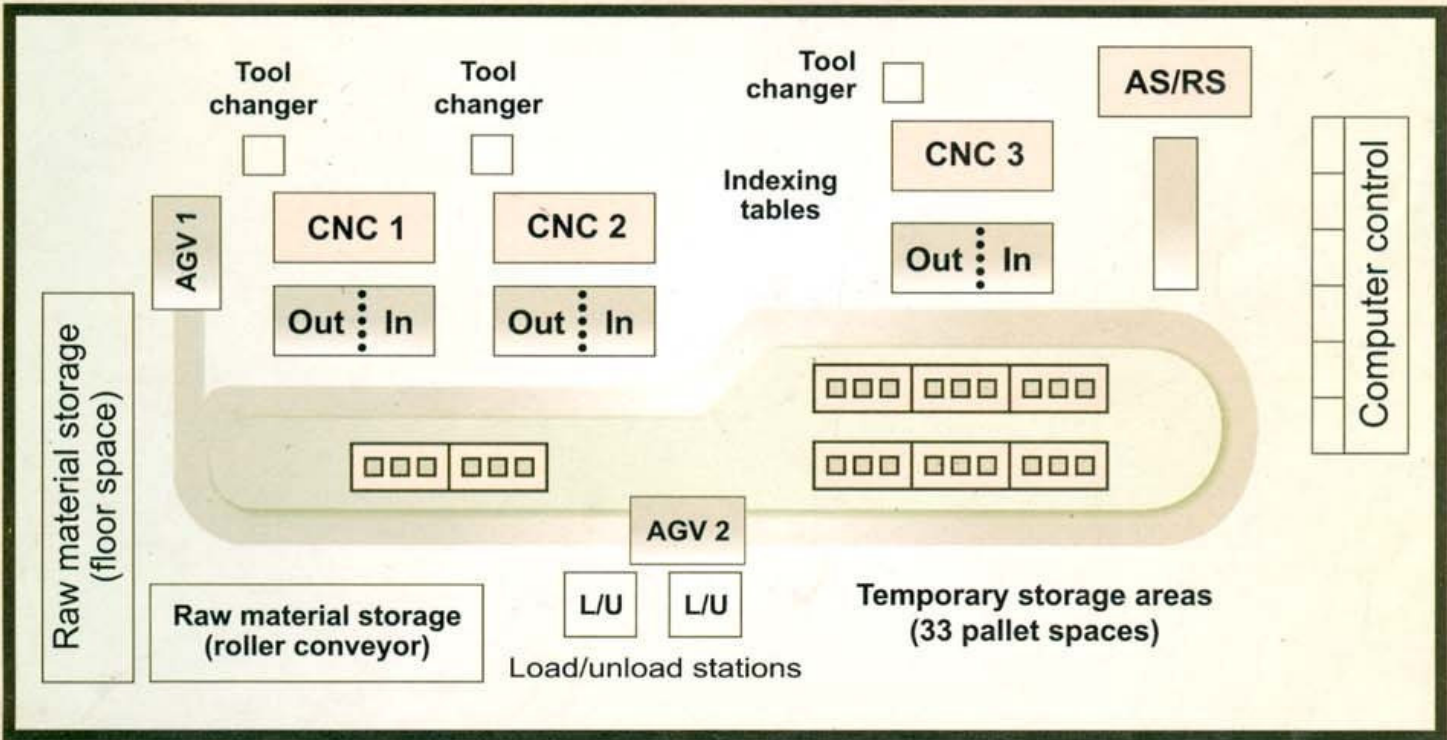


# FLEXIBLE MANUFACTURING SYSTEM



**H.K. SHIVANAND**  
**M.M. BENAL**  
**V. KOTI**



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# FLEXIBLE MANUFACTURING SYSTEM

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*To*  
*Our beloved parents*

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## Foreword

During recent years the subject of Flexible Manufacturing System has gained considerable importance in teaching curriculum of Mechanical, Industrial Engineering and Management and Automobile Engineering students. Formerly Flexible Manufacturing System used to form a small part of Computer Integrated Manufacturing, but at present it is taught as an elective for UG students and separate full subject to students of PG.

The outstanding virtue of this book is that the student is given a clear understanding of the fundamental concepts in Flexible Manufacturing System. Emphasis has been given through out the book to explain the physical picture.

The authors Dr. H.K. Shivanand, Mr. M.M. Benal and Mr. Vishwanath Koti posses a long experience of teaching the subject to UG and PG students. Besides Dr. H.K. Shivanand and Mr. M.M. Benal have been active research workers in the field of Manufacturing and Composite Materials. Their teaching and research experience has greatly enhanced the value of the book.

I am confident that this book will be widely welcomed and used as a textbook on Flexible Manufacturing System in different engineering students. The book will also prove to be of great use to practicing budding engineers.

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# Preface

The main objectives of this book is to produce a good textbook from the student's point of view. The book is intended as a text to be used by students in technical institutes. It is written for postgraduate and undergraduate students. The underlying theme of the book has been to expose the reader to a larger number of mechanical systems and the techniques of the systems. The course material presented in the book has been evolved from the author's experience in teaching this course for many years to the undergraduate students of Mechanical, IEM and PG students of Computer Integrated Manufacturing.

Terminology and definitions are introduced and explained as needed, emphasis has been placed on the topics considered most important and the material is arranged for easy understanding. This textbook is arranged so that the engineer in practice can use it for self study. To make the text meaningful and valuable to all engineers and students, the authors have attempted to include case studies.

We sincerely hope that the book will prove to be useful to the readers and save much time and labour of the students preparing the subject of the various examinations. In the preparation of this text, every case has been taken to avoid any mistakes. However, some errors might have crept inadvertently.

Suggestions, modifications, comments and corrections for the improvement of the text are welcome.

The authors wish to express their sincere thanks to the principals and managements of their respective colleges. Further they would like to thank Mr. Saumya Gupta, Managing Director and Mr. V.R. Babu, and Mr. C.K. Suryanarayan, New Age International Publishers for their commitment and encouragement in bringing out this book in time with good quality.

**DR. H.K. SHIVANAND**

**M.M. BENAL**

**V. KOTI**

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# Acknowledgement

A work of this nature while entailing a lot of efforts cannot be completed without the help of some external sources. We will be failing our duties of authors if we do acknowledge with gratitude the invaluable contribution of these sources.

It is really thrilling experience to produce this book, which would have not been made possible without many well-wishers help. It would have been very difficult to write this book without the enthusiastic support, typing and preparation of Sri Sharath, PG student, Sir MVIT, Bangalore. We are very grateful for his help.

We express our gratitude to Prof. S.C. Sharma and Prof. V.K. Basalalli for their valuable suggestions and inspiration. It will not be out of place here to express thanks to our families for their unfailing patience and cheerfulness during the long job of preparing the manuscript.

The authors wish to put on record the invaluable contribution, of a very large number of students in the form of feedback and assistance during preparation of the course material.

We deeply express our gratitude to our well-known Sri Krisnadevaraya Educational Trust, Bangalore, for encouragement and support.

The authors also wish to thank the Director, New Age Publishers for valuable assistance during planning and preparation of the book, elegant printing and excellent setup of the book.

Finally there are many others who have encouraged, inspired and helped us to complete this work. We gratefully acknowledge their support and contribution.

**DR. H.K. SHIVANAND**

**M.M. BENAL**

**V. KOTI**

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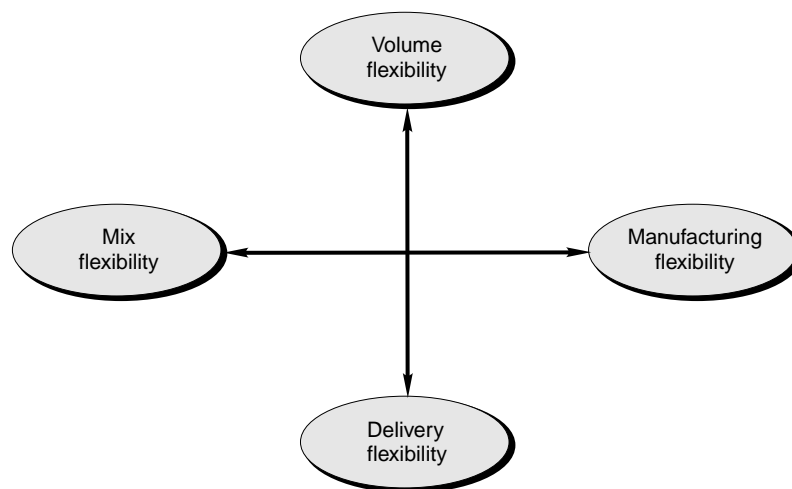
## FMS Introduction and Description

### 1.1 INTRODUCTION

In the middle of 1960s, market competition became more intense. During 1960 to 1970 cost was the primary concern. Later quality became the priority. As the market became more and more complex, speed of delivery became something customer also needed.

