in operations. He speaks of standard method and standard time. These developments help in controlling and improving output.
- Motion studies by Frank and Lillian Gilbreth (around 1915) suggest economies in motion and resultant enhanced output. They observed bricklaying – why do the labourers have to lift heavy blocks from ground level – wasting time as well as effort.
- Henry Ford does away with 'fitting' - until then used for making components and then fitting them on to make the product. With stringent specifications, he standardises the components and eliminates the need for a 'fitter'. It generates huge savings and is a phenomenal development. Assembly line flow would not have been possible without such standardisation.

Realisation of the Importance of Smooth Flow

- Henry Ford (1914) starts assembly line mass manufacture of cars with hitherto unimaginable improvements in the outputs. Costs come down drastically. Ford also explicitly realises the importance of arrangement of work places without which an assembly line would suffer. He also comes up with the concept of Design for Manufacture, i.e. the components are so designed that they can be made more easily and fitted more easily to make the assembly.

[1] Benjamin Franklin (under pseudonym of Richard Saunders), *Poor Richard's Almanack*, 1733 (First Printed), now available from Skyhorse Publishing Inc., USA (2007) and also from Big Fish Publishing, USA (2010).

- Walter A. Shewhart (1924) writes on statistical quality control. With this systematisation, the job of producing standard parts is facilitated which, in turn, helps smooth flows on the production floor. Wastes are reduced.

Mid 20th century (1960s):
Realisation of the Pervasive Importance of Quality

- Joseph M. Juran's expose on costs of quality and Genichi Taguchi's 'loss function' (inverted parabola) explain as to how deviation from acceptable quality could hit various areas of activity and the total economic loss could be very high. Without their explicitly mentioning it, the customer was important in their consideration. Deming with the '14-points' brought in motivational angle in quality while stating the prime importance of customer and society.
- The realisation that 1 per cent defectives mean 10,000 ppm pitched the desired scale of improvement very high. Such improvement in quality levels could only be achieved with a complete re-definition of processes and culture within the existing manufacturing systems.

1970s:
Just-In-Time Production System

- Toyota Motor Company in Japan tried to utilise the gains of Ford's mass assembly line flow while doing away with assembly line's drawback of being weak on variety of products by devising a unique "Just-In-Time" system that was based on 'pull' by customers on the production system. It was a revolutionary departure from the traditional 'push' system. Toyota might have done this as it had to survive and prosper in a small domestic market in automobiles while facing competition from giants such as Ford and General Motors who had the advantage of economies of scale due to large volume of demand back home.
- In order to be flexible to meet varying customer demands promptly and yet have a profitable operation, Toyota's Production System needed small-batch production, quick and simple production information systems (Kan-ban system), very short set-up times, single minute exchange of dies (SMED), zero defects, highly dependable and empowered suppliers supplying materials in small quantities almost "just-In-time" and of zero defects, machines made highly dependable through total productive maintenance (TPM), multi-skilled workforce who are empowered to take leadership roles when needed and a supportive top leadership that guided the transformation to everything 'lean' and 'fit' and did so with much sensitivity.

1988 and later:
'Lean' thinking

- John Krafcik is the first to coin the term 'lean' in an article in *MIT Sloan Management Review* (Fall 1988) based on his research on Toyota Production System. Continuing the research further, Jim Womack, Daniel Jones, and Daniel Roos wrote a best-seller book called *The Machine that Changed the World* (1990).[2]

[2] James P. Womack, Daniel T. Jones, and Daniel Roos, *The Machine that Changed the World.* Free Press *(a division of Simon & Schuster, Inc.), New York*, 1990.

- Lean thinking goes beyond Just-in-Time system in being highly explicit about its focus on customer. Any product, process, operation that does not provide value to the customer is a 'waste' and should be eliminated. A related question is: Can 'lean' thinking and 'profit' motive go together? Should improvements be done for enhanced profit for the firm or for the sake of the customer? Should 'customer satisfaction' be a sub-set of 'profit to the firm' or should profit be a by-product?
- Lean is a philosophy. Lean is not just a bunch of techniques to reduce waste – although techniques are essential for making 'lean' happen.
- Lean philosophy can have applications in various endeavours other than manufacturing.

TYPES OF WASTE

Toyota, which is the originator of the 'lean operations' movement, classifies waste into three broad types, viz. (1) Muda, (2) Muri and (3) Mura. All three are Japanese words and are explained below.

Muda

The rough equivalent of this word is 'non-value adding work'. 'Muda' can be of two types.

Type 1: Non-value-added tasks which seem to be essential.

Type 2: Non-value-added tasks which can be eliminated immediately.

Type 2 'muda' is easier to identify. It is all those operations/aspects that obviously do not add value to the customer. It is the inventory that is unnecessary, production that is in excess of requirements, flow of materials that is sub-optimal, extra work that the customer does not appreciate, transport of the materials that is unnecessary, movement of workers that is wasteful, delays that can be avoided, and defective units that need not be produced.

Type 1 'muda' is not always obvious. It is hidden under the cloak of supposedly essential non-value added work. Under a prevailing technology, the prevailing system of work or, more generally, the prevailing business environment, that non-value adding task is necessary to be performed. So, the business conditions need to be changed to eliminate this type of waste.

Shigeo Shingo, a Japanese thinker who has been the best-known exponent of single minute exchange of die (SMED) and error-proofing or poka-yoke, observed that only the last turn of a bolt tightens it—the rest is just movement. The turns other than the last turn are waste – but these are hidden as work that must be done under the current system. They may be called as 'non-value adding work'. But does it really 'work'? That is the question one must always ask. The point is: 'waste' could be disguised in many ways.

Seven Types of Muda

Taiichi Ohno, credited to be a major contributor in the development of Toyota Production System, lists seven basic 'Muda'. These are as follows.

(1) *Transport:* This waste corresponds to unnecessary conveyance. Companies may love to convey products. It may be easy to have a posse of conveying machinery – fork-lifts, overhead cranes, mini-trucks, trucks – instead of thinking hard on how to organise flows. The remedy can only be to reorganise the flows of materials within the plant or even outside. Inside the production plant, the required machines should be placed closer together or one may change to a cellular layout to reduce transportation.

In an office, papers may travel unnecessarily. The waste could be due to: (a) multiple (unnecessary) points/desks to be touched, (b) desks not optimally arranged for efficient flow of the necessary papers, and (c) unnecessary papers/communications. An O&M (Organisation and Methods) study could check the purpose of the papers and the purpose of multiple decision/noting points and eliminate (c) and reduce (a) to the only essential ones. A study of the office layout could reduce (b). Multiple, unnecessary and thoughtless handling of materials/papers causes this 'muda' of transport.

(2) *Inventory*: Inventory can be associated with several ills in the organisation as was seen in the chapter on Just-In-Time production system. High levels of inventory are as much a cause as a symptom of things going wrong. Inventories – whether of raw material, work-in-process and finished goods – all contribute to heavy costs of carrying them.

They are also a symptom of problems in the value stream because more often they are used to cover up or insure against these problems in the processes, in maintenance, in supply chains, in information flows, in logistics, in the coordination between different departments like marketing and production, and sometimes even in the presentation of finances.

When these inventories sit for long, they cause the very same problems that they are supposed to cover up. In short, inventories mostly do a 'cover up' job. They need to be exposed and expelled.

(3) *Over-production:* This is a common occurrence with 'push' style of operations. Firms produce products before the customers need them, either in anticipation of demand, or over-calculation of demand, or in order to make up figures for the year-end, or to generate evenness of load on the facilities. This may result in carrying inventories. Sometimes the firm may carry dead inventory that cannot even be used differently.

Not only does the firm carry unwanted inventory but would also have wasted good production hours in making that inventory and in the process would perhaps have also lost out on other opportunities by tying down the operations facilities.

(4) *Over-processing:* These are the unnecessary work elements or procedures. The reasons for over-processing could be:

- **(a)** Lack of thought over how the processes could be improved, and
- **(b)** Attempting to over-please the customer with features/embellishments/quality characteristics that the customer really does not appreciate.

The above is like putting three coats of paint when two will be enough. The customer does not care whether there are two coats or three, as long as the paint does its job and retains its characteristics.

(5) *Motion:* Movement of people and equipment that does not add value to the product/service causes this waste. For instance, a worker may move back and forth long distances to get a tool. Instead, the necessary tools could be kept close to his workplace thus eliminating this 'muda'.

In some factories, a worker has to go up and down two flights in order to fetch a necessary input material. This is not only a wasted motion and effort but overburdens him/her. This gives rise to another type of waste (Muri) of unreasonable work pushing the worker beyond his/her physical limits and thereby being a source of multiple variations and defects (which is another type of waste Mura or inconsistency).

(6) *Waiting:* These are time delays and idle times during which value is not added to the product. If the machines, men and material wait, (1) it is waste of these resources and (2) it demoralises the employees. The latter gives rise to 'mura' of erratic work output from the employees. It may even give rise to uneven workload on the processes and people. This is 'muri'.

Moreover, time is money. Delays in reaching the product/service to the customer will result in loss of credibility and loss of business for the company. Projects have to be completed on time whether they are in hardware or software. When business suffers, unevenness ('mura') is generated in the organisation. It gives rise to erratic overloads on equipment and on people. When natural limits are stretched, quality variations and erratic behaviours can occur ('mura'). The latter can result in bad work from the employees, which is a terrible waste ('muda').

(7) *Defective units:* A defective unit means a loss of that much output. If it cannot be reworked, it also means a loss of that much material and the machine life, the human labour, time and attention that have gone into producing it. This is the obvious loss. Of course, the process of rework itself entails cost.

The less obvious loss is the disruption of processes when a defective component is fitted, when a machine or production line grinds to a halt or slows down for a while to allow rectification of the defect, when the defective component gives rise to a problem in the process and thereby produces more defective units to compound the matters. Bad quality generates further bad quality.

Even more serious problem with bad quality is that the credibility with the customers suffers. Faith is an important element of business or of any relationship for that matter. If this takes a hit, the effects on the business/relationship could be long-term. Credibility is fragile; it breaks easily into fragments, but it is difficult to put them back together. Figure 38.4 summarizes the above seven types of Muda or wastes.

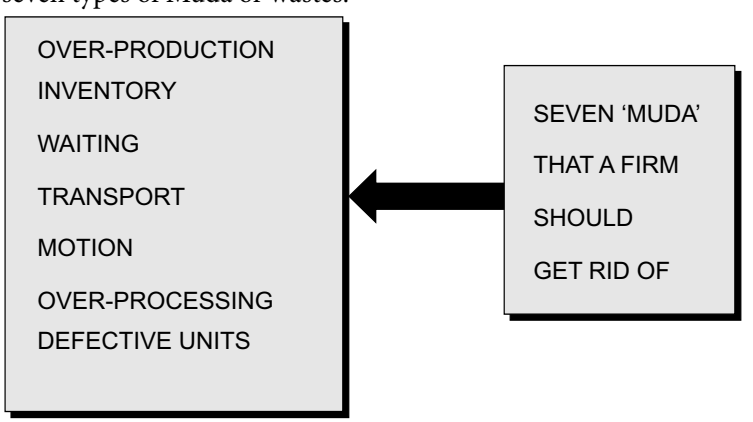


Figure 38.4 Seven Types of Muda

Muri

This is the unreasonable work that is imposed on the equipment and people due to poor management. A machine is made to run faster than its limits, a process is asked for greater level of performance than it can handle, people are made to work harder than their limits and are made to

work in bad working conditions. Unfortunately, it is not uncommon to encounter such 'muri' in several factories around the world. People do work and stay in abhorrent environments. But, then this has its own negative effects on quality, variations, and productivity.

It can also be a cause of accidents. Bhopal gas tragedy may not have occurred and certainly not with such huge loss of lives, mutilation of limbs and carry-over of genetic effects had the plant not been so close to a crowded part of the city. That in itself was poor planning. The systems and checks were not adequate to take the overload when the accident occurred.

Mura

This is the waste of inconsistency and variation in the quality and volume of products and services. When there is unevenness in the flow of operations, it may give rise to several wasteful stocks, stoppages, delays, sudden increases and decreases in speed of work and unmanageable variations in the processes and their outputs. In fact, Just-In-Time system of production tries to remove the unevenness of flows. By having smooth flow of value-adding activities, this production system exposes many problems hidden behind the heap of inventory. Quality related problems, supply related problems, machine maintenance problems, people problems and several other come into the open and these can then be dealt with.

Muda (waste), Muri (overburden) and Mura (unevenness) are Interdependent

The wastes of muda, muri and mura are interdependent or tangled with each other. In a sense, they cause each other. For instance, muri may cause mura and this, in turn, may cause muda as was mentioned earlier in this chapter. Due to this reason, eliminating wastes is like killing a demon that comes alive after every slaying.

When the machines and men are overloaded ('muri'), they may cause (i) deviations from quality, (ii) deviations in productivity and, therefore, in the output, and (iii) breakdowns (machine breakdowns, employee absenteeism, in serious cases staff strikes). All these cause the production system to go haywire, i.e. cause much unevenness ('mura'). In order to combat the uneven output, the management may strike a panic button and decide to have more inventories of finished goods and work-in-process ('muda') in the hope that these can cover the customer demands despite what happens inside the plant. However, this adds to the 'muda' of inventories and also further complicates the matters by adding to the unevenness of production outputs and flows ('mura') within the plant. Actually, because of the earlier overburdening of the employees and machines, problems in quality had taken root. This would have its ripples in the market. The customers may lose the trust in the firm's product. This may cause a drop in the demand for the product. This causes further unevenness of flows or 'mura'. This further adds to the problem of keeping stocks ('muda') at a time when the demand has fallen. This 'muda' causes problems in working capital and hence the company may cut costs by delaying maintenance or delaying payments to their suppliers or sometimes even delaying wages to the employees. All these thoughtless actions cause further disturbances or unevenness of suppliers not supplying on time or employees not cooperating (output suffers as a result). Thus, 'muda' causes 'muri' and 'muri' causes 'mura' and the 'mura' causes 'muda' once again. It is a vicious cycle. Try to tinker one of them without proper thought, and we have more of a problem. It is not even a cycle, it is a tangle. Fig. 38.5 depicts the interactions between the three.

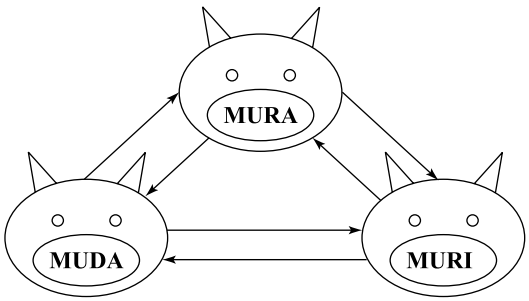


Figure 38.5 The Vicious Tangle of Mura, Muri and Muda

The above occurrence is not uncommon. Cases have been seen where a large airline buys a number of new aircraft at a huge cost without thinking or erroneously anticipating demand. When the demand does not match the equipment already available, the costs of capital ('muda') and of maintenance cannot be adequately covered. Losses make the airline to cut corners in its service; flights are cancelled/postponed/clubbed together without notice to the travelling customers. Flight schedules go haywire ('mura'). This affects its sales further and the idling costs mount ('muda'). The airline now starts delaying salaries and allowances (which are bigger than the salaries) of the pilots and other flight staff for as long as six months. Pilots and flight crew is overburdened ('muri'), many a time, with overtime work. This 'muri' causes further 'muda'. The quality of service further suffers – with delays of flights, near-accident situations, lapses in service inside the aircraft during flights. The number of travellers using the airline goes down erratically causing added 'unevenness' or 'mura'.

The cycle of this muda causing mura causing muri causing further muda has to be broken with a proper well thought-out plan of action. It should be a proactive plan. When management only reacts to a tricky situation, the tangle only gets worse. Break the tangle at a planned convenient point, but be aware that one of the heads of the three-headed monster might show up. Be ready to take action on it as planned.

'5S' TECHNIQUE OF ELIMINATING WASTE

'5S' stands for the five words in Japanese that start with the letter 'S' when spelt in English. These words are the five actions that would help remove 'waste' from the operations. At the ground level, these S's seem like simple tips on 'housekeeping'. But, proponents of 'lean' operations believe that any action towards going 'lean' should start from good housekeeping. It is the foundation for lean operations.

5S ensure that in the work area only necessary equipment, tools, materials are present, that there is a place for everything and everything is in its place – neat, clean and ready to use, that the work practices are standardized and the focus on these principles is maintained. A brief description of each one of these S's, to be performed in stages, is given below.

Seiri (Sort)

Organise the work area by sorting and keeping only the tools, materials and instructions necessary for the process in question, eliminating all the unnecessary items from the work area. Clutter

can be a cause for many problems like delays, defective quality, drop in productivity and wrong communication. Imagine a situation when gauges are not calibrated on time because too many are held. Delays, quality problems and productivity loss could result.

Seiton (Straighten)

The second stage of 5S involves orderly arrangement of all the necessary items so that they are easy to use and accessible for anyone – not only the present operator but any other substitute person should also be able to locate and use. There should be a place for everything and everything should be in its place. All tools, parts, instructions, supplies, or equipment should be kept close to the point of use and so arranged that the work flow is facilitated. That is, the flow path should be set in order or 'straightened'. Ergonomics, i.e. facilitation of the operator's movement is one of the considerations in suitably arranging the work area. Orderliness has many benefits – improvements in productivity and quality, error-proofing, ease of work, and better safety among other.

As one checks for orderliness in one work area, one would discover aspects of orderliness of the flow of current output work into other work area. This could set the ball rolling for an orderly arrangement of all related work areas with respect to each other i.e. facilities layout.

Seiso (Shine)

This is the third stage. Cleanliness or keeping everything – machines, equipment and tools – in the work area 'shining' has many advantages. If everything is clean, then that work station is immediately ready for use. This cuts down on the preparation time – because one is sure that equipment that is clean is always available and ready for use.

The concept of cutting down on the preparation time is an important one and one can see its useful extension not only in single minute exchange of dies (SMED) but also in the pit-stops of the Grand Prix where the change of tires and refueling takes just a few seconds.

Cleaning reveals or lays bare open many hitherto unnoticed problems. Any non-conformity stands out. Needless to mention that in several cases cleanliness helps in maintaining quality.

It is easily understood that the 'clean rooms', which are used in the manufacture of micro-electronics and nano-technology based products, need to be clean. They definitely have to be absolutely dust-free. Also in the manufacture of pharmaceuticals or peripherals, cleanliness is of paramount importance. However, even in the engineering industry, cleanliness helps in the ease of work flow and prevention of errors. Cleaning comes closer to preventive maintenance because systematised cleaning would involve checking or inspecting.

Seiketsu (Standardise)

What has been done in the earlier three stages of 5S has to become standardised. Work practices should be standardised and should be identical across all work stations doing the same particular job. This will enable all employees doing the same job to work in any work-station with the same tools and supplies that are in the same location in every station.

Standard work is one of the important basics of 'lean' operations. Everybody should know exactly what her/his work responsibilities are. Confusion, doubt and subsequent deviation mean unevenness – of quality and of flows – which is the waste 'mura'. It is known that one mura would set the ball rolling for other muda and muri.

Shitsuke (Sustain)

5S is not a one-time affair. Any 'lean' system – 5S is a part of it – is a work in progress. The organisation has to continue applying the various S's and continue to improve. Generally, once a problem is sorted out, the organisation shifts its attention to other problem elsewhere. This results in the previous problem-area slipping back to the old ways. 'Shitsuke' measures ensure that the 5S become part of the organisation's work culture.

5S was developed by Hiroyuki Hirano. That 'housekeeping' helps in productivity and quality improvement was already known to many in the industrially developed world. However, Hirano brought home the vital role of housekeeping principles in all operations. It was not just housekeeping, i.e. as it existed but a make-over programme for the house. Moreover, he provided a structure for the improvement programmes pointing out a series of clearly-identifiable steps, each building upon its predecessor. While the Western businesses were doing the operations housekeeping in a haphazard way, Hirano impressed upon the need to break the programme down into a series of steps. There was a definite order as to which step came first and which would come next. For instance, he explained that any effort to consider layout and flow before the removal of the unnecessary items was likely to lead to a sub-optimal solution.

The five steps of 5S technique have been depicted in Fig. 38.6 below. While the organisation's flag can be hoisted after the five steps are climbed, Hirano's last step emphasises that climbing up these steps should be a continuous affair and should become part of the organisation's culture. Again, for the Western business world the concept of organisation 'culture' was quite new and illuminating.

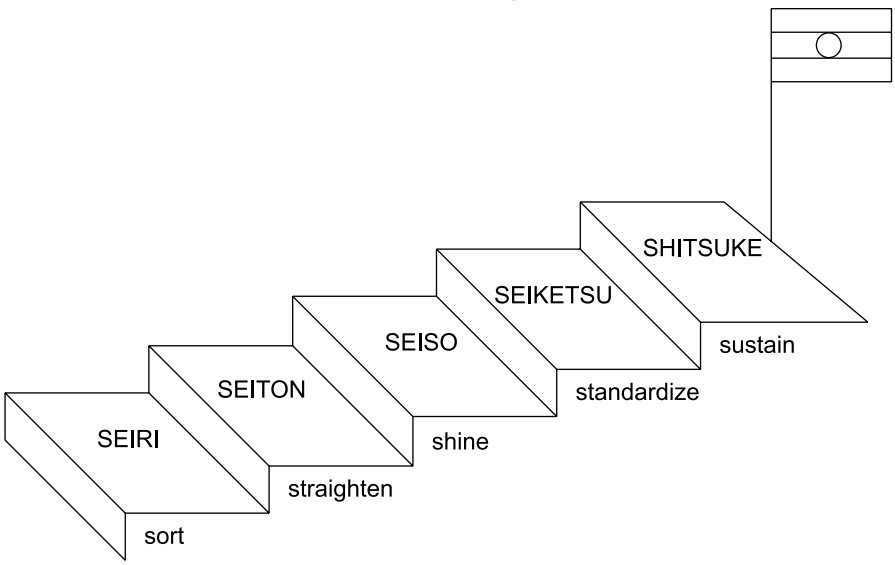


Figure 38.6 Five Steps of 5S

LEAN OPERATIONS IN THE SERVICE SECTOR

Services, in a large part, can be intangible. The product offered, unlike in manufacturing operations, may not be a tangible product. For instance, in consultancies, in education, or in entertain-

ment much of the work and the output is not tangible. The work, in these instances, is not amenable to being defined unambiguously. Moreover, it is not repetitive. In contrast, despite producing a variety of models, automobile production at Toyota is essentially repetitive and the work is measurable.

Comparison of Service and Manufacturing in the Context of 'Lean'

When the work (inputs and operations) or output involves knowledge – gathering, analysis and dissemination or decision, the inputs and/or outputs could defy metrics. How could a top level management consultant's work be clearly defined, let alone being measured? How could a psychiatrist's work be explicitly defined and his output clearly measured? Both these cases involve expertise and judgment that depend on 'tacit knowledge' of the management consultant and psychiatrist. When a management consultant arrives at a solution to a vexing problem and when a psychiatrist diagnoses the state of the patient and deals with him, they both depend upon the knowledge that they have stored in their head over all these years of study and practice. The process and the product in these cases seem so much different from that in manufacturing. Not all 'lean' manufacturing ideas can translate from factory floor to consultant's desk or the doctor's chair.

It is, therefore, natural to have reservations regarding the application of 'lean' ideas to knowledge work in particular and to services in general. Service industries tend to lag behind manufacturing in the improvement of operations.

Table 38.1 presents some of the differences between manufacturing and service business in the context of 'lean operations'.

Table 38.1 Comparison of Service and Manufacturing Business in the Context of 'Lean Operations'

Aspect	*Service Business*	*Manufacturing Business*
Product	Many aspects are intangible.	Most aspects are tangible.
Design of product	Customer involved in design of service.	Company designs the product.
Demand	Two types of demand exist: (1) Value demand (2) Failure demand.	Mostly value demand.
Production	Production and consumption can be / is mostly simultaneous.	Production is distinctly different from consumption.
Customer Involvement in Production	Customer involved in production.	Customer far from production.
Process	Many aspects are individual-based and based on 'tacit' knowledge.	Most aspects can be standard.
Inventory	Non-inventoriable/virtual. But, there can be inventories of personnel or of waiting customers.	Inventoriable items (Supplies, WIP, finished goods) can buffer uncertainty.
Delivery	Considerable variability may be there depending upon the person delivering service.	Some variation can exist.
Standardisation and Variety	Standardisation is difficult. Open universe in variety of service is possible in most cases.	More amenable to standardisation. Predefined variety is offered.
Uncertainty	Uncertainty in task times in demand and in customer's role in production of the service.	Operations far more controllable.

Difficulties in Extending 'Lean' Principles to Service Business

The differences thought out in the above table give an indication of the difficulties in the transplanting of 'lean' principles applicable in manufacturing business to the service business.

1. *Dichotomy:* The orientation of service business is different from manufacturing. Customer is involved in the design of the product and sometimes in the production itself. Many customers in beauty salon during the hair styling keep telling the hair stylist as to what they want. Master's degree and Doctoral students design their service 'product' (the research thesis) and participate in a big way in the production itself. While this is happening, the stylist/professor has to ensure that the final outcome or final product is of universally acceptable standard quality. It is a dichotomy of dynamic process versus standard outcome.
2. *Low Manageability:* In the service business, product itself is intangible in most cases. Processes involve 'tacit' knowledge. Manageability – of operations and of outcome - is, therefore, low in terms of task times, total operation time, and final outcome's quality. One has to work in an environment of less specificity and more variability; whereas, JIT manufacturing and 'lean' need high degree of specificity – products and processes need to be specified in detail. Standardisation helps maintain operations 'lean'.
3. Absence of Safety Nets: In the service business, there are no safety stocks to 'cover up' errors. Mistakes and inefficiencies are nakedly out in the open.

Box no. 38.1 list the difficulties in making services 'learn' :

38.3 DIFFICULTIES IN MAKING SERVICES 'LEAN'.

- Difficult to locate 'non-value adding' tasks under a strong current of customer orientation
- Dichotomy of dynamic processes and standard outcome
- Lack of specificity and hence lack of manageability
- Absence of safety nets

Suggestions for Extending 'Lean' Principles to Service Business

Once the difficulties have been understood, the solutions follow. These may be as follows.

1. *There are Elements of Work that are Tangible and Repetitive. Check for 'Waste' in those Parts of Service Work.*

Hospitals, hotels, restaurants, BPOs, IT solution providers, movie houses, railways and almost all services have many and large parts of work – paper work, xeroxing, printing, telephoning, emailing, movement of people, maintenance of equipment, etc. – that are no different than the parts of work in manufacturing. These elements of work can easily be made 'lean' by checking for 'value addition' and 'waste' that includes mura, muri and muda.

2. Constantly Search for Waste

Since services are heavily customer-oriented, there is that much more necessity and urgency to eliminate waste and pass on the benefits to the customer. Services need to constantly search for 'wastes' in all the operations. For instance, the consequences of 'rework' in services could be huge. Services consist of not only 'value demand', usual demand for service from the customers, but also

'failure demand', demand caused by a failure to do something right for the customer. For example, many calls received by 'call centers' are either chasing down enquiries made earlier or to correct earlier work that was not done properly. By treating 'failure demand' and 'value demand' alike, one may get a false picture of greater productivity. So, there is a need to look constantly as to what is going on and remove wastes.

3. Search for Small Waste, Not Just the Big One

Large wastes would already have been removed. Hence, there is a need to care about the small stuff. Constantly ask "Why?" A value stream map would indicate the areas of waste. Track each step and question it.

5 Whys: There is a Japanese technique called '5 Whys'. A 'why' would elicit a reply. This reply needs to be questioned again as to 'why?' The reply to it is further subjected another 'why?' This should go on (5 is only a symbolic large number) until one is satisfied to have found the root cause. Since by their very name and nature services apparently seem to be serving the customer, the non-value added work tends to get hidden. Thus, it is hard to locate waste and a persistent 'why?' is essential.

4. Service Jobs Tend to Bloat Over Time. Hence, Periodically Review Structure and Content of Every Job

Since a service job is unstructured and because it could have inputs during its conduct from various quarters including the customer, it has a tendency to expand over a period of time, with more and more low-value tasks added on to it. This leads to (a) too much work (muri) and (b) unnecessary work (muda). This in turn leads to bottlenecks (mura), delays in completing the job, overburdening of employees (muri) and slippages in quality (muda), etc. Hence, a periodic review of the content of jobs is necessary.

5. Specify All Work Including Knowledge Work

Specification of a job would involve putting down on paper all details about the 'what', 'when', 'where' and 'how to' of the job, viz. its micro-contents, interconnections, sequencing, timings, and desired result. At first, knowledge work would seem like a nebulous entity defying any specification because it is supposed to be 'in the head of the worker', consisting considerably of 'intuition', difficult to be put down into replicable and concrete steps.

Not all knowledge is 'tacit': However, a large part of knowledge work can be specified. The key is to challenge the assumption that all knowledge work is inherently tacit.[3] Staats and Upton who studied work at Wipro, the IT services giant's facilities in India, found that many aspects of the code writing process like daily builds (integrating all the pieces of code written on a day into the programme), peer review, testing and customer reviews that happen within a project and across projects could be standardised. Whereas, initially everyone thought of each of these code-writing jobs as unique one-time project not amenable to any standardisation. Only when this presumption was questioned that the possibility of specifying the work emerged. Many a time there is a psychological barrier that wants to keep 'knowledge work' in the realm of the cryptic.

Have patience: Moreover, just because certain knowledge work cannot be specified today does not mean that it cannot be standardised tomorrow. What is a relatively stray occurrence today may

[3] Staats, Bradley R. and David M. Upton, "Lean Knowledge Work", *Harvard Business Review*, October 2011, pp. 101-110.

perhaps become more common occurrence a year later. The work may be better understood and can be put in a protocol.[4] Success (or value addition) can, thus, be repeated. Much of 'knowledge' seems to go from the stage of esoteric to tacit to repeatable to routine.

Specificity helps in most service operations. Take the case of snake-bites in rural India. It is estimated that more than 50,000 people die in India every year due to snake-bites and most of the snake-bites are occurring in the rural areas. What would help is a clear set of standardised procedures from the Health Ministry. A simple check-list of time-bound do's for any doctor handling a snake-bite patient would go a long way. It is said that most doctors do not know how to handle a snake-bite case; they do not even know the recommended dosage of anti-snake venom serum.[5]

6. List out Common Errors

Generally, it is thought that 'errors' in service work lack clear definition. A lot of time may get wasted because of it. "What does constitute an error?" may be necessary to be settled right at the outset of a service operation. "What can go wrong?" is as important to know as "What does the work consist of?"

Therefore, a list of common errors and their definition would help in preventing errors.

7. Although the Customer is Involved, Service Work Can be Specified

A question is generally raised: Wouldn't customer's involvement in the service process make it less specific and more uncertain?

Customer may be involved in the design of the service product and the process. But, it can be frozen and can be specified. Hair style need can be finalised, thesis topic and mode of investigation can be finalised, contents of a hamburger or a subway sandwich can be decided upon – even the method of deciding upon the contents can be decided by the subway shop. With adequate effort, many aspects of the customer participation can be standardised; this can reduce the uncertainty in the entire process. Sometimes customer involvement helps in standardising the service work, as will be seen in the next point and Box No. 38.4. Service work does not necessarily have to have more 'mura' or unevenness.