A new strategy was formulated (*Customizability*). The companies have to adapt to the environment in which they operate, to be more *flexible* in their operations and to satisfy different market segments. Thus the innovation of FMS became related to the effort of gaining competitive advantage.

First of all, FMS is a manufacturing technology. Secondly, FMS is a philosophy. “System” is the key word. Philosophically, FMS incorporates a system view of manufacturing. The buzzword for today’s manufacturer is “agility”. An agile manufacturer is one who is the fastest to the market, operates with the lowest total cost and has the greatest ability to “delight” its customers. FMS is simply one way that manufacturers are able to achieve this agility.



**Fig. 1.1** Types of flexibilities

## 1.2 DEFINITION

A flexible manufacturing system (FMS) is an arrangement of machines ... interconnected by a transport system. The transporter carries work to the machines on pallets or other interface units so that work-machine registration is accurate, rapid and automatic. A central computer controls both machines and transport system.

Or

“FMS consists of a group of processing work stations interconnected by means of an automated material handling and storage system and controlled by integrated computer control system.”

FMS is called flexible due to the reason that it is capable of processing a variety of different part styles simultaneously at the workstation and quantities of production can be adjusted in response to changing demand patterns.

## 1.3 BASIC COMPONENTS OF FMS

The basic components of FMS are:

1. Workstations
2. Automated Material Handling and Storage system.
3. Computer Control System

**1. Workstations:** In present day application these workstations are typically computer numerical control (CNC) machine tools that perform machining operation on families of parts. Flexible manufacturing systems are being designed with other type of processing equipments including inspection stations, assembly works and sheet metal presses. The various workstations are

- (i) Machining centers
- (ii) Load and unload stations
- (iii) Assembly work stations
- (iv) Inspection stations
- (v) Forging stations
- (vi) Sheet metal processing, etc.

**2. Automated Material Handling and Storage system:** The various automated material handling systems are used to transport work parts and subassembly parts between the processing stations, sometimes incorporating storage into function.

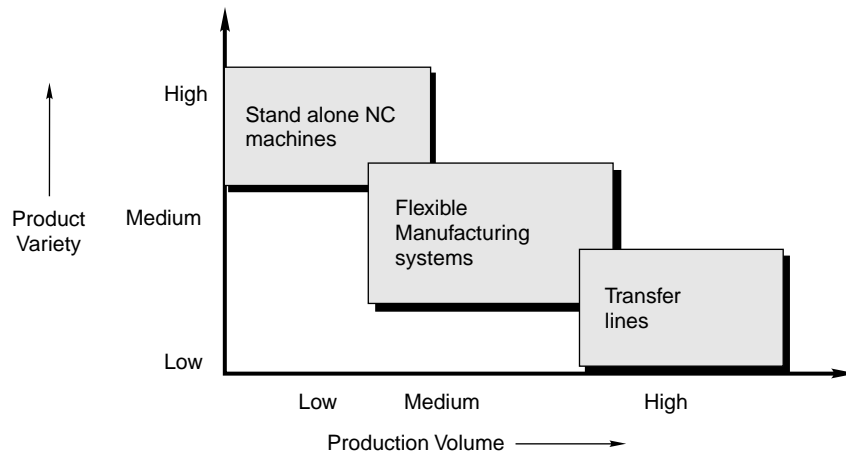
The various functions of automated material handling and storage system are

- (i) Random and independent movement of work parts between workstations
- (ii) Handling of a variety of work part configurations
- (iii) Temporary storage
- (iv) Convenient access for loading and unloading of work parts
- (v) Compatible with computer control

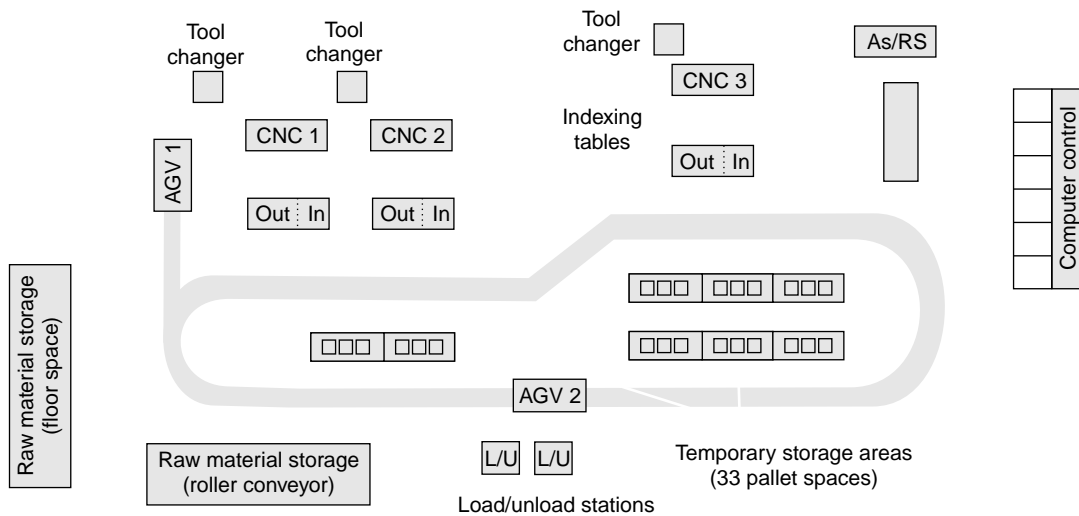
**3. Computer Control System:** It is used to coordinate the activities of the processing stations and the material handling system in the FMS. The various functions of computer control system are:

- (i) Control of each work station
- (ii) Distribution of control instruction to work station
- (iii) Production control
- (vi) Traffic control
- (v) Shuttle control
- (vi) Work handling system and monitoring
- (vii) System performance monitoring and reporting

The FMS is most suited for the mid variety, mid value production range.



**Fig. 1.2** Application characteristics of FMS



**Fig. 1.3** Flexible manufacturing system

## 1.4 THE SIGNIFICANCE OF FMS IN THE 1990s

The installed worldwide FMS base in 1989 was estimated to be around 500 to 1200 systems, the higher figure arising when a system is defined as having 2 or more CNC machine tools connected by a materials handling system, and controlled by a central computer. Ranta and Tchijov suggest that this number will rise to around 2500–3500 by the year 2000. This led them to suggest that “the strategic majority of production of the metal-working industries in the industrialized countries will be produced by FMS or similar systems [by the year 2000].”

Kelley’s empirical research in 1987 strongly contradicts this. In a large (>1000 firms) survey of US metal working firms, she found that less than 5 per cent of those plants *with computerized automation* have an FMS and that FMS constituted only 1.5 per cent of the total number of installations of computerized automation. Why are there still so few FMS in the world given that small-batch engineering production is a significant proportion of manufacturing output?

There are significant practical reasons for the disparity between the promise of FMS in the 1980s and its narrowness and scarcity of application in the early 1990s. These reasons are outlined below separately, though they are very much interdependent. Different approaches to flexibility and their meanings are shown Table 1.1.

**Table 1.1** Different approaches to flexibility and their meanings

<i>Approach</i>	<i>Flexibility meaning</i>
1. Manufacturing	<ul style="list-style-type: none"> <li>■ The capability of producing different parts without major retooling</li> <li>■ A measure of how fast the company converts its process from making an old line of products to produce a new product</li> <li>■ The ability to change a production schedule, to modify a part, or to handle multiple parts</li> </ul>
2. Operational	<ul style="list-style-type: none"> <li>■ The ability to efficiently produce highly customized and unique products</li> </ul>
3. Customer	<ul style="list-style-type: none"> <li>■ The ability to exploit various dimension of speed of delivery</li> </ul>
4. Strategic	<ul style="list-style-type: none"> <li>■ The ability of a company to offer a wide variety of products to its customers</li> </ul>
5. Capacity	<ul style="list-style-type: none"> <li>■ The ability to rapidly increase or decrease production levels or to shift capacity quickly from one product or service to another</li> </ul>

So, what is flexibility in manufacturing?

There are three levels of manufacturing flexibility.

### (a) *Basic flexibilities*

- **Machine flexibility:** The ease with which a machine can process various operations
- **Material handling flexibility:** A measure of the ease with which different part types can be transported and properly positioned at the various machine tools in a system
- **Operation flexibility:** A measure of the ease with which alternative operation sequences can be used for processing a part type

**(b) System flexibilities**

- **Volume flexibility:** A measure of a system's capability to be operated profitably at different volumes of the existing part types
- **Expansion flexibility:** The ability to build a system and expand it incrementally
- **Routing flexibility:** A measure of the alternative paths that a part can effectively follow through a system for a given process plan
- **Process flexibility:** A measure of the volume of the set of part types that a system can produce without incurring any setup
- **Product flexibility:** The volume of the set of part types that can be manufactured in a system with minor setup

**(c) Aggregate flexibilities**

- **Program flexibility:** The ability of a system to run for reasonably long periods without external intervention
- **Production flexibility:** The volume of the set of part types that a system can produce without major investment in capital equipment
- **Market flexibility:** The ability of a system to efficiently adapt to changing market conditions

**1.5 DIFFERENT TYPES OF FMS**

The different types of FMS are

- Sequential FMS
- Random FMS
- Dedicated FMS
- Engineered FMS
- Modular FMS

**Sequential FMS:** It manufactures one-piece part batch type and then planning and preparation is carried out for the next piece part batch type to be manufactured. It operates like a small batch flexible transfer line.