8. Specify 'What' and 'How' Employees will Communicate with the Customer and with Each other

There is little tolerance for errors. There are no safety nets like 'inventories' in service work. In such a situation, the opportunity to directly communicate with customer and possibly his direct participation should be seen as a benefit. With the customer's participation, the work can be finalized and specified. But, the organisation should decide as to who should be communicating, when and how often, what and how. That is a structure for communications – internal between the team members and external with the customers and sometimes suppliers – has to be thought out and decided upon. Large complex projects like technical consulting or management consulting projects would need the various elements of the project specified as much as possible. It is essential to plan for what to communicate, who will communicate with whom, for what purpose, when, how frequently, and how (method or manner of communication). Communications are absolutely critical to service work and these have to be structured as early in the stage of the project as one can. Structured communication lends shape to the job at hand, lowers uncertainty, keeps

[4] Bohmer, Richard M.J., "Fixing Health Care on Front Lines", *Harvard Business Review*, April 2010.

[5] Kelkar, Suhit, "After the Serpent's Sting", *Open*, January 16, 2012, pp. 38-41.

the customer in the loop, enhances 'value', decreases the possibility of errors, and if errors do occur, it provides some amount of insulation from the effect of the errors. Box No. 38.4 describes a management consulting project.

38.4 A NATIONAL LEVEL CONSULTING PROJECT

For a management consulting project that could potentially impact one half million employees of national government, a young consultant was named the team leader (TL). The team had ten senior members including the Director and the Deputy Director of the organisation. The project, to start with, was only mentioned in very broad terms. In order to bring clarity to the goals, i.e. the requirements of the customer, the TL requested the government to appoint a person who would act as a liaison officer and interpret the customer's requirements. The government appointed two senior bureaucrats to oversee the project. By involving the customer directly into defining the project, the TL brought specificity to the work of the project. Customer involvement actually helped him.

Since it was a complex project, the TL distributed the work and allotted specific work to the individual members of the team. However, in order that the common thread should run through all investigations, he fixed a schedule of review and strategic meetings twice a month where all members would attend and communicate their aspects of investigation todate. Free discussions would enable to chart out the next course of action or suggest corrections, if necessary, to the existing action plan. In order to do away with hierarchy, the meetings would be held in the offices of the team members on a rotation basis. All the essential details of the discussions and the decisions taken were recorded. This ensured that valuable lessons learnt were not lost for the future.

In order to bring in uniformity into the investigations and interviews with the outsiders, the content, general format and time-frame was decided. In fact, for the first of such interactions with the outsiders, most of the team members were present. Standardisation of communications ensured a good quality control in the process.

Separate meetings of the entire team would be held with the government's liaison officers, initially with a frequency of every two weeks and later every one month. This helped ensure that wasteful work was avoided and desired 'value' was provided to the customer.

It was also realised that the employees of the government had a big stake and, therefore, national level labour unions were also involved in discussions at the national capital in all the phases of the project at regular planned stages of the project. Since the requirements of two customer sets (government and staff) were to be met in order to bring in specificity to the goals, meetings where both sets of customers would sit together were held at different stages of the project.

Specifying value, specifying work content, planning schedules, standardising communications within and outside, involving customers and thus ensuring value addition and waste minimisation, the project was completed in planned time and to the good satisfaction of the customers.

9. Address Problems as Soon as They Arise

The JIT production system had the employees pushing the 'Andon' button to raise an alarm as soon as a problem occurred. The production came to a halt. The point is: The employees had a responsibility to rectify the error/problem as soon as possible and restore the production line back to life. In the JIT system, interestingly, the operation itself became a problem-solving machine.

If the problem is a recent one, it is easier to locate the cause. Older wounds are difficult to heal. This is one of the principles underlying 'lean manufacturing'. This principle can be used in service

operations and the problems can be addressed quickly. Festering problems can be disastrous, more so in services as they lack safety nets.

10. Write Down the Lessons Learnt

'Lean operations' believe in minimising errors and definitely not repeating them. Therefore, all lessons learnt – problems, causes, rectification actions taken, success rate – have to be noted down and the learning not only internalised, but also made explicit. This is all the more important for service work in order to enhance its tangibility and standardisability.
Table 38.2 lists all the above points for extending 'lean' principles to service operations.

Table 38.2 Suggestions to Extend 'Lean' to Service Operations

• There are Elements of Work that are Tangible and Repetitive. Check for 'Waste' in those Parts of Service Work.
• Constantly Search for Waste. Search for Small Waste also, Not Just the Big Ones. Use '5 Why's'.
• Service Jobs tend to Bloat Over Time. Hence, Periodically Review Structure and Content of Every Job
• Specify All Work including Knowledge Work. Not all Knowledge is 'Tacit'.
• List out Common Errors.
• Communications are generally very important in Service Work. Specify 'What' and 'How' Employees will Communicate with the Customer and with Each Other.
• Turn Customer Involvement into a Factor to help Standardisation and Reduce Uncertainty.
• Address Problems as soon as they Arise. Festering Problems can be Disastrous, as Service Work lacks Safety Nets.
• Write down the Lessons Learnt. The Future Work may Become that Much More Tangible.

ROLE OF LEADERSHIP

'Lean operations' is not just a bunch of techniques, although techniques are important. Adopting JIT or Toyota Production System requireds a change in the business philosophy. Lean thinking goes a step beyond JIT. It requires a cultural change in the organisation. The lean thinking has to get internalised in the organisation. In this context, the commitment of top leaders to lean philosophy is vital.

'Lean' Values and Behaviour

Without the inculcation of proper values and organisational behaviour, any effort to make operations lean will meet with only fleeting success. Similar problem is encountered with the introduction of JIT system in an organisation without appropriate preparation of the mindset. Lean operations are a little more rigorous. The lean values have to percolate and touch all people in the organisation. The top leadership has to formulate those values and set the ball rolling.

Team Effort

Lean is a team game. It requires the participation of all in the organisation and even all those connected to the organisation. One of the roles of top leadership is to facilitate team work. They have

to create and sustain conditions for it. And, this team has to be gently maneuvered towards the 'lean' way. In a while, the entire team has to start 'eating, sleeping and dreaming' lean.

'Lean' does not requires just the participation, but active participation of all. This requires that the bottom line of workers too take a leadership role with regard to their work. Thus, the job of the top leadership is to ensure that the conditions are right for a second or third line of leaders to emerge in all areas of the organisation.

The behavioural values important for the success of lean operations are:

(a) Mutual respect: Care for other's point of view, respect for other's suggestion for improvement.

(b) Team feeling: Put the team above self. Lean operations are about overall solution to eliminate waste.

Continuous Vigil and Continuous Improvement

In fact, 'lean operations' require participation on a continual basis. 'Lean operations' is not a one-time affair. The leadership has to not only set the ball rolling, but see that the lean game goes on. One has to be constantly on the lookout for waste so that it is removed.

Wastes tend to creep into the processes over time. Methods may evolve, sources and resources get to be different, machines undergo modifications, people and their moves may change. All these may bring in wastes with them. The team – the organisation – has to be vigilant and should eliminate waste as soon as it is spotted.

Kaizen: Moreover, the organisation has to strive for continuous improvement. Lean thinking does not accept status quo. Nothing is ever good enough. Kaizen is a vital part of lean philosophy. Learning curve may plateau, but Kaizen continuously looks for opportunities to improve.

Jishu Kanri: This Japanese term refers to 'voluntary management' group – a small group that meets regularly to share, study and solve problems related to their area of activity. Jishu Kanri projects may involve waste elimination, and improvements in quality, workplace safety, environment, etc. A part of these activities could take place outside of the regular work hours, for which workers are compensated. This is a part of Kaizen although Kaizen need not involve a group; it could be an individual initiative as well.

Gengitsu: While this Japanese word translates as 'real thing', what is implied is that the top leadership must go to the 'actual place' of work (also Gemba in Japanese), have a first hand knowledge of the wastes, the improvements taking place and the possibilities of further improvement. 'Real thing' also means that one should know the 'actual facts', i.e. one has to be ever vigilant for opportunities for improvement and should go to the real root of any problem. In short, one must face the facts and go to the root of them. Gengitsu applies to everybody in or connected to the organisation.

'Successful leaders create leaders under them. Winning organisations have leaders at every level': Azim Premji of Wipro has said. Similarly, Deepak S. Parekh of HDFC has said, 'A leader has to be a captain of a football team that has talented professionals. Leadership is not a one-person phenomenon'.[6] These sayings resonate in the background of lean operations.

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[6] Chary, S.N., *Business Gurus Speak*, Macmillan, New Delhi, 2002.

LEAN OPERATIONS AND JIT

JIT system is very close to 'lean manufacturing' in its attributes and hence, both of these are sometimes clubbed together. While JIT is the forerunner of 'lean manufacturing', the two overlap substantially. However, there are some differences between the two, because 'lean operations' are a further improvement on the principles governing JIT.

1. JIT Accentuates Only One Dimension of Lean Manufacturing

JIT relies heavily on improvements in 'flow'. Implementation of smooth flow exposes most of the problems. Waste reduction happens as a consequence. That is, by making all production operations closer to a line production, it spots and removes the inefficiencies due to stoppages associated with intermittent production. Uniform or 'even' flow compels even (i.e. standardised) processes, even quality (zero defects), even supply of materials, even running of equipment, and even empowerment across the entire manpower. Requirement of even flow also compels nearly single unit production, which forces quickly changeable set-ups and in-time supplies. Thus most of the benefits accrue to JIT because of its even flow. Of course, such even flow would not have been possible if the flow did not originate (get 'pulled') from the customer's end.

Lean operations are about eliminating all kinds of waste – not just the flow considerations. Every activity is under scrutiny – product design, work methods, process design, process flows, transport of material, movements of people, quality checks and procedures, inventories, supply chain, information flows, employee training and empowerment to name a few.

2. Lean Operations Expand Human Capability

Lean goes one step further than JIT and consists of work-systems that expand human capabilities. Lean operations explicitly encourage creative problem solving by the workers. Waste or 'non-value adding activities' are eliminated with mainly an internal effort, i.e. by the employees of the organisation. In fact, since a lot of waste is small waste, it can generally be noticed mainly by those who are close to the daily operations. Making the operator or handler or mechanic or other worker notice the problem and suggest remedies requires an education of the employees making them capable to shoulder such responsibilities. In order that they take the initiative requires that they be empowered.

Moreover, HR policies of lean operations encourage high levels of commitment to the organisation and vice versa. This is not to say that JIT does not expand the workers' capabilities or that commitment levels could be low. JIT too depends on these two qualities. But in 'lean operations', the emphasis is significantly higher.

3. Lean is Direct About its Focus on 'Customer Satisfaction'

In 'lean', any operations done for any purpose other than providing value to the customer is waste. 'Pull production' is a bare necessity under this dictum. In fact, nothing is 'push'. Lean operations do not believe in 'push' of any kind. 'Lean' checks for 'value' to the customer at every point and for every action.

JIT is much less direct about its emphasis on customer service. Could it happen that Toyota Motor Company that pioneered JIT, momentarily forget its customers? This sounds strange.

But, not too long ago (2009-10), Toyota's reputation seemed to have been tarnished due to a number of recalls of its Prius and Lexus models due to quality related problems. One of the reasons put forward by a professor in University of Tokyo was that "Toyota became so proud of its

manufacturing systems and concepts like Kaizen and JIT that it forgot about the most important thing: its customers."[7]

The case of Sony may also be interesting. It is said that Sony's digital Walkman was better engineered than Apple's iPod, but was less popular. It is said, Sony overlooked the aspect of ease of use to the customer.[8]

4. Profit Motive in JIT and Lean: Emphasis is Different

Lean is, indeed, very concerned with customer service. So much so that one is tempted to ask: What happens to the profit motive? Is profit only a by-product? In this aspect, JIT and Lean may have some conflict.

'Lean operations' seems to be the natural progression of Operations Management as a discipline towards its increasing outward focus on service to customer and service to the society.

5. Lean is an Evolutionary Concept

Main method of 'lean' is not the tools or techniques or a predetermined flow system, but the reduction of Muda, Muri and Mura. Lean is an evolutionary concept.

These differences should not take the credit away from the Toyota Production System or JIT. Certainly, JIT brought in an entirely new emphasis on customer satisfaction. Its concept of single unit flow system – where it combines the benefits of very small lot production and a flow system of production – has been an extraordinary development in the field of manufacturing management. In fact, its attempt to make the flow even has singularly brought out various 'wastes' – of inventory, of over-production, of large production runs and of not having good quality the first time itself, among other. It showed the world as to how a production system could be linked to the customer demand and, therefore, how the production function could play a critical role in organisational strategy. 'Lean operations' is a natural progression from JIT. It has greater claims to being a philosophy.

QUESTIONS FOR DISCUSSION

1. Give an example of a necessary non-value adding activity. The example should be different from that given in this chapter.
2. What does 'value stream mapping' do? What does it do not do? – That is, what are its limitations? Answer in the context of lean operations.
3. Explain the difference in 'lean' and 'traditional' thinking. Is there a difference in the purposes? If so, what is it?
4. Describe the 'Muda' of over-production. How is it different from 'over-processing'?
5. Why was the elimination of 'fitting' a crucial step in Henry Ford's assembly line production of automobiles? Explain.
6. Why is 'housekeeping' important in production? Is the '5S' different from good housekeeping? Explain in brief.
7. How will one apply 'lean operations' concepts in service business? Explain in brief.
8. Is customer involvement a hindrance in applying lean principles to service business? Explain in brief.
9. How is 'lean manufacturing' a step ahead of JIT production system? Explain.
10. Can 'profit motive' and 'lean operations' be compatible? Explain your answer.

[7] Ryozo Yoshikawa, (Professor, University of Tokyo), "Toyota Recalls: Lessons", *The Times of India*, February 15, 2010, p. 12 (*Times of India* excerpted it from *New York Times*).

[8] Ibid.

SECTION VII

Present Concerns and Future Directions

Chapter 39 Environmental Considerations in Production and Operations Management
Chapter 40 Where is Production and Operations Management Headed?

Production and operations function is evolving. The new management systems as described in several earlier chapters are as much responsible for this evolution as the strides in technology and social changes that are driving – in a cyclical fashion – the development of new management systems.

As the production and operations function is evolving, we are faced with hitherto uncared for issues and concerns such as the environmental and ecological concerns. It makes us question our fundamental beliefs and value systems. As a result, the direction of the production and operations discipline seems to need a reorientation.

Technology is growing by leaps and bounds. The recent few decades have witnessed a phenomenal growth in the fields of computers and information technology, telecommunications, nuclear energy, and space and satellite technology. Concurrently and sometimes as a result of it the socio-economic changes are occurring. These changes make it imperative for the operations management systems to suit the new technology and new socio-economy. The evolution of new business philosophies, production and operations management paradigms and systems can be traced to the technological, economic and social changes.

New concerns have to be addressed. Emerging new directions have to be checked and charted out.

39 Environmental Considerations in Production and Operations Management

"Whatever befalls Earth, befalls the sons and daughters of the Earth. The Earth does not belong to us, we belong to the Earth."

—Red Indian Chief Seattle's letter to the President of the USA in the year 1854.

Earth's bounty and our endowment—the natural physical environment, which we generally refer to as the 'environment'—is under threat. The environment comprises all that surrounds us—the physical entities like the landmass of diverse kinds, the water bodies like the rivers or the oceans or lakes, and the diverse living organisms like the plants,. Trees and animals–big and very small. The threat is mainly due to modern man's thoughtless actions, which are increasingly depleting and degrading the environment. In this context, Chief Seattle's words of wisdom, mentioned above, are worth pondering over. It must be remembered that we are an integral part of the environment and what harms it harms us.

HOW DO PRODUCTION AND SERVICE OPERATIONS DISTURB THE ENVIRONMENT?

Operation in any organization—whether it is a manufacturer or a service provider—can disturb the environment in many ways. Operations use natural resources, either in a direct or an indirect manner.