**Random FMS:** It manufactures any random mix of piece part types at any one time.

**Dedicated FMS:** It continually manufactures, for extended periods, the same but limited mix of piece part batch types.

**Engineered FMS:** It manufactures the same mix of part types throughout its lifetime.

**Modular FMS:** A modular FMS, with a sophisticated FMS host, enables an FMS user to expand their FMS capabilities in a stepwise fashion into any of the previous four types of FMS.

**1.6 TYPES OF FMS LAYOUTS**

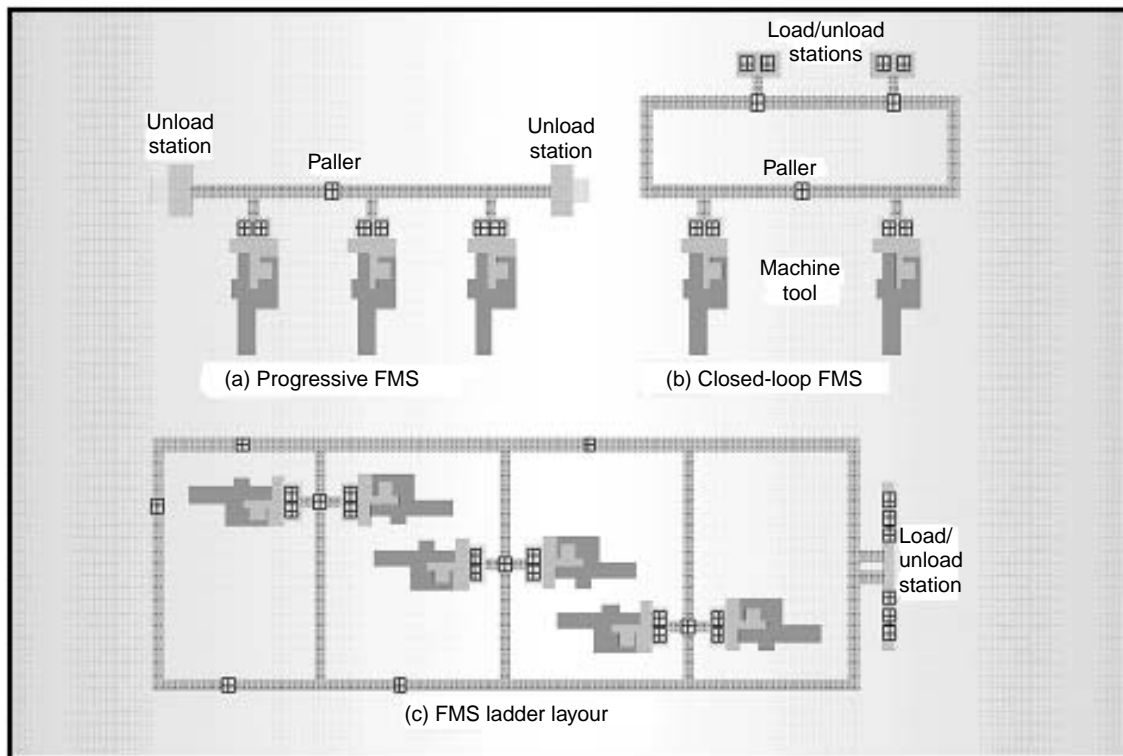
The different types of FMS layouts are:

1. Progressive or Line Type
2. Loop Type
3. Ladder Type
4. Open field type
5. Robot centered type

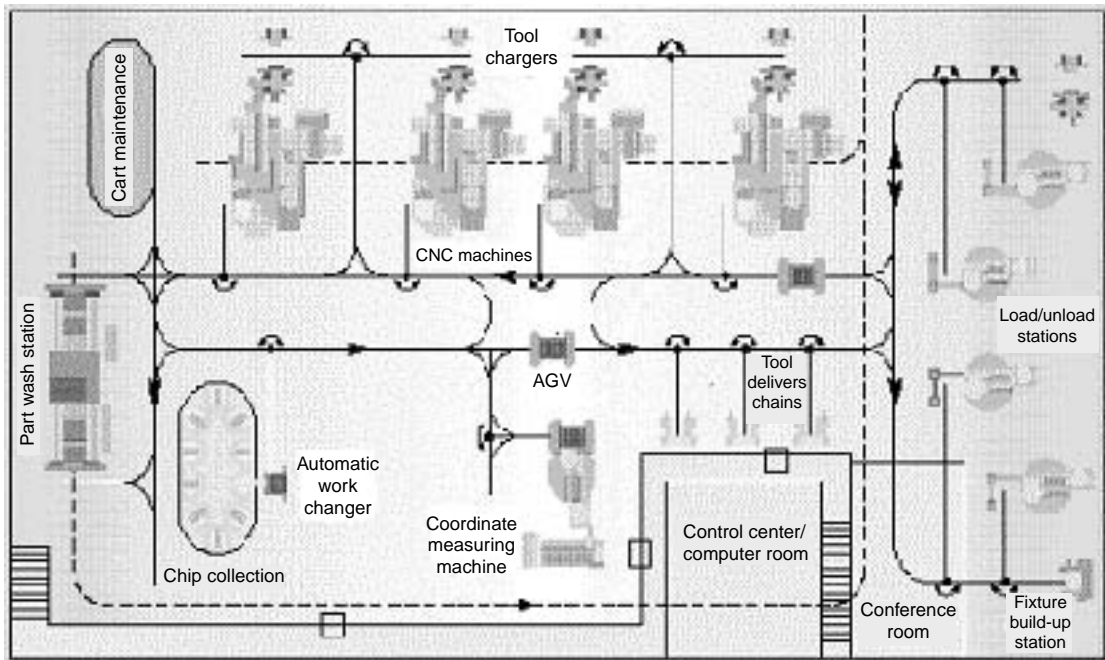
**1. Progressive or Line type:** The machines and handling system are arranged in a line as shown in the Fig.1.4 (a). It is most appropriate for a system in which the part progress from one workstation to the next in a well defined sequence with no back flow. The operation of this type of system is very similar to transfer type. Work always flows in unidirectional path as shown in Fig.1.4 (a).

**2. Loop Type:** The basic loop configuration is as shown in Fig. 1.4 (b). The parts usually move in one direction around the loop, with the capability to stop and be transferred to any station. The loading and unloading station are typically located at one end of the loop Fig.1.4 (b)

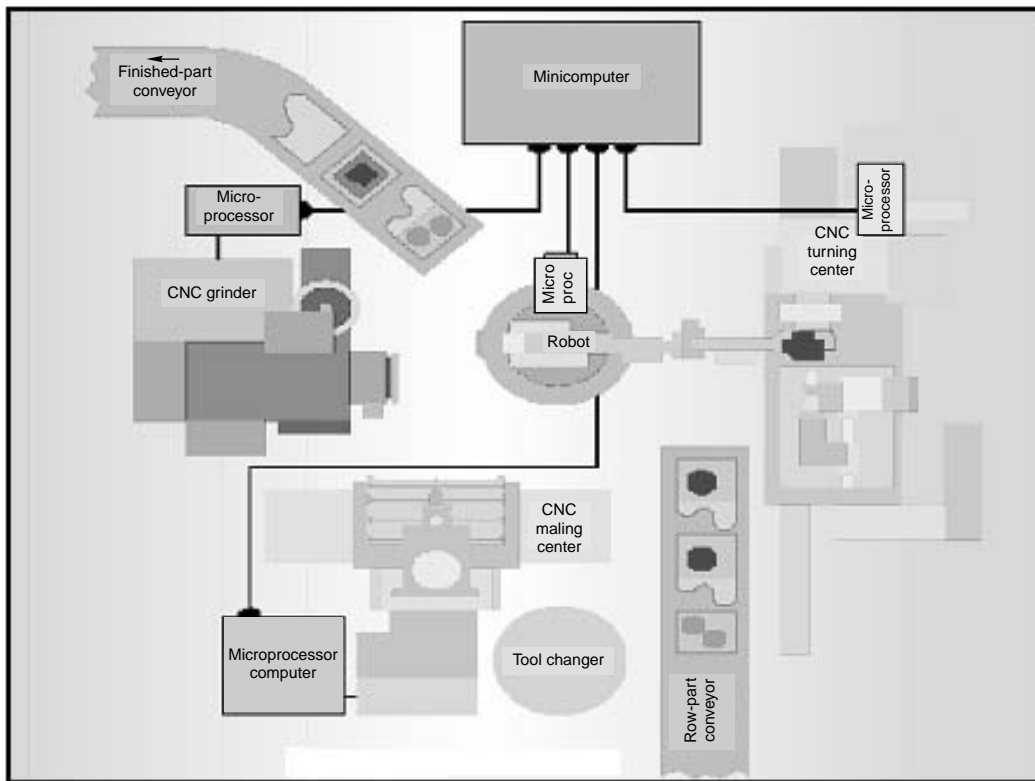
**3. Ladder Type:** The configuration is as shown in Fig. 1.4 (c). The loading and unloading station is typically located at the same end. The sequence to the operation/transfer of parts from one machine tool to another is in the form of ladder steps as shown in Fig.1.4 (c)



**Fig. 1.4**



(d) Open field FMS



(e) Robot centered FMS

Fig. 1.4 (Contd.)

**4. Open Field Type:** The configuration of the open field is as shown in Fig.1.4 (d). The loading and unloading station is typically located at the same end. The parts will go through all the substations, such as CNC machines, coordinate measuring machines and wash station by the help of AGV's from one substation to another.

**5. Robot Centered Type:** Robot centered cell is a relatively new form of flexible system in which one or more robots are used as the material handling systems as shown in Fig.1.4 (e). Industrial robots can be equipped with grippers that make them well suited for handling of rotational parts.

### 1.6.1 Factors Influencing the FMS Layouts

The various factors influencing the layouts of FMS are:

- Availability of raw material
- Proximity to market
- Transport facilities
- Availability of efficient and cheap labor
- Availability of power, water and fuel
- Atmospheric and climatic condition
- Social and recreation facilities
- Business and economic conditions

### 1.6.2 Seeking Benefits on Flexibility

Today's manufacturing strategy is to seek benefits from flexibility. This is only feasible when a production system is under complete control of FMS technology. Having in mind the *Process-Product Matrix* you may realize that for an industry it is possible to reach for high flexibility by making innovative technical and organizational efforts. See the Volvo's process structure that makes cars on movable pallets, rather than an assembly line. The process gains in flexibility. Also, the Volvo system has more flexibility because it uses multi-skill operators who are not paced by a mechanical line. So we may search for benefits from flexibility on moving to the job shop structures.

Actually, the need is for *flexible processes* to permit rapid low cost switching from one product line to another. This is possible with *flexible workers* whose multiple skills would develop the ability to switch easily from one kind of task to another.

As main resources, flexible processes and flexible workers would create *flexible plants* as plants which can adapt to changes in real time, using movable equipment, knockdown walls and easily accessible and re-routable utilities.

## 1.7 FMS—AN EXAMPLE OF TECHNOLOGY AND AN ALTERNATIVE LAYOUT

The idea of an FMS was proposed in England (1960s) under the name "System 24", a flexible machining system that could operate without human operators 24 hours a day under computer control. From the beginning the emphasis was on *automation* rather than the "reorganization of workflow".

Early flexible manufacturing systems were large and very complex, consisting of dozens of Computer Numerical Controlled machines (CNC) and sophisticated material handling systems.

They were much automated, very expensive and controlled by incredibly complex software. There were only a limited number of industries that could afford investing in a traditional FMS as described above.

Currently, the trend in FMS is toward small versions of the traditional FMS, called flexible manufacturing cells (FMC). Today two or more CNC machines are considered as a flexible *cell* and two or more cells are considered a flexible manufacturing system.

Thus, a **Flexible Manufacturing System (FMS)** consists of several machine tools along with part and tool handling devices such as robots, arranged so that it can handle any family of parts for which it has been designed and developed.

## 1.8 OBJECTIVES OF AN FMS

A study, carried out with West Germany manufacturing has shown the major aims of installing an FMS to be:

- Decreased Lead Times
- Increased Through put
- Increased machine utilization
- Improved Due Date Reliability
- Decreased Store Inventors Levels
- Decreased Work in Progress
- Increased Quality

## 1.9 AIMS OF FMS

- To reduce costs
- Better utilization of the production equipment reduction of stocks (ex: Work in progress—capital shorter through put times)
- Reduction of piece part unit costs.
- To increase Technical Performance:
  - Increased production levels
  - Greater product mixture
  - Simultaneous product mixture manufacturing
  - Integration of the production system into the factory's logistical system
  - Smaller batch sizes
  - Shorter or zero change over or reset of times
- To improve Order Development:
  - Shorter lead times/delivery times
  - Determination of production capacities
- To assist future Corporate Security:
  - Increased Competitiveness
  - Increased Quality
  - Improved Company Image

## 1.10 THE PRINCIPLE OBJECTIVES OF FMS

The principle objectives of FMS are

### 1. To improve operational control through:

- Reduction in the number of uncontrollable variables.
- Providing tools to recognize and react quickly to deviations in the manufacturing plan
- Reducing the dependence of human communication.

### 2. To reduce direct labor:

- Removing operators from the machining site (their responsibilities activities can be broadened).
- Eliminating dependence on highly skilled machines (their manufacturing skills can be better utilized in manufacturing engineering functions).
- Providing a catalyst to introduce and support unattended or lightly attended machining operation.

### 3. To improve short run responsiveness consisting of:

- Engineering changes
- Processing changes
- Machining downtime or unavailability
- Cutting tool failure
- Late material delivery

### 4. To improve long-run accommodations through quicker and easier assimilation of:

- Changing product volumes
- New product additions and introductions
- Differentiation part mixes
- Increase Machine Utilization by:
  - Eliminating machine setup
  - Utilizing automated features to replace manual intervention
  - Providing quick transfer devices to keep machines in the cutting cycle
- Reduce inventors by:
  - Reducing lot sizes
  - Improving inventors turn-over
  - Providing the planning tools for JIT manufacturing

## 1.11 ADVANTAGES AND DISADVANTAGES OF FMS IMPLEMENTATION

The various advantages and disadvantages of FMS implementation are

### 1.11.1 Advantages

- Faster, lower-cost changes from one part to another which will improve capital utilization
- Lower direct labor cost, due to the reduction in number of workers

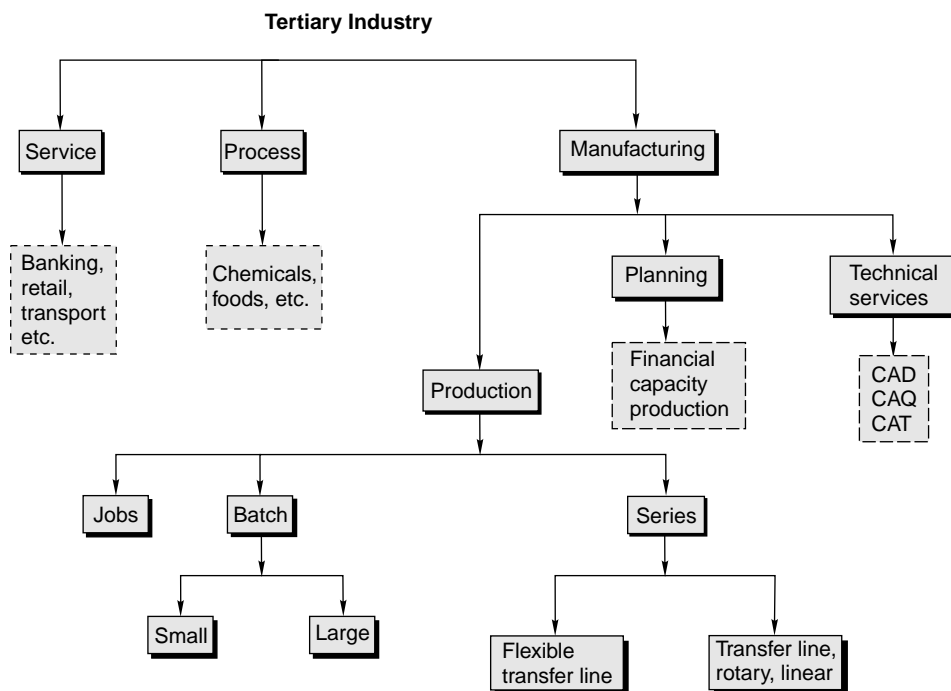
- Reduced inventory, due to the planning and programming precision
- Consistent and better quality, due to the automated control
- Lower cost/unit of output, due to the greater productivity using the same number of workers
- Savings from the indirect labor, from reduced errors, rework, repairs and rejects

### 1.11.2 Disadvantages

- Limited ability to adapt to changes in product or product mix (ex. machines are of limited capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
- Substantial pre-planning activity
- Expensive, costing millions of dollars
- Technological problems of exact component positioning and precise timing necessary to process a component
- Sophisticated manufacturing systems

## 1.12 AREA OF APPLICATION OF A FMS IN INDUSTRY

The following chart in the Fig. 1.5 shows the various applications in an industry.