Unsustainable Use of Natural Resources

Some natural resources are regenerating kind, like the trees and grass. Water also regenerates through a perennial cycle of evaporation and condensation. But, regeneration or renewal takes some time. When our usage exceeds the nature's restoration capacity and speed, there is imbalance and the nature is not able to 'sustain'. When the nature's resources are used faster than they are replenished, the natural resources start getting depleted and a series of chain reactions may start happening. Unsustainable use of natural resources, due to heightened manufacturing and service activities, is not only making less and less of the vital resources like fresh water or clean air or forests or fertile land being available today, but is also leading to many disasters like floods, droughts and cyclones among others.

Looking at the total human population, the rapidly increasing industrial activity is appearing to get counterproductive. It is a paradox that increasing productivity in industrial operations can soemtimes lead to counterproductive result if the effort is not thought out properly. Imgine cutting up Bamboo trees rapidly, exceeding the nature's capacity to regrow the trees; Bamboo will no longer be available in the future.

Excessive Use of Energy

Excessive use of energy is leading to increased building of hydel dams, nuclear plants, and coal-fired thermal power plants which all can cause environmental problems like global warming, depletion of forests and biodiversity, pollution of water bodies and landmasses, radiation damage, and the displacement of people on a large scale, all of these can create opportunities for disasters. Several dams are built and when one cannot look after their maintenance properly, there is a disaster like the flooding of large areas of Bihar, in the year 2008, by River Kosi resulting in two million people rendered homeless and over two thousand dead.

Waste Generation due to the Process or its Requirements

The processes have been producing wastes–gaseous, liquid and solid–that are discharged into the environment. Thoughtless discharges can cause damage to the environment and hence to the people, animals and vegetation.

Discharge of Gaseous and Liquid Pollutants Burning of fossil fuels like coal, natural gas, and petrol or diesel can cause much air pollution. The primary culprits could be:

- Thermal power plants
- Chemical and related industries
- Automobile emissions
- Planes, ships using fossil fuels
- Burners and incinerators of various kinds.

Global Warming

Increasing concentration of carbon dioxide in the atmosphere is a major worry as it absorbs the heat of the solar radiation radiated back from the warmed surface of earth. This is like a greenhouse garden and, therefore, gases like carbon dioxide and methane are called the greenhouse gases (GHGs). This 'greenhouse effect' causes the average temperatures in the environment to rise– phenomenon known as global warming can cause havoc across the world leading to cyclones, vagaries of excessive or deficient rainfall, floods, drought, food scarcity, melting of polar and other glaciers, rise in the sea levels and submergence of many small island, island nations and coastal areas among other mal-effects.

Ozone Hole

An increased concentration of chlorofluorocarbons (CFCs), until recently used in various aerosol products, has depleted the protective ozone layer in the stratosphere and formed an 'Ozone Hole' over the Antarctic region allowing increased amounts of sun'sultra-violet (UV) radiation to reach the earth. This can increase the incidence of skin cancer and other problems.

Pollution of the rivers, lakes and seas due to the discharge of chemical effluents of the manufacturing and other industry is causing scarcity of freshwater and is also causing much damage to the human and animal health.

Problem of Solid Waste

Just as there could be liquid and gaseous effluents or by-products, there could be several solid waste products due to industrial operations; the industry could be in any sector–manufacturing or service. For instance, the engineering industry has steel scrap, hotel industry has waste food, and construction industry has rubble. Mindless dumping of such wastes can pollute and deplete land and freshwater resources, and can cause health problems. Some of these problems can surface after several years as in the case of Love Canal in the city of Niagara. Hooker Chemical Corporation had dumped its solid wastes into the canal and closed it unscientifically. After a couple of decades, toxic leachates started oozing out from several houses in the locality. It was a major civic problem.

Nuclear Waste and Radioactivity

Nuclear energy is one of the important sources of electrical power. Uranium 238–a raw material–is in abundance in the world. Hence, the problem of depletion of resources, as in the case of the fossil fuels (petroleum, natural gas and coal), would not arise for a very long period of time to come. India has a huge availability of Thorium, which can also be used as a starting material for the generation of nuclear power. However, there are highly radioactive waste generated which pose a gigantic problem. Spent rods in the nuclear reactor, the old obsolete nuclear reactor, and the waste materials generated in the process itself could remain dangerously radioactive for thousands of years and these need to be safely disposed off for that many years if we care for our unknown generations to come. Nuclear technology is a double-edged sword. It is useful in a myriad ways, including in medicine. But, even waste from nuclear medicine–although low in radioactivity–needs special care in its disposal.

Thermal Pollution and Noise Pollution

Heat generated during a process, if not reused, has to be discharged in to the environment. Many a time, hot water from the heat-exchange processes is discharged into the streams raising the waterbody's temperature and damaging the fish and several other organisms in it. Natural processes are interdependent; depletion of organisms in the waterbody damages the waterbody itself.

Noise is another byproduct of operations processes. Noise beyond 80 dB is considered potentially hazardous to us. According to a study by All India Institute of Speech and Hearing, the noise levels in restaurants in Bangalore reached up to 88 dB.

Design of Wasteful Products

Industries, particularly the manufacturing type, sometimes thoughtlessly make products with components that are of no practical utility after the present use. There are times when the industries pander to the 'throwaway' culture–for instance, throwaway cans and cartons in which the items are packaged. Rapidly changing designs and consequent obsolescence of products also creates a problem of disposal of the obsolete items. For instance, electronic items get updated and hence get obsolete almost every other year. Thus, industries can add to the already existing 'after use' problems.

In short, anything wasteful adds to the environmental problems. Excess and wasteful resource utilization, wasteful processes generating byproduct wastes, and wastefulness at the point of consumption are all harmful to the environment. And, what harms the environment harms us too.

Spreading of Monoculture

Industrial operations–be it manufacturing or service industry–require a specific kind of resource or raw material or auxiliary supplies. For example, paper manufacture may need bamboo and eucalyptus trees, and hotels and hospitality industry may need specific type of fish or prawns and other food items. Even a substitute fuel for automobiles, like the biofuel or ethanol, would need specific kind of vegetable raw material. Industrial operations may thus show a preference for monoculture, whereas nature prefers biodiversity.

Enhancing Customer Wants

Industries—be they manufacturers or service providers—may like to produce items or provide services that keep enhancing the future wants from the customers. Consumers get so to say 'addicted' to consuming more, or to using a service repeatedly. Some of this escalation in consumption could be harmful to the environment. For instance, manufacturing larger and larger cars that guzzle more and more of the scare petrol/diesel and pour out increasing quantities of pollutants into the atmosphere. Enhancing one's business is good, but it should be done with responsibility.

Choice of Environmentally Unfriendly Systems, Processes and Products

The memory of Bhopal gas tragedy is still fresh in the minds of all Indians even after a couple of decades. Thousands or residents of the city died and many more were handicapped for life due to the accidental release of the poisonous gas MIC (methyl iso-cyanate) from the Union Carbide's insecticide factory. The tragedy showed the need for a thoughtful process and operations systems planning, a lack of which can create a disaster of horrendous proportions. The dangerous plant was located in a thickly populated part of the city, which in itself was a major operations location-planning blunder. Then, proper operations systems to contain the gas–if accidentally released–were found wanting. The use of MIC itself is questionable. The following box pins the environmental responsibility, in a nutshell.

WHO DONE IT? 39.1

- Pollution: Operations generating harmful by-product wastes/effluents
- Unsustainability: Operations using/consuming natural resources unsustainably
- Resource depletion: Operations using natural resources wastefully and excessively
- Disturbing nature's cycles: Operations—wasteful and in excess—interfere with nature's cycles like water cycle, oxygen cycle and nitrogen cycle
- Causing disaster: Wrong choice of operations systems, processes and products

Operations function has contributed very significantly to environmental damage. So, it should also take responsibility for it and act to rectify the damage done and prevent any future damage.

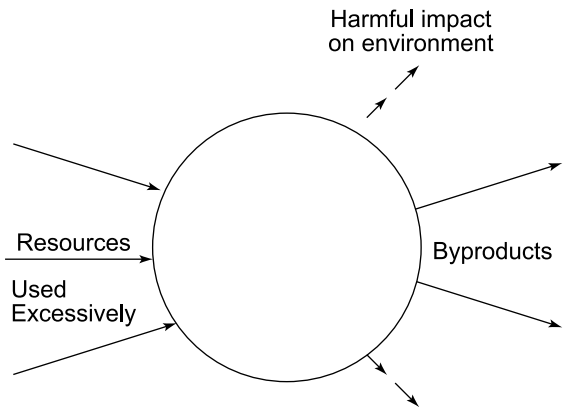


Figure 39.1 How Processes can Cause Environmental Damage

MAKING THE PROCESSES 'GREEN'

Production/operations management function can arrest, rectify and prevent the damage to the environment by means of several actions on its part. The first thought that arises in one's mind is that of the production/operations processes, because the function has always been closely identified with its processes. The first attempt will therefore be to make these processes environment-friendly or 'green'.

Let us revisit the causes of environmental damage. Production/operations processes can cause environmental damage by:

- Excessive use of resources
- Waste generation
- Harmful system, processes and products/byproducts

As the above diagram shows (Fig. 39.1), the damage to the environment could occur in three ways. Wasteful use of nature's bounty, immediately or potentially harmful process itself and the byproducts the process generates and lets out into the environment.

If these causes are handled appropriately, the environmental damage could be minimised and/or averted.

Increase Resource Productivity

Productivity concepts are useful in containing the excessive use of resources. By increasing the productivity of resources i.e. by efficient utilization of raw materials and work-in-process materials, these materials will be required in less quantity. The consumption of natural resources, from which these production materials may be derived, would also correspondingly reduce. Thus, good old productivity concepts and materials management principle can be of immense utility in saving the environment.

Machines can be made more productive and the operations facility can, thus, reduce its requirements or electrical power. This is environmentally very beneficial.

However, a word of caution is in order, It is not always that an increase in a production plant's productivity would translate to a decrease in the use of natural resources. If a wood mass is crunched faster and pulped into paper, the machine and /or labour productivity may be higher, but the destruction of the forests too could be that much faster. The faster a mine is dug up and exhausted, the more efficient the process of mining has been. But, that cannot be a yardstick for the conservation of natural resources and environment. Therefore, while productivity increases are welcome, one has to take care that these measures are helping the environment as well.

'Reduce' is the Primary Mantra

The basic concept is: 'Reduce' the quantity of inputs–per unit of output–that directly or indirectly lead to the consumption of natural resources. If this is accomplished, there is scope for increasing the production and business volumes without exceeding the nature's regenerative capacity limits. The idea is to increase the efficiency of the operations, so that they use inputs like materials and energy to the minimum extent possible. The mantra of 'reduce' is very helpful towards sustainable production/operations (i.e. operations that take care of the sustainability of the environment).

There is one more 'reduce', that of reducing the requirements at the point of the consumer himself. He should ask less variety of fewer goods in less quantity. But, this is in the realm of a 'cultural shift', form the current consumer culture to a frugal culture. This cultural shift is beyond the scope of this book and hence it will not be discussed here.

'Reuse' is Another Mantra

In addition to 'reduce', a firm can practice a policy of 'reuse' wherever feasible. The concept of 'reuse' can be compared to that of 'durability'–an attribute of product quality. The same item may be used again with some repairs or rectification or simple cleaning. For example, a beverage company can reuse the used beer cans or soft drink bottles after some cleaning. Several firms are already doing it. Firms will practice the 'reuse' principle easily when the costs of collection and rectification of the item (after use by the consumer) are significantly lower than the costs of producing that item. A soft drinks bottler will arrange to collect the used bottles and use them again only if the costs of doing so are significantly lower than the cost of using new bottles. However, with some effort, the costs of collection and restoration can be brought down in the case of several items.

Together, 'reduce' and 'reuse' policies can substantially help–directly and indirectly–in bringing down the rate of depletion of our natural resources.

Lean Production

Increase in productivity with regard to resource inputs can reduce the environmental effects. Hence, concepts like 'lean production' can be in consonance with the environmental objective without really intending to or not consciously trying to do so. 'Environmental wastes' such as excess energy or water use present largely untapped opportunities to the 'lean' practitioner. After all, the overall goal of 'lean' operations is to continually reduce operations' wastes -which means less energy used per unit of product or service produced/delivered, less materials used or they are reused more efficiently. This can also translate to less material emitted to air and water, and water, and less solid/hazardous waste generated.

Not only efficient processes, but improved materials management systems also can help in the case of conserving the environment. The firm may not allow the raw materials to sit in the inven-

tory and turn into a waste due to spoilage/ageing and/or obsolescence. Similarly, there may be less wastage in the work-in-process inventories. Just-In-Time (JIT) system of production, which places much emphasis on preventing wastage in materials, would certainly support the cause of applying brakes on resources depletion and environmental degradation.

'LEAN' PRODUCTION CAN ALSO BE' GREEN' PRODUCTION 39.2

Important concepts of Productivity:

- Resources Productivity
- Green Productivity

A production process has to be Lean, Mean and Green. Lean and Mean Production could, most probably, be also Green.
But, ensure that it is so.
Organsations must have a broader view of Productivity—Include the Environment.*

Lean production may need some actions with regard to the manufacturing/service processes and equipment. Some of these are mentioned in Table 39.1.

Table 39.1 Lean Production: Some Necessary Actions

Preplanning: Plan for equipment to catch wastes and spill-overs.
Equipment Modification: Modify the process equipment for enhanced efficiency of resource use, reduced wastes generation, easy detection of waste generation, proper capture and reuse or recycle of waste products and waste energy.
Process Modifications: Modify the processes for enhanced efficiency of resource use, improved monitoring of process parameters, and monitoring of equipment/process failures.
Preventive Maintenance: Maintain the equipment and other facilities in good shape. This prevents excessive resource use, and wastes due to rejects and low quality products

Eliminate Waste Products

Waste products are of two kinds.

- the byproducts of the production process or operations: these are the solid, liquid and gaseous pollutants.
- the final products that have been used by the consumer and have lost their capacity to serve the original purpose: these are products that are thrown away after their use.

Elimination of waste can be accomplished in the following ways:

(a) Do not generate waste
(b) Treat the waste (if generated) so as to enable it to be reused wholly or in part in the same process or in other process within the same plant or in some outside plant/firm. When the waste, after some treatment, is reused in part, such reuse is called as 'recycling'.

Non-generation of by waste byproducts requires a thorough review of the existing processes and a transformation in them. A good research and development should find alternative processes that do not generate (or minimally generate) waste. The problem of waste should, as much as pos-

* Source: S.N. Chary, " Generating Environmental Consciousness While Teaching a Course on Production Management", IABE International Conference, USA, 2003.

sible, be nipped in the bud. It goes without saying that the new/transformed process should also be economically viable or as attractive as the earlier process.

'Recycle' the Waste

If the waste is generated, in the form of byproducts or 'after-life' products, parts of it can be recycled. There are many components of a machine/equipment that have a much longer life than the machine. These components, if they can be easily separated, can be reused. There are other kinds of waste. Engineering industry generates scrap. The steel turnings, the chips, the old machinery's steel parts, etc. can be sent to steel producing plants as a part of the raw material. Hot water from the heat exchangers, instead of being discharged into water streams and causing damage to the aquatic animals and other organisms can be recycled into the plant for preheating other inputs of heating office rooms.

Treat the Waste Before it is Released into the Environment

If the waste cannot be eliminated due to the constraints of technology or of economics (i.e. it is not at all economical to reuse or recycle it), the waste may be treated to make it less harmful (preferably, harmless) to the environment before it is discharged or discarded in the environment. Of course, this should be the last resort because there is no discharge into the air, water or landmass that is totally harmless. As far as possible, the three R's (viz. reduce, reuse and recycle) should be practiced. Industries, both manufacturing and service, should reduce their 'ecological footprint' as much as possible.

*Ecological Footprint**

Environmental scientists speak of the stress on the environment due to an organization's activities as that organization's ecological footprint'. The carbon dioxide (and methane and other greenhouse gases) generated–which contributes to global warming–is referred to as the 'carbon footprint.' Carbon footprint is a part of the total 'ecological footprint'. These footprints need to be as minimal as possible.