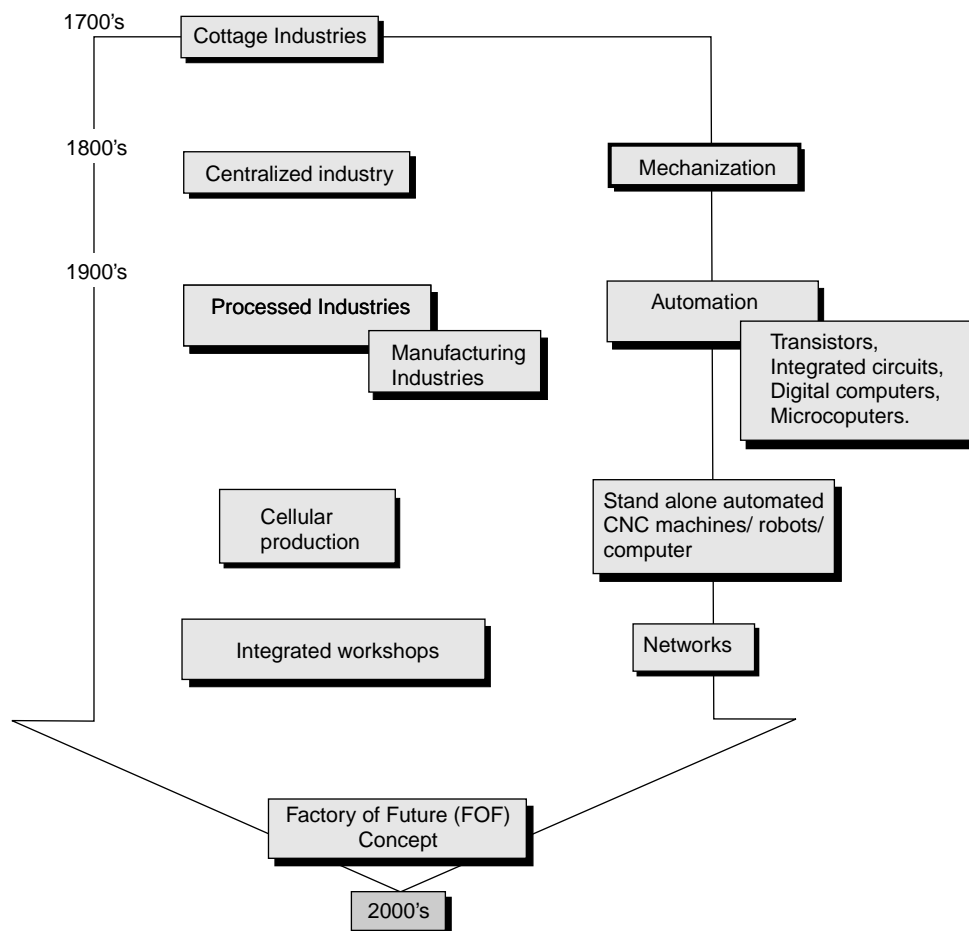
**Fig. 1.5** Area of applications of FMS in an industry

### 1.13 VARIOUS EQUIPMENTS AND THEIR FUNCTIONS REQUIRED FOR AN FMS

The two important equipments of FMS are:

1. **Primary equipment:** It adds value to the piece parts being manufactured. It consists of work centers, which physically machine a piece part, and process centers, which assemble, check or wash, etc. the piece parts.
2. **Secondary equipment:** It is used to support the primary equipment in achieving this goal. It consists of support stations such as pallet/fixture load-unload stations and tool commissioning/setting area, etc. It also consists of support equipments such as robots, pallet/fixture/stillage stores, pallet buffer stations, tool stores, raw material stores, transport system (AGVs, RGVs, robots) for tooling and piece parts, etc.

### 1.14 INNOVATIONS THAT HAVE ADVANCED THE MANUFACTURING INDUSTRIES



**Fig. 1.6** Innovations that have advanced the manufacturing industries

### 1.15 CIM TECHNOLOGY

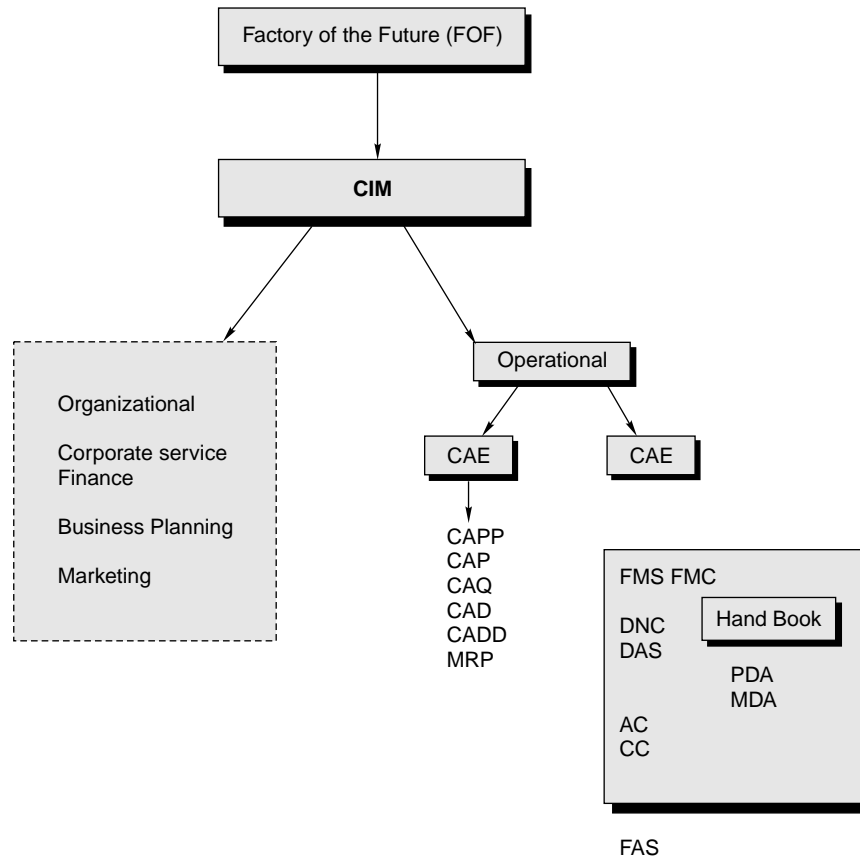


Fig. 1.7 CIM Technology

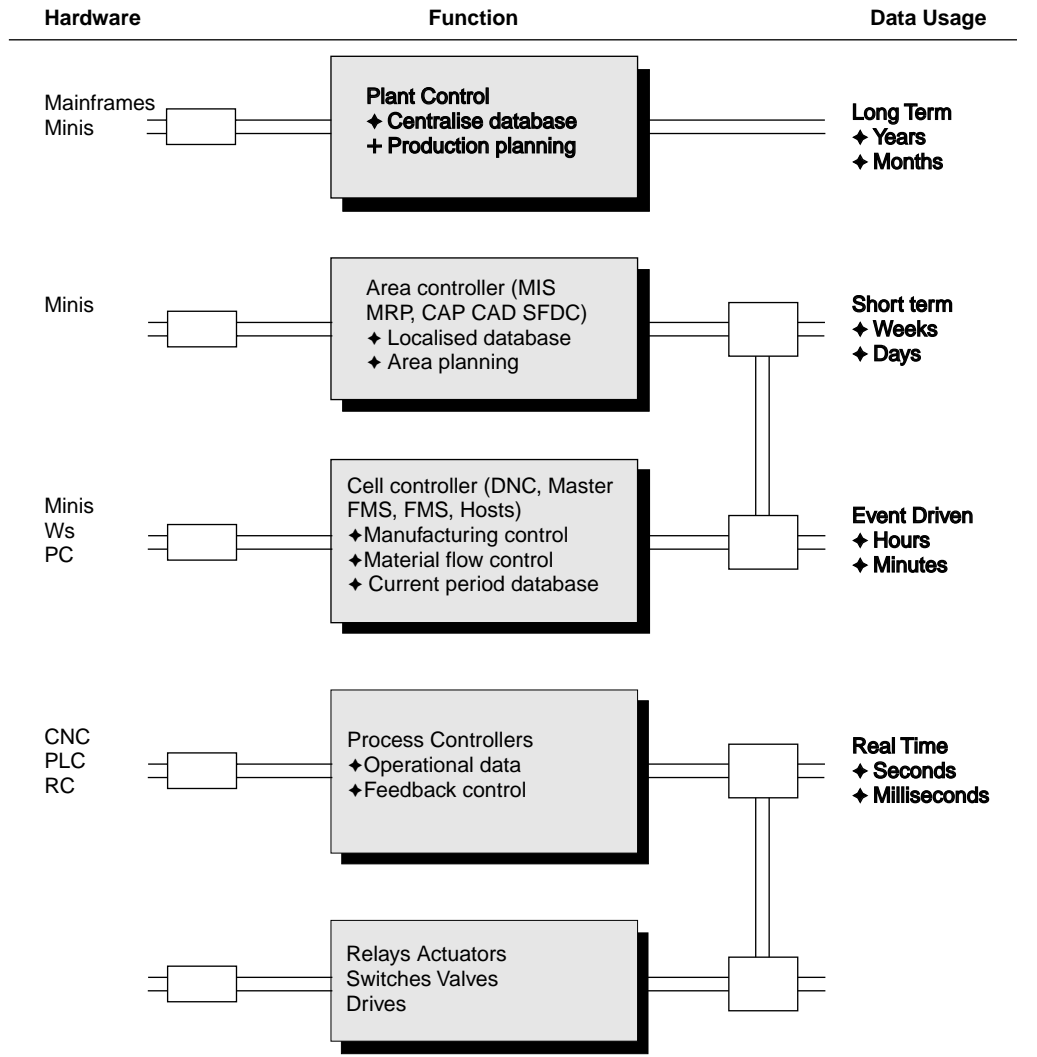
CAPP	Computer Aided Process Planning	FMS	Flexible Manufacturing System
CAP	Computer Aided Planning	FMC	Flexible Manufacturing Cell
CAQ	Computer Aided Quality Control	FAS	Flexible Manufacturing Assembly
CAD	Computer Aided Design	DNC	Direct Numerical Control
CADD	Computer Aided Design and Drafting	DAS	Data Acquisition System
MRP	Materials Resource Planning	PDA	Production Data
CIM	Computer Integrated Manufacturing	AC	Area Control
CC	Cell Control		