Keep on Improving the Waste Disposal Methods Any waste that is disposed into the environment leaves its ecological footprint. How, where and when it is disposed has significant bearing on the potential environmental damage. Nature's processes would try to restore balance; but it has its own limits on how much can be restored and how fast. When these limits are crossed, there is 'environmental overshoot'. Any design of disposal method has to seriously consider the nature's processes. Also, there is a need to keep on improving the waste disposal methods–new technologies, new timings and new places of disposal in order to reduce and/or soften and/or delay the impact. Like new methods of landfill, new methods and places to permanently store the nuclear wastes, new methods of treating chemical effluents, etc.

'Cleaner Production', Non-waste Technology and Industrial Ecology

'Cleaner production' refers to a system of production that eliminates waste and thus does away with dirtying or polluting the environment. The 3 R's—Reduce, Reuse and recycle—are important pillars of this system. 'Non-waste technology'—the technology to eliminate waste—is at the heart

* While the words 'environment' and 'ecology' are popularly used interchangeably, 'ecology' is the (study of the) complex web of relationships among the different populations of species —among themselves and between them and the non-living environment. ' Environment' Comprises all that surrounds us, i.e., the physical world and the biodiversity. 'Environment' is, therefore, a more comprehensive and broader term.

of it. Nothing is wasted. Nothing is perceived as 'waste'. The supposed 'waste' is either used internally within the organisation, or it used in other organizations. Therefore, 'waste' can be seen as 'resource'. There is nothing that should be called waste. It is our lack of technology and ignorance that perceives some things as useless and, therefore, wastes.

Pollutants (waste) + Knowledge (technology) = Potential Resource

Cleaner production makes use of industrial ecology. In nature's ecosystem, one organism is dependent upon another. Applying nature's concepts of ecosystem to the industrial scene, an organisation's 'waste' can be a 'resource base' for another organisation. Such a principle is called as Industrial Ecology.

Distillery 'waste; byproducts can be dried and used for supplementing cattle feed. Coal-fired power plants (most thermal power generating plants are coal-fired) produce fly ashfine suspended particulate matter–that can cause extensive health problems (mainly respiratory) in and around these plants. However, fly ash can be recovered from the stacks of the power plants and used as a raw material in cement plants. As a matter of fact, one of the large multinational cement companies, with recent entry into the Indian market, is using fly ash for its cement manufacture. Gypsum (crystalline calcium sulphate) is an annoying byproduct of the manufacture of phosphoric acid from the mineral rock phosphate. But gypsum can be mixed with colliery waste; this is self-combusting and produces cement and sulphuric acid, two useful products from supposedly waste materials.

Industrial ecology can help us in grouping such mutually helpful organizational facilities together. With a view to reduce transport and other costs, such facilities/industries can be located nearer to each other. One can think of further integration of the technological 'ecosystem encompassing the industries, raw materials and energy supplies and all 'wastes'.

This 'ecosystem' of community-plus-industry would be a concept that could save the environment from much damage. The following boxes mention such live examples.

INDUSTRIAL ECOLOGY AT COROMANDEL FERTILIZERS 39.3

Coromandel Fertilisers Limited at Vishakhapatnam, Andhra Pradesh, has a fluorine recovery unit. It supplies Fluorine to a neighboring firm, Alufluoride Limited for the production of aluminum fluoride. The two firms have a long-term agreement about this.

'ECOCITY' IN CHINA* 39.4

In China, Peter Head–a British engineer whose construction firm helped build Sydney Opera House and Beijing Olympics "Bird's Nest" stadim–is helping build an 'ecocity' in Dongtan, a farming area near Shanghai. The ecocity's power plants will use waste from rice mills as an energy source. Almost all the city's waste will be recycled and reused. Vital facilities like hospitals and schools will be so located that these will be accessible to the ecocity' dwellers easily by walk or by bicycle. Dongtan's mass transport will be run on renewable energy. Its farmland will supply organic food to the city. By 2010, about 5,000 people were expected to settle in that city; by 2050, the ecocity is projected to have five lakh (500,000) people.

Be Wary of the Obviously Hazardous Processes

Of course, it goes without saying that a process that is immediately or potentially very harmful to the environment–e.g. when it leads to radiation damage or chemical poisoning–should be replaced

* Ref.: "Heroes of the Environment," Time Asia, HongKong, Oct. 62009, p.68

by another process. The hazardous parts or the entire process may need to be redesigned/replaced. Minutest possibility of radiation leakage is harmful to human and other life. The processes should be such as not to offer any chance for such accident in the relevant foreseeable future.

OPERATIONS AND ENVIRONMENTAL ISSUES HAVE SEVERAL SIMILARITIES

It would be interesting to note that issues in production and operations and in environment are quite similar. Management of the material and energy resources is as important to environment as to production. 'How much?' is the perennial question of the materials managers. The timing of the procurement of the materials is of much importance. In fact, correct timing is the basis of MRP and JIT. 'When? Is as important as 'How much?' of the inventory.

In conserving the environment too, the 'absolute quantity' of consumption of natural resources is important for the non-renewable resources and also to the renewable resources that take a long time to renew or regenerate. Once petroleum reserves are finished, they cannot be regenerated. Once the iron ore is exhausted, there is no more iron left in the ground for the future generations.

Rate of consumption of natural resources is a big issue in conserving the renewable resources. A rate of consumption faster than the rate of natural renewal would make the situation unsustainable i.e. the natural resource would eventually vanish. One could compare it to a queueing system, where the system goes off-balance when the 'arrival rates' are greater than the 'service rates'. A slight change can sometimes make a huge difference to the system's stability. The same is true of the environment. Along with the 'rate' the timing or scheduling or 'when?' is important. For instance, the response to queries like 'When can the effluents be released into the stream?' and 'When should the next crop be taken?' are vital to the ecology of the freshwater stream and of the farmland respectively.

It is well understood that the location decision is important for the viability of a firm. Location decision has also much bearing on environmental impact. For example, had the Union Carbide plant been located far away from the thickly populated Bhopal city, the human tragedy due to the accidental release of the MIC gas may not have been of such horrifying proportions.

The details regarding the process and its byproducts are much interest from both the angles–economic and environmental.

The following Box 39.5 states the similarity of issues between production management and environmental protection.

SIMILARITY OF ISSUES* 39.5

- How much?
  - absolute quantity
  - rate
- Where?(location)
- What is the process?
  - byproducts
  - by-effects
  - when ?

* Source: S.N. Chary, "Generating Environmental Consciousness While Teaching a Course on Production Management", IABE International Conference, USA, 2003.

It can be surmised that good production and operations management can also good environmental management. A well-managed operations system is more likely to be good for the environment. It will surely be so, provided the good production management practices are accompanied by a consciousness about environmental implications. No doubt, 'lean' processes can be good for the environment; but let the environmental concerns be a part of the embedded value streams.

LIFE CYCLE CONSIDERATIONS

There are several stages in the life cycle of a product or service. These are:

Design of product or service and
–Concurrent design of production/operations processes
Materials supply/Supply chain management
Processing/production of the product or service
Delivery/distribution of the product or service (involves supply chains, once again)
Use or consumption at the customer's end
Resource recovery/reuse/recycle
Disposal of final after-use waste

The environmental considerations of operations system should cover the entire life cycle. The various steps in the lifecycle of a 'Green product/service' are mentioned in Table 39.2.

Table 39.2 Steps in the Lifcycle of Green Product or Service

- Innovative design of product/service
- Right materials
- Green production/operations
- Efficient distribution
- Use with low environmental impact
- Reuse or recycling possibilities for the leftover materials/energy
- Easily degradable/assimilatable after-life non-reusable non-recyclable waste so that the landfills and their effects (on the environment) are minimized

Design

It was mentioned in the chapter on product design that almost 75 per cent of the life cycle costs of a product are decided at the product design stage itself. Same is true of the environmental costs. A large portion of the environmental costs of a product or service gets decided at the design stage in the life of an operations system.

We cannot fundamentally solve environmental problems by merely focusing on manufacturing/service processes. Remedying environmental damages during manufacturing/service processes is usually more expensive and less effective than preventing the case of environmental danages in the first place during the stage of product/service design. Environmental objectives and constraints must be an integral part in the product/service design.

The product/service design would be environmentally friendly when:

- the product/service design would be environmentally friendly when:
- the product itself contains as little of material as possible; the material could be precious to the environment.

- the design facilitates the manufacture/making of the product/service (i.e. the processes) with as little use of natural resources like energy and water.
- the design addresses and-of-life issues; for instance, it should facilitate reuse of the product after its life.
- The design facilitates recycling after its life, the components and its assembly may be designed such that recyclable parts (i.e. after life) are easily separable. (Basically, the cost of recycling should be low enough to encourage recycling measures.) Scrap value or scrap-friendliness may be enhanced by ease of disassembly, preferably using only a few types of materials in product construction (e.g. same type of metal).
- the design is such that the product does not end up in recycling soon; thus, if we put both this need and the one preceding together, it is a paradoxical requirement of 'designing items that last yet come apart easily'.
- the design is such that non-reusable on-recyclable material after, that is disposed in a landfill or other, does not create environmental problems in the long run and there would be no after-life safety concerns. (Use as little of materials like PVC as possible in the design of the product; because PVC is not recyclable and if it ends up in possible in the design of the product; because PVC is not recyclable and if it ends up in a landfill it can let out harmful acidic substances or chlorine from the landfill.)
- the product is durable i.e. it can be repaired easily and reused; this reduces the requirement of the amount/number of the product in the first place.
- the design makes the shipping of the product or delivery of the service easy, reducing the ecological footprint of the product or service. (Shipping involves many potentially environment unfriendly actions such as the use of petrol/diesel for transport and the use of packaging materials like plastics that have limitations to recycle.
- the product does not fire up or enhance further wants; because more wants, more demands and more products means more risk of damage to the environment.

Product or service design has to consider issues form the birth of a product to its graveyard and beyond (recovery from graveyard). Product or service design contributes fundamentally towards environment-friendliness of the production and operations system. Popularly, this is known as 'Green Product' development.

Supply Chains

Any inefficiency in the backward and forward linkages in the supply chain would translate to wasted materials, excessive energy usage, additional pollutants to the air and generation of solid waste materials. It is therefore desirable that the environmental considerations should extend to the entire supply chain.

Reverse Supply Chain

Infrastructure is required to facilitate return and reuse of the item or to recycle parts of the item after its life. For instance, there has to be a system and physical arrangements to take back the empty soft drinks bottles from the shops/restaurants or individual customers. We may call this as the 'reverse supply chain'. One needs to manage this supply chain as well. Managing the reverse supply chain has special problems as mentioned below.

- There is uncertainty with regard to the availability–quantity, quality and timing–of the

returned products, containers and packaging. Hence, planning the recovery process is that much more difficult.

- Collection and transportation of these returnable is an issue and adds to the abovementioned uncertainty. It also adds to the costs.
- Customers need to be provided information about where and when they could offload their old products for recycling purposes. So customer is also the raw material 'supplier'.
- Separation of recyclable parts (mechanical or chemical) and their reuse into the parent process or into a different outside process poses another challenge with regard to the system of collection–decentralized collection and transport of the recyclable parts, and their scheduling or timing. The key word here is 'decentralised'. The issue is to collect the parts from various dispersed sources and streamline them into the parent plant.
- Recovery of used products and salvaging components or parts for recycling has its own special set of problems. There are more uncertainties in recycled parts than say in returned bottles. What to recover, how much to recover, where to store, where to send, and how when to send are some of the questions that need to be addressed. There are questions of how to obtain better use from used products through 'remaining life estimation' of used components in consumer products.

An efficient management of the reverse supply chain will contribute to cleaner environment. Environmental sustainability considerations expand the scope of supply chain management to look at the entire production/operations system and post-production stewardship as opposed to just the production of a specific product.

Enlarged scope of Supply Chain Management in light of sustainability considerations is:
Issues of production/operations + Post-production issues

Example of some of the organisations who have provided such stewardship are furnished in Box 39.6.

RECYCLING OF THE PRODUCT AFTER ITS USE 39.6

Consumer electronic products get obsolete very fast and, therefore, have major disposal problem after their use. Sony provides 175 consumer-electronics recycling drop-off centres around the US. Eventually, it aims to have a network with a drop-off centre within 20 miles of most residents in the US.

Compact fluorescent lamps (CFLs) may save tremendously on energy consumed per unit of lumen as compared to the old incandescent filament bulb still being used in most places around the world. But CFLs have Mercury (a potentially poisonous metal) content. Therefore, it poses disposal problems after its use. Many firms are coming forward to address this issue. IKEA is a major retailer with an in-store-fluoresent-recycling programme. Philips USA does not offer such an in-house take-back programme, but has a partnership with a national recycling firm for the return of the used lamps. The company is also working with National Electrical manufacturers' Association (NEMA) to establish a network of retail take-back programmes.

ORGANISATIONAL RESPONSE TO ENVIRONMENTAL SUSTAINABILITY

Sustainability introduces additional responsibility–social responsibility –on the organisations. There are added costs. The closed system nature of sustainability has its own effects on the firm as a whole –its operations strategy and cost structure.

Firms may take up this social responsibility because of following reasons:

- as a competitive opportunity
- as compliance to current legislation
- as a matter of pure public interest

Green Production/Operations as a Competitive Strategy

Many manufacturers have introduced environment-friendly products to the so-called 'green consumers'. Their products, their production processes, and their supply chain members are all 'green'. This is done basically to reap the 'first mover's advantage in an increasingly environment-conscious market. Some of the 'breakthrough' or very new products have to face the challenges of premature markets, absence of historical data and consumer inputs that could provide leads, and high degree of uncertainty with regard to technology development and future regulatory framework. Many firms have willingly taken these risks.

Some companies, like Ford Motor Company, Believe in 'Connecting with the customers; on the environmental issues in addition to taking positive measures such as recycling, waste management and emission control. Box 39.7 that follows describes Ford's new corporate mantra. ;Cleaner, Safer, Sooner".

Service industries too have picked up the gauntlet. Many starred hotels pride themselves on their eco-friendly service, in terms of their energy use, water use, rainwater harvesting, conservation, efforts, organic inputs and other aspects.

'CLEANER, SAFER, SOONER": FORD MOTOR COMPANY'S NEW CORPORATE MANTRA 39.7

Automobile manufacturers around the world have been infamous for causing much environmental damage. However, Ford Motor Company of the US is trying to do more than correct the past image. It wants to show that environmentally responsible businesses can both be possible and profitable.

It rebuilt and reengineered its Windsor Engine Plant in Windsor, Ontario by enhancing 'industrial ecologies' within the firm by recycling shipping containers, handling petroleum products in closed loops, saving most of the solid waste and using new environment friendly air handling systems. The manufacturing plant's environmental impact reduced controlling wastewater runoff, and by reducing sound and sight pollution with green buffer zones. The company undertook a Total Waste Management programme to recycle useful materials back from landfills into industrial applications.

In fact, Ford Motor is proud of having the world's first four ISO 14001 certified plants. The River Rouge Industrial Complex in the Detroit area–which contains assembly, engine, glass, tool and die, frame and stamping, and steel plants that supply Ford–that was once criticized of destroying

the Rouge waterfront is now being redesigned by an environmental architect to create modern manufacturing systems that actually 'enhance the environment'.

Aware that one of its immensely popular products, an SUV by the name 'Excursion' was called by some environmentalists as 'Extinction', Bill Ford–the company's Chairman is reported to have said, "If we don't produce that vehicle, somebody else would, and they wouldn't provide it as responsibly as we do." This line of products is extremely profitable for the company. However, Ford Motor has taken steps to see that these vehicles when operated produce the minimum possible pollution. All Ford SUVs and trucks are now certified as LEVs (low emission vehicles). Moreover, 80 per cent of excursion is recyclable and 20 per cent of it is rebuilt from recycled material.

While the company is experimenting with new fuel and power technologies like ethanol, natural gas, fuel cells and electricity, the present petrol and diesel driven cares are given 'e-labels' to disclose their environmental impact from making and driving them. The car's carbon dioxide output, fuel consumption, safety performance, its overall recyclability, etc. are made public so as to guide consumer decisions. Ford Motor Company also seeks to provide its customers constant automotive service for each unit, as the company believes that a well maintained car is an efficient and environment-friendly car. In addition, Ford gives tips to customers on 'How to drive green." It realizes the importance of connecting with the customers for a cleaner product and for sustainable development. "Cleaner, Safer, Sooner" is Ford's new mantra.

The company funds zoo exhibits in Atlanta and Kansas City, where it has major assembly plants, to promote conservation programmes.

Some other companies could take up to 'Greenwashing' or 'environmental story-telling i.e. unsubstaintiated claims for sustainable design in an effort to woo the environment-conscious customer segment.

Compliance to Governmental Controls

In order to bring in a level playing field, government has to introduce legislation and other controls. Since global warming and consequent climate change is a serious issue currently, there are regulations on mandatory reductions in emissions. Kyoto Protocol–an international agreement made under the aegis of United Nations Framework Convention on Climate Change –stipulates a timetable for nations for reductions in carbon emissions (Greenhouse gas emissions). Montreal Protocol, another international agreement called for drastic reduction in the use of Ozone-depleting substances. The nations, in turn, institute their own regulations with a view to reduce emissions by the firms located in their respective country. India has a comprehensive Air Act, a set-up of central and state pollution control Boards, and a project on National Ambient Air Quality Monitoring with hundreds of air quality monitoring stations all over the country.

Eco-labeling

Sometimes the government would like to bring in the consumer into the picture. Ecolabel is a label on a product that makes it easier for the consumers to identify the green or environmentally certified. One of the intentions is to increase consumer awareness regarding environmental degradation and to use the consumer awareness to pressurize the industry to make their operations environmentally friendly. The scheme as such is voluntary; a firm may or may not opt for an ecolabel.

Ecolabeling started with the NGOs (non-governmental organisations). However, governments

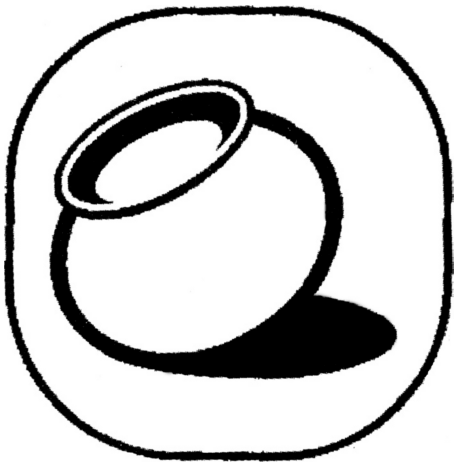


Figure 39.2 Logo of 'Ecomark' of India

Note: Earthen pot as a logo puts across an environmental message. It is made of earth–a renewable resource. It produces no hazardous waste. Its solid and graceful form represents both strength and fragility –which also characterises the ecosystem.
Source: Central Pollution Control Board, Delhi

the world over are finding it to be a good auto-regulatory tool. European Union has its EU Ecolabel and India has its 'Ecomark.

'Ecomark' of India

It is a government (Government of India) operated seal of approval programme for environmentally preferable products. It is given by the Bureau of Indian standards (BIS); however, the implementation of the scheme is reviewed from time to time by Central Pollution Control Board. The product categories to which the Ecomark is given include soap, detergents, paper, packaging materials, food, cosmetics, electrical and electronic good, plastic products, textiles and leather. The criteria used to grant the label would include:

- Pollution minimisation: whether less pollution is generated than comparable products.
- Savings to non-renewable resources
- Energy conservation
- Reduction in waste generation
- Bio-degradability of the product
- Recyclability of the product and use of recyled materials in its making, as compared to other comparable products

The criteria follow a 'cradle-to-grave' approach i.e. from the production of the item to its final use. Ecomark is awarded to consumer goods that meet specified environemtal criteria and quality requirements of Indian Standards. The logo of Ecomark is shown in Fig. 39.2 below.

Other Ecolables

Internationally, there are a number of ecolables. There is the 'Eco Logo' of Canada, ' Energy Star' label of the US Environmental Protection Agency, and the EU Energy label. 'Dolphin Safe' label is

used for canned tuna to show that the fish has been caught without harming or killing the dolphins. Dolphins are a common by-catch in fisheries especially in Eastern Tropical Pacific Ocean. There is 'Sustainable Timber' ecolabel given by Forest Stewardship Council, Germany. Consumers can thus choose sustainably harvested wood over alternatives that may be contributing to deforestation worldwide. 'Blue Sign' label is for textiles and Green Leaf eco-rating is for the hotels. As said earlier, not all ecolables are awarded by the government/s; many are given by voluntary organisations.

Carbon Offsetting

'Carbon offsetting' is a process by which a firm compensates for its own emissions by investing in other activities that reduce greenhouse gases. Such a case is mentioned in Box 39.8

CARBON OFFSET: THE CASE OF MILLIKEN AND COMPANY 39.8

Milliken & Company–a fabric, yarn and chemical manufacturer –has reduced its energy and water consumption by 25 per cent of its 1995 levels. It operates small hydroelectric plants, which power its factories and also supply electricity to the local grids. The company plants a million trees a year and manages 1,40,000 acres of forests in the southeast and New England regions of USA that help sequestering (i.e. absorbing) a billion pounds of atmospheric carbon per year. In addition to these 'carbon offsetting' actions, it also continually refines its manufacturing processes in order to reduce their environmental impact. Its ' Trees For All' initiative provides tree planting incentives to the firms in its supply chain.

Since there is now pressure on the organizations to reduce their GHG emissions, there is a market for these offsets. UN's Clean Development Mechanism (CDM) allows companies form the rich nations to meet emissions targets by funding clean energy projects in developing nations. There is a market for trading in these offsets.

Voluntary Action

Many firms strongly believe in their social responsibility and take environment-conserving actions voluntarily. While it may be a good long-term strategy, many firms are good corporate citizens. For such firm, the environment is like health and safety. They do it because it is the right thing, not because they want to use it as a marketing platform. Despite all the criticism Harihar Polyfibres Limited of Karnataka faced, the company took positive action in cleaning up its effluents and co-operated with the local state pollution control board in evolving standards for chemical effluents that were not addressed until then.

Teamwork by organisations

The measures that were suggested in the section on cleaner production require joint action by all industries and businesses in the vicinity. Implementing 'industrial ecology' necessitates much cooperation by all. Industries/businesses need to show much leadership in this respect. Some may have to replace their raw materials by the wastes of other industries, some others may have to re-locate some of their operating units so as to make this possible. Industry needs to comply strictly with the government's environmental regulations and tax policies. There may be a phasing out of existing subsidies and there may be changes in the tradable permits. Firms have to learn to operate in the changing business environment as a single community. Much teamwork is called for on the part of the industries, most of it on a voluntary basis.

'E'-principles and the 'R'-actions

In addition to the earlier E-principles of Efficiency, Economics, Empowerment and Excellence, we now have environment. These are the guiding principles for any organization. Towards the E-principle of caring for Environment, there are several R-actions possible.
There are:
Reduce
Reuse
Recycle
Replace (e.g. petrol by biofuel, AC by natural air cooling)
Reform–the process and the design of the product
Refuse–business with firms that are unfriendly to the ecology
Relocate–if the firm's operations severely damage the surroundings

Production/operations management and environment have to be viewed symbiotically.

QUESTIONS FOR DISCUSSION

1. What is 'sustainability'? What is 'sustainable development'? Explain.
2. How can the manufacturing operations adversely affect sustainability? Explain.
3. Can 'service' operations adversely affect sustainability? Explain giving examples.
4. Worldwide what are the major environmental concerns today? How can production/operations management help in mitigating these concerns? Discuss.
5. Does Lean Production help in protecting our environment? Discuss.
6. Could operations efficiencies be sometimes counter-productive–when looked at from the environmental angle? Explain your response.
7. What is 'cradle-to-grave' approach in considering the environmental effects of a product design? Explain.
8. Isn't providing a service fundamentally different from manufacturing a product? Can the design of a service have significant effect on the environment? Give examples and explain. How would you have redesigned the service you have mentioned? Explain.
9. What are the 'after life' environmental issues regarding a product or service? Discuss.
10. Take any one industry and discuss the importance of the principles of Reduce, Reuse and Recycle with regard to that industry. Focus your discussion on the environmental issues.
11. Explain the importance of good housekeeping in an organization with reference to the environmental impact of the organisation's activities.
12. How would good inventory management contribute to a better environment? Discuss.
13. Discuss the various governmental actions, in respect of companies, taken with an intention to better the state of the environment.
14. How is 'supply chain management impacted due to the environmental considerations? Discuss.
15. What is 'Ecolabeling? Discuss its merits and demerits.
16. Discuss the merits and demerits of 'Carbon offsetting'.
17. How would have good production and operations management practices averted the terrible Bhopal gas tragedy? Research and discuss.

ASSIGNMENT QUESTION

Select any organisation using an Ecolabel. Study the benefits derived and problems faced by that organisation in adopting the Ecolabel.

40 Where is Production and Operations Management Headed?

It has been said that in the high-tech manufacturing facility of the future, the only delineation between the manufacturing floor and the office will be where the carpet starts.
—Robert F. Greendale* (Ergo Tech Systems, USA)

It the last two or three decades, technology has made tremendous progress, particularly in the areas of automation and computerisation. To match these advances, improved systems of production are also being used and further developed. In the automated factory of Yamazaki Machinery Works in Nagoya, Japan it is stated that only one person is employed as a watchman for the night-shift, while 18 machining centres keep on working in the $ 18 million felexible manufacturing facility. ** Of course, such facilities exist mainly in the developed countries and comparatively few have been adopted in India. But, we cannot be oblivious to these developments, since we have been investing significantly in the industrial and industry-related sectors and also if our products are to compete in the international market.

Both automatic and automated factories are envisaged for the future. While the former is peopleless, the latter still requires people to deal with out-of-the way situations and to do a number of indirect tasks. perhaps one could have both, where the parts produced in the automatic factory which fail to meet quality standards can be sent to the automated factory where such unusual items could be handled. For a low variety and high volume production an automatic factory would be suitable; whereas, automated plants are suitable for a larger variety of production. All such automatic and automated plants require the use of robots, Flexible Manufacturing Systems, Automated Guided Vehicle Systems (AGVS), Automated Storage and Retrieval Systems (AS/RS), Integrated Inspection and Computers to provide the essential links.

FLEXIBLE MANUFACTURING SYSTEM (FMS)

Once a Group Technology (GT) for the parts and products is available, a computer can be used to design the production oeprations, control the parts flow and control the machine tools in a small

* Divisional Manager, Ergo Tech Systems, USA, quoted by: Evely Brown, 'Flexible Work Stations Offer Improved Cost-effective Alternative For Factory', *Industrial Engineering*, Vol. 17, No. 7, July 1985.

** J.A. White, 'Factory of Future will Need Bridges between its Islands of Automation', *Industrial Engineering,* Vol. 14, No. 4 1982, pp. 61–68.

batch type of production situation. Such Computer Aided Manufacturing (CAM)* is very useful for small-lot production. If the machine tools feature NC or CNC technology, it gives tremendous felexibility to the operations and numerous parts in the 'family' can be addresed with no change-overs. For an efficient and flexible manufacturing system (which could address a diverse requirement efficiently) the availability of a suitable material handling system is very important. When the material handling function between machines in such a GT cell is brought under computer control, we have a Felexible Manufacturing System (FMS). Thus an FMS generally has the following three components:

(i) CNC machine tools;
(ii) Computer controlled material handling system; and
(iii) Supervisory computer control network.

The structure of a flexible manufacturing system is shown in FIg. 40.1.

FMS systems are generally very useful for production involving an intermediate range of variety and an intermediate amount of volume.

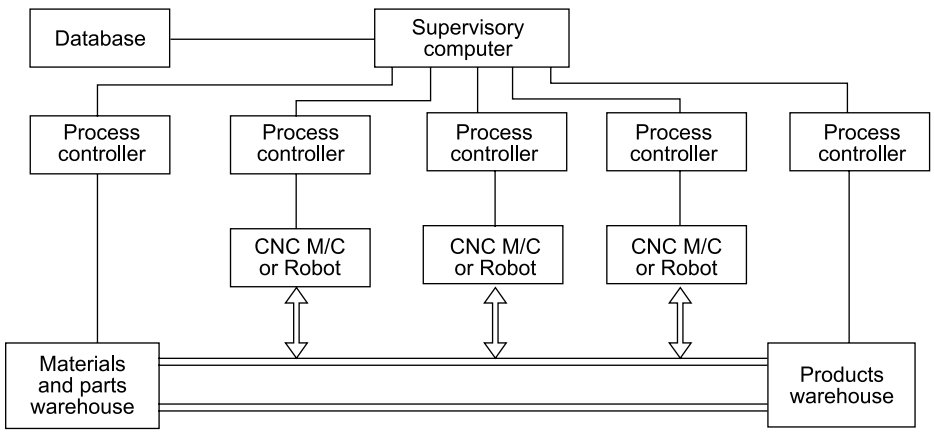


Figure 40.1 Flexible Manufacturing System—A Structure

Adapted From: R.E. Young, 'Software control strategies for use in implementing Flexible Manufacturing Systems', *Industrial Engineering*, Vol. 13, No. 11, Nov. 1981, pp.88–96.

The benefits of such automation include flexibility in producing variety and volume, low setup times, high output rates and low process-induced variability in the output. In addition to the enhanced flexbility and speed, there is an improvement in the quality of the produce. Table 39.1 mentions these advantages.

However, for such automated systems, the capital costs and the maintenance costs could be high. FMS could be very flexible and effective within the range that it is designed for. But it is limited to the range of tasks and flexibillity it is designed/programmed for. Machines, including robots—which are described next—have this inherent infelexibility. Human beings can have flexibility of the other kind; they can be trained for a *broader* variety of tasks and they can be deployed at different places as they can be cross-trained.

* As a supplement to CAM there could be CAD (Computer Aided Design). The link between the physical design of the product and the design of the manufacturing process is very essential for increased efficiencies.

Table 40.1 Advantages of FMS

• Machine Flexibility:	Ability to produce new product types. Ability to change order of operations executed on the part.
• Routing Flexibility:	Ability to use multiple machines to perform the same operation on a part. Hence the parts can be routed differently when required.
• System Capability:	Ability to meet large scale changes in volume and variety.
• Efficiency:	Coordinated flow of work by the central computer. High machine utilisation. Low setup times. High output rates. Inventory reduction and Lead time reduction due to above factors.
• Improved Quality:	Low process-induced variability.
• Automation:	Can be operated without people. Can be programmed remotely. Therefore, the system can work under adverse environments. Enhanced safety of personnel due to above factors. Better quality of work-life for employees.

Inflexibility of Flexible Manufacturing Systems

In this sense, parodoxically, flexible manufacturing system is 'Inflexible'. When new machines are to be added, it can be very expensive. Changes in system configuration require time-consuming and expensive alteration to software. Successful FMS systems that have paid back in five years have usually been very small with less than four CNC machines. Large FMS systems (even medium ones) require very complex software in order to provide the machine and routing flexibilites. The complexity of the software needed to provide such short-term flexibility usually becomes a huge stumbling block for long-term flexibility. In today's business-world, within a short span of five or less years, totally new products may be needed. Reconfiguring the FMS for these chagned requirements would be extremely expensive.

Complex, Expensive and Inflexible Software

In an automatic system like FMS, failures must be anticipated and provision for the same should already be incorporated in the software. Tool breakage, machine and vehicle failure are quite common and the ways to get out of these difficulties must be incorporated into the software of the supervisory computer control network. Therefore, the supervisory computer's software becomes more complex, expensive and inflexible for any further changes in the future. In a way, the software may become the 'hardware'.