### 1.16 HIERARCHY OF CIM

The computer integrated manufacturing includes all of the engineering functions of CAD/CAM along with firm's business functions that are related to manufacturing.

The activities in factory's environment can be logically distributed into a hierarchy to run on a data exchange network system.

There are 5 levels of control or organization as shown Fig. 1.8.



**Fig. 1.8** CIM hierarchy

Control functions are executed at Level 1 and 2 of the CIM hierarchy consisting of CNC, NC, RC and PLC equipments.

Levels 3, 4 and 5 define the organizational levels such as FMS host, area controller, plant control or MRP computer, etc.

Level 1 of the hierarchy include the drives, motors, limit switches, etc. of the production equipment.

Level 2 includes the controllers, which enable a machine to achieve an autonomous standalone capability. The CNCs, PLCs and microcomputers enable the machine to which they are dedicated to run unsupported from controllers on other hierarchy levels.

A production cell host computer can be installed above the stand-alone machine to provide organization and monitoring of a group of such machines. This is the level 3(a) where usually personal computers and minicomputers are installed. It is often dependent upon the size of the system and complexity, whether the manufacturing industries define these systems as

3. Flexible manufacturing system (FMS)—Large systems
4. Flexible manufacturing cells (FMC)—Small systems

Level 3(b) is the one where the host computer is often known as a coordination or master host.

Level 4 configures the control level for an area within a factory. The input and output of material into the area is planned at this level. The planning for a particular area involves an interactive dialogue between the computer on this level and say FMS host, the computer is termed as an area controller. If not and the planning is carried out without any feedback, the computer at this level is open loop shop floor scheduling system.

If no planning is carried out by the computer, but only the collection and evaluation of data from level 3, the computer is classed as a management information system. The minicomputers and mainframes of level 5 provide the automation of the factory wide or corporate functions. Such functions include CAP, CAD, MRP, finance, marketing, etc.

## 1.17 DIRECT REAL TIME SCHEDULE CONTROL

The major functions of an FMS host are illustrated in the Fig. 1.9

Planned work is only allocated to a specific machine when the individual piecepart has been setup in a fixture on a pallet and a machine is available, with all its necessary equipment and programs, to process it. The object of the host is to keep the expensive capital equipment utilized by supplying with it with work. This is best achieved when preparatory work is carried out simultaneously whilst the machine is still working. The host organizes the preparation and transportation of the work so that it is readily available to the machine when it next requests some work. The best machine utilization can be obtained when a machine's layout includes an internal machine buffer. The host can then organize this internal buffer to be always loaded with work. If this buffer is always loaded with work there will always be work available for the machine to transfer immediately into the spindle's work area. Piece parts are moved from a machine under the organization of the host to other machines, or to a system buffer station, if the next machine in a piecepart's process route is busy and cannot accept a piecepart into its buffer.

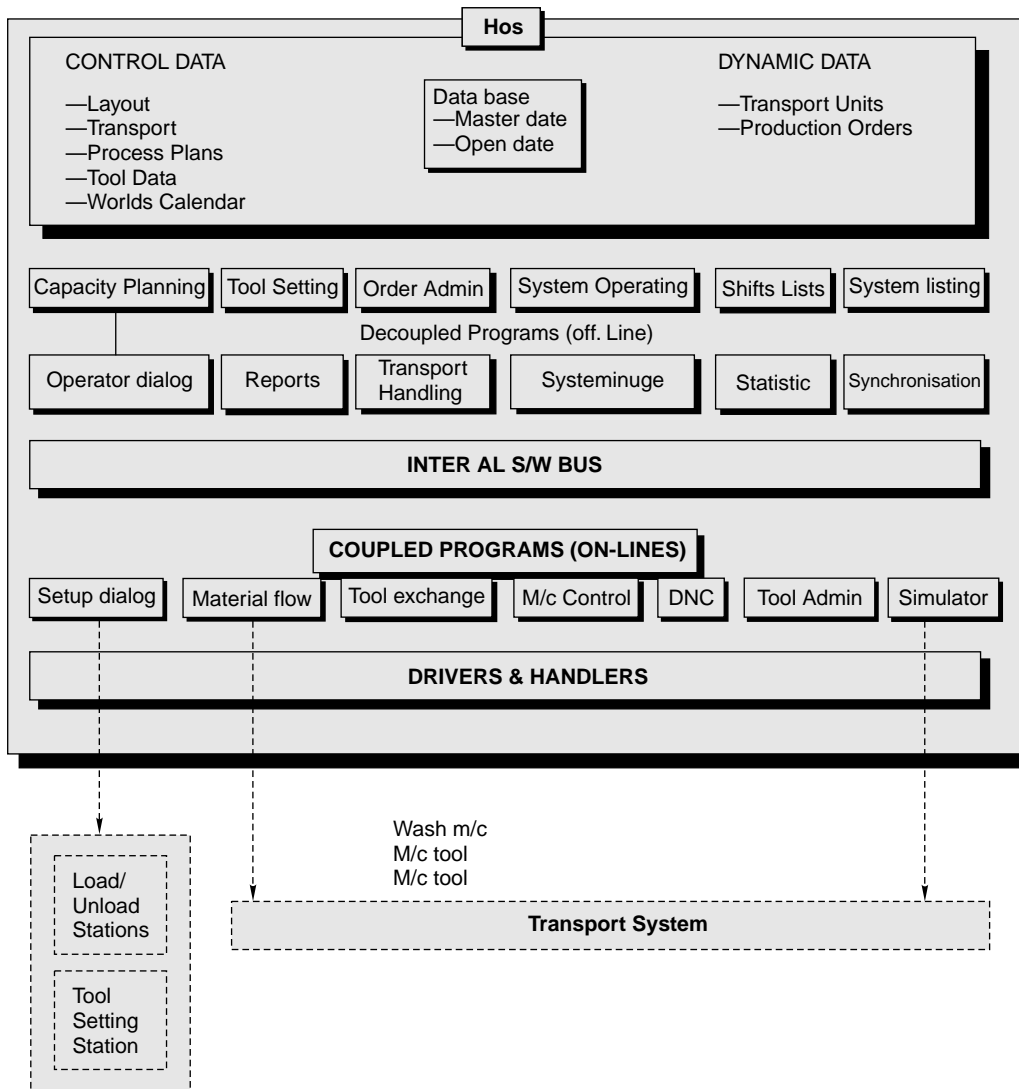


Fig. 1.9 The major functions of FMS host

### 1.18 FMS CONCEPTS

To get clear information with application of FMS the concepts concerned to FMS must be understood. The concepts cover mixes, machine allocations, flows, planning and scheduling.

System mixes:

(a) **Piece part mix: The distinction must be made between:**

- total piece part mix
- planned piece part mix
- 'live' order mix
- 'live' piece parts

The total piece part mix is that mix, which over the months and years, FMS has the manufacturing capability.

The host of FMS can organize the manufacture of a wide range of various piece parts within the given primary equipments manufacturing capabilities.

The machines have a finite capacity for any particular period in which production is to be followed or planned.

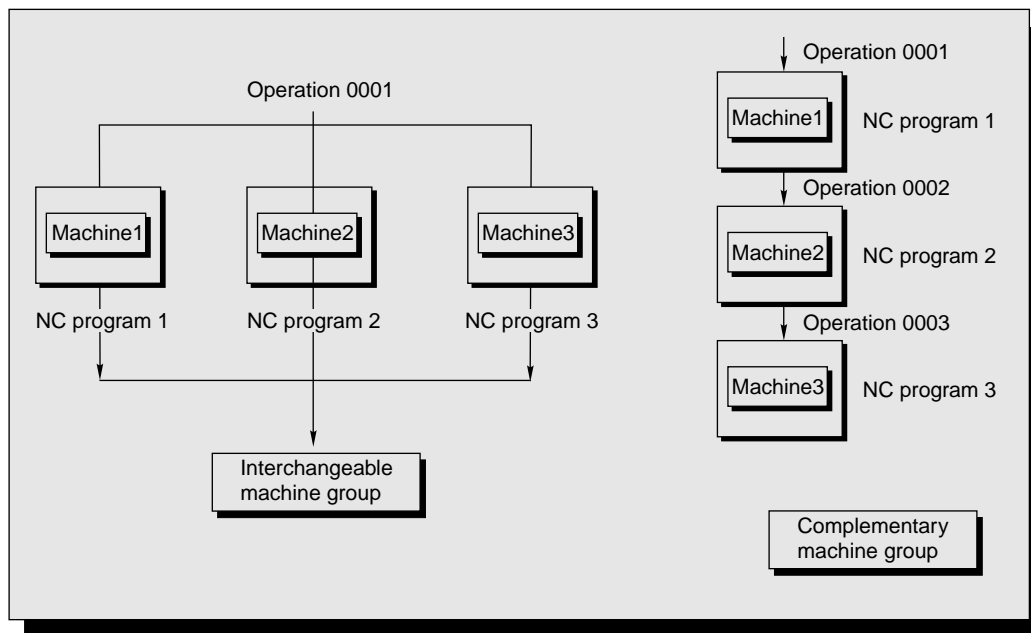
A subset of the total live piece part mix is manufactured simultaneously in the system. As the piece parts drop out of the system more piece parts of the planned live mix can enter the system at the load and unload stations, thus the FMS is constantly fed with new work.

**(b) Piece part mix types:** The piece parts can be classified as

- Prismatic (cuboid shaped components—for drilling, milling, reaming, etc.)
- Rotational (round cylindrical components)—or turning, grinding, etc.
- Hybrid (rotational and prismatic shaped components) ex-crank shaft

**(c) Machine allocation mix:** An operation on a piecepart needs a NC program loaded into a machine tool's controller for the machine to execute the operation. When an FMS operation is considered, then as a single NC program which itself has several operations, each one better known as a cutting operation.

The allocation of work centers to machine the different operations of a piece part is defined as either interchangeable allocation or complementary allocation as shown in the Fig. 1.10.



**Fig. 1.10** Process routings in an FMS

# 2

## Manufacturing Cell

### 2.1 INTRODUCTION

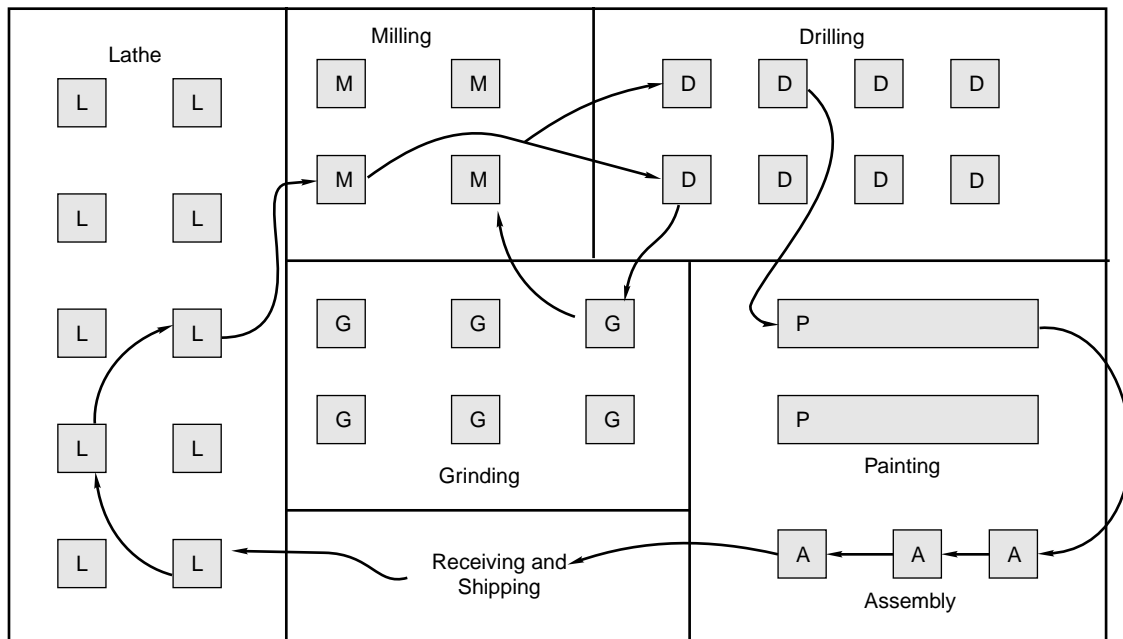
Factory layout must contribute to simpler and improved process and production flows. Change to process or functional layouts based on cells or groups, so that each work-center specializes in one or a narrow family of processes can produce benefits.

A cell is a self-sufficient unit, in which all operations to make a ‘family’ of parts, components or complete products can be carried out. The cell is like a mini factory within which a cell team can manage as their own operation—a server to other operations. Thus client server relationships can be emphasized. The way in which a cell gives support to other cells down stream and receives support ex-from engineering or computing specialists can be reviewed.

Cell layouts can be U-shaped or a segment of a line (a product or sub assembly stage) allowing a self-organizing, multi skilled group of fewer people to manage the operation. Shorter processing times, better team attention to quality problems, reduction of work in progress, lower handling costs and simpler scheduling can be achieved.

#### 2.1.1 Definition of Cell

A definition of manufacturing cell in its broadest sense implies the logical arrangements of stand-alone manual or NC equipment into groups or clusters of machines to process parts by part family, processing parts in the manufacturing cell includes completing as much as the work piece processing as possible within the cell before moving it to the next sequential processing stock inspection or assembly station. Today the term “manufacturing cell is much broader and further implies some level of automated part loading, unloading, delaying or exchange to the clustered machines.



**Fig. 2.1** Product Flow from cell to cell

## 2.2 CLASSIFICATION OF CELL

Flexible Manufacturing Cell can be divided into four general categories.

1. Traditional stand-alone NC machine tools
2. Single NC machine cell or Mini cell
3. Integrated multi machine cell
4. FMS

### 2.2.1 Standalone NC Machine Tools

Standalone NC machine tools are characterized by a limited storage, automatic tool changer and are traditionally operated on a one- to one-machine operator ratio. In many cases, stand-alone NC machine tools have been grouped together in a conventional part family manufacturing cell but still operating on a one-to-one machine to operator ratio. Machines within a cell of this type have some times been painted by a similar color, which further add cell distribution for a particular group of parts and differentiate it from other cells. Some stand-alone NC machines are characterized and operated as a cell by virtue of a change in the machine to operator ratio. These machines are usually redundant and are operated on a two-to-one or in some cases a three-to-one machine to operator ratio.

### 2.2.2 Single NC Machine Cell or Mini Cell

Single NC machine cell is characterized by automatic work changers with permanently assigning work pallets or conveyors, robot arm mounted to the front of the machine, plus the availability of

bulk tool storage. There are many machines with a variety of options, such as automatic probing, broken tool detection and high-pressure coolant control, which pulls into this category. Mini cell is rapidly gaining popularity, functionality and affordability because it can be purchased for a fraction of the cost of a complete FMS and can be programmed and loaded with parts to run unattended for several hours.

### 2.2.3 Integrated Multi Machine Cell

Integrated multi machine cell is made of a multiplicity of a metal-cutting machine tool typically of the same type, which have parts, either at the entry of the cell or in front of each machine. Multi machine cells are either serviced by a material handling robot or parts palletized in a two or three machine, in-line system for progressive movement from one machine station to another. Typical applications of a multi machine cell serviced by a robot of high volume production of a small, well defined design-stable family parts.

### 2.2.4 Flexible Manufacturing System

Some times referred to as a flexible manufacturing cell is characterized by multiple machine automated movement of palletized parts to and from processing stations to another work station and is controlled by a central computer.

## 2.3 UNATTENDED MACHINING

The concept of unattended machining implies running a machine tool with no operator in attendance for extended periods of time, usually eight or more hours. The parts, tools and NC programs are considered to be loaded and available at each machine station are delivered on an as needed basis to each machine.

The development of unattended machining is really a matter of expanding the scope of machine applicability, improving the assurance that the run of parts will be completed, avoiding wrecks, and machining the entire operation user friendly.

The benefits of unattended machining are essentially the same as a cell or a subset of an FMS. These include increased machine utilization, improved quality through increased consistency and predictability of operation, reduced direct labor, work-in-process.

Unattended machining is generally attempted with single or multi machining cells consisting of turning centers. Although some unattended machining similarities exist between turning centers and machining centers each has it's own applications features and requirements.