What is needed is an improved computer software technology that is neither very expensive nor complex, but is able to do multiple complex and changing tasks. Although at the present we do not have such software technology, the future may witness a breakthrough in this technology.

ROBOTICS

Another development in the technology of control systems which holds much promise for the future is Robotics. The robot industry, although in its infancy, is rapidly growing in developed

countries such as Japan and USA. Robot have the obvious advantage of being able to work in especially harsh and demanding work environments such as unloading die casting machines where there is dirt, heat molten metal or sandblasting; or handling chemicals which are corrosive; or investment casting where there are heavy loads in addition to an abrasive environment. Moreover, robots can work tirelessly for 24 hours a day and can work in the dark as well, the latter fact making energy savings possible. Plus, one can expect consistency in quality. However, as yet, the usage of robots is limited because of the various kinds of 'blindness'* they are susceptible to such as—

(i) Target Blindness: inability to pick up a randomly positioned part.
(ii) Material Blindness: inability to discriminate between two different materials.
(iii) Blindness to Machines: cannot communicate with them.
(iv) Blindness to People: cannot communicate with them.
(v) Blindness to Environment: inability to adapt to a changing environment.
(vi) Blindness to Deterioration: unable to detect its own deterioration in performance.

Therefore, at present, the use of Robots is confined to situations where these blindnesses are not an impediment. However, it is a virgin field for research with tremendous potential in production systems. Many new research studies are being conducted in areas such as remote data transmission, voice enconding, high-speed micro-manipulators and environmental sensing. Concurrently, Industrial Engineering research is also being done on Robot Time and Motion systems analogous to the MTM type of system for human work analysis, so that alternative robotic work methods can be compared and evaluated.**

Linking up Various Areas of Automation

However, less or more advanced the robotics may be, it is logical that it should be acompanied by an automated material handling system. Similarly, various other 'islands of automation' should be linked together for maximum synergistic effect. Automation in a production system with NC/CNC/DNC machines should, naturally, be accompanied by automatic material routing, transport, positioning and storage through systems such as AGVS for maximum effectiveness. One can add to this automatic gauging or inspection simultanesouly with the production operation, which can in addition to saving total time, provide immediate feedback to the producing machine for any corrective measures. Such a linking of the various facets of automation can materialise with the use of a computer for integration. The 'factory of the future' should have such integration of operations from design through engineering, production, inspection, materials movement, loading, unloading, and storage and retrieval so that the maximum benefits of automation are achieved. To support it one would need sophisticated maintenance and safety systems. A maintenance system, curently available, is that of condition monitoring in which faults developing/incipient in the machine can be diagnosed much ahead of an otherwise disastrous breakdown. Moreover, more automation does not mean less safety requirement, but more. In short, a plant should be flexible and efficient.

However, this is limited to, shop floor integration.

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* J.A. White, 'Factory of The Future will Need Bridges between its Islands of Automation', *Industrial Engineering*, Vol. 14, No. 4, April 1982, pp. 61–68.

** (i) S.Y. Nof and R.L. Paul, 'Work Methods and Measurement—A Comparison between Robot and Human Task Performance', *International Journal of Production Research*, Vol. 17, No. 3, 1979, pp. 277–303.
(ii) S.Y. Nof and H. Lechtman, 'Robot Time and Motion System Provides Means of Evaluating Alternate Robot Work Methods', *Industrial Engineering*, Vol. 14, No. 4, 1982, pp. 38–48.

COMPUTER INTEGRATED MANUFACTURING (CIM)

The 'factory of the future' is the terminology earlier used by General Electric Corporation of USA. The same is also called as, 'Computer Integrated Manufacturing (CIM)'. At a broad level, CIM can be viewed as an integration of:

1. Product Design and Process Design
2. Production Planning and Control, and
3. Production Process itself

through the application of Information Technology. This is shown in Fig. 40.2.

Product Design and Process Design (PDPD) generally cover the following major aspects:

- Computer Aided Design (CAD), which captures the geometry of the part by using the computer data base. This is an essential input to production.
- Computer Aided Engineering (CAE), which is useful in verifying the part design for various essentials such as the engineering logic of the design and/or stress in the part, etc.
- Computer Aided Process Planning (CAPP), i.e. planning each operation that the components, subassemblies, etc. have to go through.
- Group Technology (GT) for grouping products into families and accordingly designing the processes.
- Engineering Control for documentation of components that go into the final product and for modifications or changes in part designs. Engineering Control consists of several other things such as the software for driving the robot or vision systmes and/or CNC machines and their coordination.

Production planning and control (PPC) in CIM consists basically of Manufacturing Resource Planning (MRP), Preventive Maintenance Planning, and sometimes Simulation and Optimisation. Central to these is the cost management system. The planning control system provides the essential input information and corrective actions for the Production Process (PP).

Production Process (PP) consists of:

(i) FMS with all the necessary CNC machines or Robots (for production) in a GT or cellular format,*

(ii) Materials handling system with automatic storage, retrieval and transfer and

(iii) Quality and Process Control system including monitoring, reporting system and insepction and testing equipment.

The Information Technology (IT) segment is central to CIM and enables the integration of all the other three segments of CIM viz. PDPD, PPC and PP mentioned earlier. This IT segment consists of the ncessary software (operating system, decision support system, telecommunications, artificial intellgence, etc.) and hardware.

CIM integrates various functions of management as they relate to manufacturing, bringing about synergies. It also makes production into a more knowledge-intensive activity instead of being labour-intensive. The integration not only improves production efficiencies, but also brings in speed of response and flexibility to serve the customer needs.

As a method of manufactuirng, the following components distinguish CIM from other manufacturing methodologies.

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* Greg Saul, ' Flexible Manufacturing System is CIM Implemented on the Shop Floor Level', *Industrial Engineering*, Vol. 17, No. 6, June 1985, pp. 35–39.

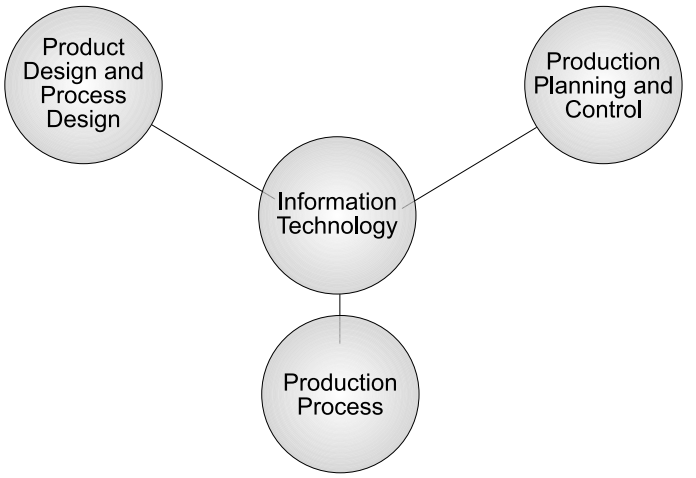


Figure 40.2 Computer Integrated Manufacturing*

- Data storage, retrieval, manipulation and presentation
- Mechanism for sensing the state and accordingly modifying the processes
- Algorithms for uniting data processing component with the sensor and modification component

Basically it is a highly interactive production system making use of data communication coupled with new management philosophies like lean manufacturing. For such high degree of interaction, a similarly high degree of integration of various functional areas of the manufacturing enterprise and also the suppliers is required. Updated information, integration of functions and players, and interaction between all these for control action are the fundamentals of CIM.

The Concerns before CIM

The challenges before an efficiently running CIM are, therefore, the following.

(a) *Data Integrity*: Ultimately, the signals for control and the actions by the CIM system depend on the data. Hence, data has to be accurate and Up-to-date and proper safeguards have to be in place. Any deficiencies in the data will mar the functioning of the CIM system.

(b) *Integration*: Integration is the essence of the CIM system. Various functions of the manufacturing enterprise as also other interactors with the manufacturing setup like the vendors have to be integrated. This is the macro-level integration that is necessary. Integration of components from different supliers with different communication protocols could be a cause of concern. A the micro-level, the CNC machines, robots, AGVs, AS/RS, etc have to work in tandem. Any failure in any one of the robots or CNC or AGV could throw a spanner in the works. Every component of the CIM has to be integrated and it has to run smooth.

(c) *Computerised Control*: All the good data and well integrated parts of the CIM system are to be properly controlled by the computers in order for the CIM to succeed. Hardware and software have to work as expected. Software, as mentioned in this chapter in the sub-section

* Gunn, Thomas G., *Manufacturing for Competitive Advantage*, Ballinger Publishing Company, USA. 1987.

of FMS, is a vital aspect. Its design and the planned actions if it does not work as designed are important aspects of a successful CIM.

CIM system is, in fact, an integrated group of various sub-systems like CAD/CAM. CAE, CAPP, GT, ERP, CNC, Robots, AGV, AS/RS, and Central Computerised Control. All have to work and work and work in tandem. The challenge before the management researchers and engineers is to reduce the complexity in the system while maintaining its interactive agility and all at a cost that is affordable.

MODERN CHEMICAL PROCESS TECHNOLOGY

Much of what was described above related to the engineering industry. Technology in the chemical process industry also is undergoing a sea change. the operational parameters are higher and the equipment and the systems have to be designed for the same. Today's chemical equipment operates at pressures of up to 6,000 atmosphere and temperatures anywhere between– 200 degrees Celsius to + 1,000 degrees Celsius. There are now new designs of reactors, distillation columns, heating, cooling evaporation, osmosis, compression, vacuum, blending, mixing, conveying, product loading, lubrication systems, gaskets, packing materials, etc. Of course, there are new control systems to operate, monitor and control the processes with little human supervision or other form of intervention.

Speeds of movement of the products and materials within the plant have increased. The range sizes for the equipment has also increased considerably. From micro-size equipment to those with weights of hundreds of tons are being used. The thickness of the material of some of the equipment could be as big as 300 mm i.e. almost a foot and could have diameters as large as 10 m. The materials of construction also vary from mild steel to highly specialised steels and titanium alloys and other special alloys for special reactants. Cladding material variety is increasing.

These are the days when processes could be from a nano-size ot the mega-size. Chemical process technology ranges from the traditional 'unit operations' to 'engineering' on the molecular level in fields as diverse as biosensors, chemical vapour depotion for computer chips, and nano level etching processes performed in 'clean rooms' to 'engineer' the required components.

The need for automation has increased tremendously. The fetching of inputs from their places of storage, the actual addition of the material in exat quantities to the reactors, the flow of liquids and gases to the reactors or mass transfer equipment like distillation columns or leaching apparatus, the control of parameters like temperature, pressure, viscosity, flow rates and pH are all performed atumatically with the use of computers. Today's chemical, petroleum and biochemical industry is run by using much automation. The use of human labour has reduced radically. Environment in and outside the plants is controlled by the use of modern separators, precipitators, cyclones, centrifuges, and other machinery. Today's cement plant is not the dusty plant that it was s decade or two ago.

As the complexity of the machinery and the level of automation increase, the production management systems also need to be geared towards such rapidly increasing sophistication. Right inputs at right times in right quantities of right quality become an imperative. Supply chains have to align themselves to these exacting requirements. Management parameters to control are being determined increasingly from the outside.

Technology is changing and the drivers of technology are also changing. In tune with these changes—rather, in order to be capable of delivering the changed requirements —the management

systems have to be established. That is the challenge the modern technology is posing to the discipline of operations management.

TECHNOLOGY IN SERVICE INDUSTRY

Service related to personalised care and hospitality are finding a friend in modern technology and high-tech equipment that can enhance the service experience and considerably increase the customer satisfaction. Speaking of hospitality industry alone, contemporary technologies such as wireless LAN, Wi-Fi and IP-telephony have become critical components of hospitality today. If world-class service is to be provided—which is in itself a 'must' in today's globalised business world—the use of up-to-date telecommunication and information technology is an imperative for hospitality firms like hotels. That is one use of the modern technology. Another use could be in connecting to the various sister firms of the hotel in the country and abroad for even as 'different' a reason as learning a new dish or recipe from an international partner firm or branch. Thus, a new exotic Finnish fish dish can be learrnt and prepared by a chef in Chennai, India. Also, through radio frequency identification, a hotel's guests can gain easy access to the hotel's restricted facilities like the spa, the salons, etc. One can use this for cashless transactions for the customers. It is also good for the security systems at the hotel, as entry can be restricted to only the genuine guests. Such access control systems, CCTVs, 'smart' rooms, etc are technologies that supplement the security systems at the hotel. 'Smart' rooms can map guest's preferences for room lighting, room temeprature, TV channels, etc and thus enhance a guest's service experience.

Entertainment industry has been changing rapidly, thanks again to the input of modern technology. There are now I-pods for music, DVDs and internet for movies. There are cable televisions, satellite televisions and home theatres. Technology has opened up huge avenues for reaching out to the customers but at the same time it has changed the mode of operations. Internet technology alone has changed the way the media is consumed and has created entirely new sectors and platforms for entertainment with a new set of operations and management issues. The significant aspect is the speed of these changes.

Similarly, technology is helping services in various other fields like healthcare, education, transport, and travel. Advances in technology are a good gift to the service industry. If operations management quickly modifies its systems to suit in technology, it will be doubly good.

STRATEGY FOR TECHNOLOGICAL CHANGE

A strategy for technology change must be evolved keeping in mind a nation's goals, needs and special environment. The cost of hardware and software should, first of all, be justified by the production/marketing volume. Although there is flexibility to manage variety and to handle changing situations, which phenomenon is described by some as 'economies of scope',* a certain minimum amount of economies of scale is necessary. The latter is not easy to achieve. Even Japan, which has been singular in its export performance, is now feeling the need to enhance the internal market. Moreover, demographical necessities, the level of unemployment and the distribution of the degrees of skills are all factors which must be considered when introducing new technology. We cannot transplant any technology or system without and equately considering our country's economic, social and cultural background.

* J.D. Goldhar and M.Jelinek, 'Plan for Economies of Scope', *Harvard Business Review*, Nov–Dec. 1983, pp. 141–48.

Yet advancement in technology is also inevitable if we are to be a part of the changing scenario in the rest of the world. For the past several descades and continuing into the present, in the global market India has taken a niche as a low cost producer of items that are either primary or are at the lower end of technology. This is also true of its computer software products. Much of our research and development takes place in the government sector and very little in the private organisations. Consequently, our developments in technology have taken place mostly in the space and atomic energy sectors with very littel trickle of benefits to the other sectors. But, it must be well understood that being a low cost low tech producer is not a very sustainable position in the global market. There is somebody else tomorrow who will figure out how to do it cheaper. India has the brain power and the technology base to move out of this 'niche'. Hence, we must be open to advancements and evolve our own strategy for technological change suited to our special needs and special environment while assessing current and future impacts.

SERVICE ORIENTATION AND CUSTOMER FOCUS

Coutries such as India are now becoming centres for services in Information Technology (IT) and Business Process Outsourcing (BPO). The vital resource in these organisations is the human rescource. Most of the operations performed here are the human operations. Operations managment is inextricably linked to human resource management in these organisations. Which are the operations that need to be examined for improvement? How should these operations that depend critically upon the human skills and abilities be managed effectively and efficiently? How should effectiveness and efficiency be defined/described in these cases? How should the known operations management principles be applied to these organisations? These are some of the questions that need to be addressed wth respect to these organisations. New dimensions of service could be learnt through a study of these operations.

Services sector has expanded rapidly in most countries of the world. In several countries it is the predominant sector of the national economy. With these developments it is being realised with force that the questions of operations and production management are not just about the machines and materials as was the care traditionally. And, this is true of the service organisations as well as the manufacturing organisations.

Service has now become the core of the business philosophy worldwide. Hence, production and operations management, as an integral part of the business has to be customer focused. That is, it should be externally, not internally, focused. 'Lean Operations' are a step in that direction. Managing production and operations is much mroe than just an efficient arrangement of the physical resources. It should be oriented towards providing service to the customers and be conscious about it responsibility to the society at large. These requirements necessitate that human relations be emphasised, a change be brought about in the work culture and in the total industrial/business culture. The world is becoming a smaller place, and mangement and society have never been required to work in such a close coperation in the history of the modern industry.

RESPONSIBILITY TOWARDS ENVIRONMENT AND TRANSITION TO A SERVICE TO SOCIETY CULTURE

The objective of an organisation is not just to increae efficiencies—and profits in the case of a business firm—but also to reduce the depletion/usage of natural resources, particularly the non-renewable resources, and redesign products, services and processes to a more environmentally sustainable level.

Supply chains must now include 'reverse supply chains' of reusable, recyclabe products and parts after their intended use is over. Less quantifiable considerations of environmental issues and society ought to be introduced in the management of operations. For itnstance, logistics would not only be concerned about cost and time but also with noise pollution, congestion and green house gas emissions.

Sustainability considerations are givng rise to new business models and new business models are giving rise to new ways of looking at production/operations. The new operations managment model is not just limited to the concerns of the manufacturing/service organisations but has to reach out to a much larger and broader goal of enviroment that belongs to the world as a whole. It is the big challenge for production and operatiosn management today.

Production and operations managment as a discipline has gathered several impressions over time: enhanced individual efficiencies, improved systems, procedures and management techniques, new technologies, emphasis on human relations and enhanced customer orientation. The next impression to catch would be that of environmental considerations minimising costs to the society. This would be on its eventual and steady progress towards the goal of a culture of 'service to the society'.

In this context, it would be interesting to recall Figure 1.2— the diagram on 'The Journey of Production and Operations Managment' — furnished in the first chapter of this book. The same diagram is reproduced below (Figure 40.3).

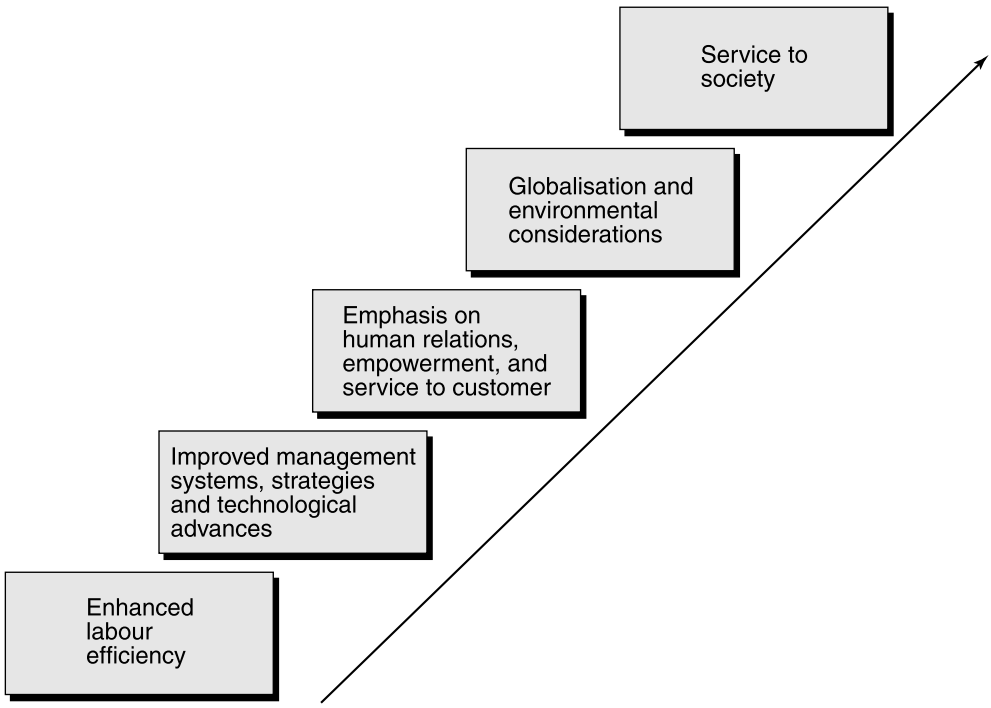


Figure 40.3 The Journey of Production and Operations Management

The above figure shows as to how the production and operations management discipline has grown from being inward-looking to outward-looking and how its scope has been widening from mainly internal efficiencies to managemnt systems and technology, to human relations and empowerment (within it from employees to business associates and customers) to global enviromental concerns to issues of service to the society. It is a fascinating widening circle of issues.

QUESTIONS FOR DISCUSSION

1. What is the impact of technological advances on Production Management?
2. What are the merits and demertis of Robotics?
3. How can you integrate group technology and MRP? What problems do you foresee in such an integration?
4. Explain the use of coding systems in group technology.
5. What might be the impact of changing attitudes about work on Job Design? How will technological advances affect Job Design? How should production management cope with the simultaneous effect of both these factors?
6. What role for production and operatiosn management do you foresee in another 15-20 years' time in India?
7. What will be the effect of depleting resources on production and operations management? How far is the problem of depleting resources applicable to India?
8. Discuss the importance fo Group Technology in CIM.
9. Can a Just-In-Time (J-I-T) system be combined with CIM? If yes, how? If no, why not? Discuss.
10. What are the implications of CIM to the Indian industry? Discuss.
11. Discuss service orientation and customer focus in Indian industry/business in the light of the Indian society. Elaborate on the interaction between the production and operations management and the society.
12. Gather information on the thermal power plants in India. What could be the measures of efficiency for these plants? How could the efficiency/efficiencies be improved? Discuss.
13. Examine the tourisms sector of India's economy. What could be the measures of performance? Operationally what improvements could you suggest? Explain
14. Take any industry (from manufacturing sector or from service sector) or organsiation of your choice. What are the enviromental and ecological problems being generated? How could the operations/processes be performed differently and/or organised differently so as to reduce the environmental problems to the society?
15. Are there any environmental problems generate by a BPO organisation? If so, what could these be? Discuss.
16. How can 'service to society' be a goal for business? Discuss.

ASSIGNMENT QUESTION

Interview the CEOs of a few organisations of your choice. Ask whether and how her/his business is moving towards 'service to society'. Present your views based on these interviews.

APPENDIX IV

EXAMPLE OF DODGE-ROMIG DOUBLE SAMPLING AOQL TABLES

Average Outgoing Quality Limit = 2.0%

Process Average %	*.0–.04*						*.05–.40*						*.41–.80*						*.81–1.20*						*1.21–1.60*						*1.61–2.00*					
Lot Size	*Trial 1*		*Trial 2*			p_t%	*Trial 1*		*Trial 2*			p_t%	*Trial 1*		*Trial 2*			p_t%	*Trial 1*		*Trial 2*			p_t%	*Trial 1*		*Trial 2*			p_t%	*Trial 1*		*Trial 2*			p_t%
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–15	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–	All	0	–	–	–	–
16–50	14	0	–	–	–	13.6	14	0	–	–	–	13.6	14	0	–	–	–	13.6	14	0	–	–	–	13.6	14	0	–	–	–	13.6	14	0	–	–	–	13.6
51–100	21	0	12	33	1	11.7	21	0	12	33	1	11.7	21	0	12	33	1	11.7	21	0	12	33	1	11.7	21	0	12	33	1	11.7	23	0	23	46	2	10.9
101–200	24	0	13	37	1	11.0	24	0	13	37	1	11.0	24	0	13	37	1	11.0	27	0	28	55	2	9.6	27	0	28	55	2	9.6	27	0	28	55	2	9.6
201–300	26	0	15	41	1	10.4	26	0	15	41	1	10.4	29	0	31	60	2	9.1	29	0	31	60	2	9.1	32	0	48	80	3	8.4	32	0	48	80	3	8.4
301–400	26	0	16	42	1	10.3	26	0	16	42	1	10.3	30	0	35	65	2	9.0	33	0	52	85	3	8.2	33	0	52	85	3	8.2	36	0	69	105	4	7.6
401–500	27	0	16	43	1	10.3	30	0	35	65	2	9.0	30	0	35	65	2	9.0	34	0	56	90	3	7.9	36	0	74	110	4	7.5	60	1	90	150	6	7.0
501–600	27	0	16	43	1	10.3	31	0	34	65	2	8.9	35	0	55	90	3	7.9	35	0	55	90	3	7.9	37	0	78	115	4	7.4	65	1	95	160	6	6.8
601–800	27	0	17	44	1	10.2	31	0	39	70	2	8.8	35	0	60	95	3	7.7	38	0	82	120	4	7.3	38	0	82	120	4	7.3	70	1	120	190	7	6.4
801–1000	27	0	17	44	1	10.2	32	0	38	70	2	8.7	36	0	59	95	3	7.6	38	0	87	125	4	7.2	70	1	100	170	6	6.5	70	1	145	215	8	6.2
1001–2000	33	0	37	70	2	8.5	33	0	37	70	2	8.5	37	0	63	100	3	7.5	43	0	112	155	5	6.5	80	1	160	240	8	5.8	110	2	205	315	11	5.5
2001–3000	34	0	41	75	2	8.2	34	0	41	75	2	8.2	41	0	84	125	4	7.0	75	1	115	190	6	6.1	115	2	195	310	10	5.3	160	3	310	470	15	4.7
3001–4000	34	0	41	75	2	8.2	38	0	62	100	3	7.3	41	0	89	130	4	6.9	80	1	140	220	7	5.8	120	2	255	375	12	5.0	235	5	415	650	20	4.3
4001–5000	34	0	41	75	2	8.2	38	0	62	100	3	7.3	42	0	88	130	4	6.9	80	1	175	255	8	5.5	125	2	285	410	13	4.9	275	6	475	750	23	4.2
5001–7000	35	0	40	75	2	8.1	38	0	62	100	3	7.3	44	0		160	5	6.4	85	1	205	290	9	5.3	125	2	320	445	14	4.8	280	6	575	855	26	4.1
7001–10,000	35	0	40	75	2	8.1	38	0	62	100	3	7.3	45	0		160	5	6.3	85	1	210	295	9	5.2	165	3	335	500	15	4.5	32 0	7	645	965	29	4.0
10,001–20,000	35	0	40	75	2	8.1	39	0	66	105	3	7.2	45	0		160	5	6.3	90	1	260	350	11	5.1	170	3	425	595	18	4.4	395	9	835	1230	37	3.9
20,001–50,000	35	0	40	75	2	8.1	43	0	92	135	4	6.6	47	0		195	6	6.0	130	2	300	430	13	4.7	205	4	515	720	22	4.3	480	11		1570	46	3.7
50,001–100,000	35	0	45	80	2	8.0	43	0	92	135	4	6.6	85	1		270	8	5.2	133	2	345	480	14	4.5	250	5	615	865	26	4.1	580	13		2040	58	3.5

Source: E.L. Grant, Statistical Quality Control, McGraw-Hill, 1964 (International Student Edition with Kogakusha Company Limited, Tokyo).

APPENDIX V

EXAMPLE OF DODGE-ROMIG DOUBLE SAMPLING LOT TOLERANCE TABLES

Lot Tolerance Percent Defective = 5.0%, Consumer's Risk = 0.10

Process Average %	*.0–.05*						*.06–.50*						*.51–1.00*						*1.01–1.50*						*1.51–2.00*						*2.01–2.50*					
Trial	*Trial 1*		*Trial 2*			*AOQL in %*	*Trial 1*		*Trial 2*			*AOQL in %*	*Trial 1*		*Trial 2*			*AOQL in %*	*Trial 1*		*Trial 2*			*AOQL in %*	*Trial 1*		*Trial 2*			*AOQL in %*	*Trial 1*		*Trial 2*			*AOQL in %*
	n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2		n_1	c_1	n_2	n_1+n_2	c_2	
1–30	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0	All	0	–	–	–	0
31–50	30	0	–	–	–	.49	30	0	–	–	–	.49	30	0	–	–	–	.49	30	0	–	–	–	.49	30	0	–	–	–	.49	30	0	–	–	–	.49
51–75	38	0	–	–	–	.59	38	0	–	–	–	.59	38	0	–	–	–	.59	38	0	–	–	–	.59	38	0	–	–	–	.59	38	0	–	–	–	.59
76–100	44	0	21	65	1	.64	44	0	21	65	1	.64	44	0	21	65	1	.64	44	0	21	65	1	.64	44	0	21	65	1	.64	44	0	21	65	1	.64
101–200	49	0	26	75	1	.84	49	0	26	75	1	.84	49	0	26	75	1	.84	49	0	51	100	2	.91	49	0	51	100	2	.91	49	0	51	100	2	.91
201–300	50	0	30	80	1	.91	50	0	30	80	1	.91	50	0	55	105	2	1.0	50	0	55	105	2	1.0	50	0	80	130	3	1.1	50	0	100	150	4	1.1
301–400	55	0	30	85	1	.92	55	0	55	110	2	1.1	55	0	55	110	2	1.1	55	0	80	135	3	1.1	55	0	100	155	4	1.2	85	1	105	190	6	1.3
401–500	55	0	30	85	1	.93	55	0	55	110	2	1.1	55	0	80	135	3	1.2	55	0	105	160	4	1.3	85	1	120	205	6	1.4	85	1	140	225	7	1.4
501–600	55	0	30	85	1	.94	55	0	60	115	2	1.1	55	0	85	140	3	1.2	55	0	110	165	4	1.3	85	1	145	230	7	1.4	85	1	165	250	8	1.5
601–800	55	0	35	90	1	.95	55	0	65	120	2	1.1	55	0	85	140	3	1.3	90	1	125	215	6	1.5	90	1	170	260	8	1.5	120	2	185	305	10	1.6
801–1000	55	0	35	90	1	.96	55	0	65	120	2	1.1	55	0	115	170	4	1.4	90	1	150	240	7	1.5	90	1	200	290	9	1.6	120	2	210	330	11	1.7
1001–2000	55	0	35	90	1	.98	55	0	95	150	3	1.3	55	0	120	175	4	1.4	90	1	185	275	8	1.7	120	2	225	345	11	1.9	175	4	260	435	15	2.0
2001–3000	55	0	65	120	2	1.2	55	0	95	150	3	1.3	55	0	150	205	5	1.5	120	2	180	300	9	1.9	150	3	270	420	14	2.1	205	5	375	580	21	2.3
3001–4000	55	0	65	120	2	1.2	55	0	95	150	3	1.3	90	1	140	230	6	1.6	120	2	210	330	10	2.0	150	3	295	445	15	2.3	230	6	420	650	24	2.4
4001–5000	55	0	65	120	2	1.2	55	0	95	150	3	1.4	90	1	165	255	7	1.8	120	2	255	375	12	2.1	150	3	345	495	17	2.3	255	7	445	700	26	2.5
5001–7000	55	0	65	120	2	1.2	55	0	95	150	3	1.4	90	1	165	255	7	1.8	120	2	260	380	12	2.1	150	3	370	520	18	2.3	255	7	495	750	28	2.6
7001–10,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5	90	1	190	280	8	1.9	120	2	285	405	13	2.1	175	4	370	545	19	2.4	280	8	540	820	31	2.7
10,001–20,000	55	0	65	120	2	1.2	55	0	120	175	4	1.5	90	1	190	280	8	1.9	120	2	310	430	14	2.2	175	4	420	595	21	2.4	280	8	660	940	36	2.8
20,001–50,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7	90	1	215	305	9	2.0	120	2	335	455	15	2.2	205	5	485	690	25	2.5	305	9	745	1050	41	2.9
50,001–100,000	55	0	65	120	2	1.2	55	0	150	205	5	1.7	90	1	240	330	10	2.1	120	2	360	480	16	2.3	205	5	555	760	28	2.6	330	10	810	1140	45	3.0

Source: E.L. Grant, Statistical Quality Control, McGraw-Hill, 1964 (International Student Edition with Kogakusha Company Limited, Tokyo).

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SECTION VI: TIMING DECISIONS

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