### 2.3.1 Features and Requirement

1. Part size must be controlled through probe measurement of the part, automated in process or post process gauging, and automatic component of the machine for changes.
2. Part must be automatically delivered, loaded and unloaded, usually by means of an integrated floor machine mounted robot arm along with part queuing by palletized conveyor.

3. Specific part identification can occur by probing unique dimensions to distinguish random parts within a given family and calling up the proper NC program as required.
4. Wrecks can be avoided through spindle torque and slide force sensing and shutting the machine down safety before part, tool, or machine damage occurs. The primary reasons for machine shutdown in an unattended application are mainly due to exceed machine horsepower limits, dull tools or excess work piece stock.
5. Some chips can be cleared from the chuck by the quick rotation of an empty chuck and applying an air blast before loading the next part
6. Parts must be easily turned and accurately located for part completion. This is important requirement if the full advantages of an unattended turning cell are to be realized.
7. A fixed probe for automatic tool length setting avoids the time consuming manual order of tool setting.

## 2.4 DIFFERENCES BETWEEN FMC AND FMS

1. Cells lack central computer with real-time routing, load balancing, and production scheduling logic. They are generally controlled by cell controllers or by their own independent but interfaced machine controllers.
2. An FMS will be almost invariably connected to higher-level computer within the manufacturing operation. In many cases it is tied directly to the corporate computing system, which may also be running the MRP system, the inventory control system, and sometimes the CAD system in design engineering.
3. Cells are typically tool capacity constrained. Both the total number of unique limits single and multi machine cells and redundant cutting tools that occupy available tool pockets. This limits the part spectrum that could be run through a cell at a given time without stopping the equipment and manually exchanging tools to accommodate different work pieces.
4. A FMS with automated tool delivery and tool management can be automatically transfer, exchange and migrate tools through centralized computer control and software independent of equipment activity. With a cellular application, the cutting tool count must be minimized to offset the limited tool buffer storage of the machine. Parts must be closely scrutinized and part prints sometimes changed in order to match the family tool range with the available tool pockets.

**Table 2.1** Comparison between FMC and FMS

<i>Flexible Manufacturing Cell [FMC]</i>	<i>Flexible Manufacturing System [FMS]</i>
1. Low flexibility	1. High flexibility
2. Small stored part program inventory and accessibility	2. High stored part program inventory and accessibility
3. Limited on-line computing power and decision-making software	3. High on-line computing power and decision-making software
4. Moderate equipments are used and resource cost is less	4. Sophisticated equipments are used and hence resource cost is more
5. Limited flexibility and variety of parts produced	5. High preparation and implementation requirements
6. Narrow benefits obtained from this but these are easily identified and quantified	6. Benefits are broad but hard to identify and quantify
7. Moderate justification, complexity and difficulty with mid-management approval is required	7. Difficult and complex justification process with high-level approval required
8. Moderate level of management commitment and support required	8. High level of management commitment and support required
9. Low staffing and training impact	9. High staffing and training impact
10. Moderate effect on other internal operations and organizations	10. High effect on other internal operations and organizations
11. Low to moderate risk and complexity, minimal facility changes	11. High risk and complexity, many facility changes
12. Short planning to implementation cycle	12. Long planning to implementation cycle
13. Quick and practical learning curve and implementation cycle	13. Lengthy and involved learning curve and implementation cycle
14. Generally no tool delivery, limits system scope and flexibility	14. Generally tool delivery and tool management; opens systems scope and flexibility

# 3

## JIT and KANBAN System

### 3.1 INTRODUCTION

The basic approach to the “Just-in-Time” (JIT) production system is to reduce product costs through the elimination of waste. In a production facility waste can be defined as defects, stockpiles, queues, idleness and delays.

The manufacturing philosophy of JIT is well defined by the following analogy. Inventory is depicted by water, covering a bed of rocks in a lake. The rocks and the lakebed are representative of problems and the manufacturing floor, respectively. Lowering the water level will expose the rocks on the lakebed (Riggs, 1987). This is the basic theory behind the JIT production system. By eliminating inventory stockpiles on a plant floor, operating inefficiencies can be exposed. Therefore, producing or receiving inventory “just in time” for the next production process can eliminate stockpile inventory.

This report will detail the history of the “Just-in-Time” production system. We will follow the JIT system from its conception in 1940 to its success today. The characteristics and advantages of the JIT production system will be further outlined. We will also summarize the specific requirements for implementation of this system. Throughout this document we will aim to provide internet links, which will provide more information on the topic.

Just-In-Time (JIT) manufacturing is a Japanese management philosophy applied in manufacturing. Essentially it involves having the right items with the right quality and quantity in the right place at the right time. Today, more and more North American firms are considering the JIT approach in response to an ever more competitive environment.

The ability to manage inventory (which often accounts for as much as 80 percent of product cost) to coincide with market demand or changing product specifications can substantially boost profits and improve a manufacturer’s competitive position by reducing inventories and waste. Just In Time (JIT) is a management philosophy, an integrated approach to optimize the use of a company’s resources, namely, capital, equipment, and labor. The goal of JIT is the total elimination of waste in the manufacturing process.

## 3.2 DEFINITION

JIT is an integrated set of activities designed to achieve high volume production using minimal inventories of raw materials, work in process and finished goods. Just—In Time is also based on the logic that nothing will be produced until it is needed.

JIT can be viewed colloquially as “Big JIT” and “Little JIT”.

### 3.2.1 Big JIT

It is the philosophy of operation management that seeks to eliminate waste in all aspects of a firm’s productions activities. Examples are Human relations, Vendor relations, management of materials and inventories.

### 3.2.2 Little JIT

It focuses more narrowly on scheduling goods inventory and providing service resources where and when needed. Examples are companies such as manpower temporary services.

## 3.3 JIT CONCEPT

JIT may be viewed as a production system, designed to improve overall productivity through the Elimination of waste and which leads to improved quality. JIT is simple, efficient and minimize waste.

The concept to produce and deliver finished goods just in time to be sold, subassemblies just in time to be assembled into sub assembled and purchase materials Just—in time to be transformed into fabricated parts, is the concept behind JIT. It is dependent on the balance between the stability of the user’s scheduled requirement and supplier’s manufacturing flexibility.

## 3.4 GOALS OF JIT

A system whose goal is to optimize process and procedures by continuously pursuing waste reduction. It consists of 7 W’s to pursue the waste reduction. The wastes identified for reduction through continuous improvements in production process are:

### 3.4.1 Waste of Over Productions

Eliminate by reducing setup times, synchronizing qualities and timing between processes, compacting layout, visibility and so forth.

### 3.4.2 Waste of Waiting

Establish layout’s and to transport and handling necessary if possible and balance uneven loads by flexible workers and equipments.

### 3.4.3 Waste of Transportation

Establish layout's and to transport and handling necessary if possible. The rationalize transport and material handing that cannot be eliminated.

### 3.4.4 Waste of Processing

Why a product should be made at all, then why each process is necessary and extends thinking beyond economy of scale or speed.

### 3.4.5 Waste of Stock

Reduce by shortening set up time and reducing lead-time by synchronizing work flows and work skills. By reducing all the other wastes there will be reducing in waste of stock.

### 3.4.6 Waste of Motion

Study motion for economy and consistency. Economy improves productivity and consistency improves quality

### 3.4.7 Waste of Making Defective Parts

Develop the production process to prevent defects from being made as to eliminate inspection. Accept no defects and make no defects, from quality process a good quality product can be achieved.

Thus the Elimination of waste can be approached by

1. Focused factory networks
2. GT
3. Quality at the source
4. JIT production
5. Equal plant loading
6. Kanban production control system
7. Minimized setup times.

## 3.5 WHAT JIT REALLY IS?

- Stockless production approach
- An operation philosophy and operation strategy.
- Not a destination but a journey.
- Reducing inventory, improving quality and controlling cost.
- An opportunity for a change or not a thread to change.
- A "Pull System" where the parts are produced only when they are required.

- It is viewed as a manufacturing evolution.
- It is commonly used to describe the stockless production manufacturing approach, where only the right parts are completed at the right time.

### 3.6 OBJECTIVES OF JIT

The basic objectives include:

- Low manufacturing and distribution cost.
- Reduced labor (both direct and indirect)
- Higher degree of product quality and less defects.
- Effective use of Working capital.
- Decrease in production lead-time.
- Reduced investments for in-process inventory.
- Increased productivity.
- Reduced space requirements.
- Faster reaction to demand. Change i.e. more flexibility to customer demand.
- Reduced overheads.

### 3.7 INGREDIENTS OF JIT

The JIT environment, management workers and vendors create an atmosphere in which costs are minimized, quality is enhanced and orders are processed on time. Thus the inventory is maintained minimum that the manufacturing problems can be identified and solve it.

Some of the ingredients are:

- Strong management commitment.
- Involvement of suppliers and establish long-term relationship with them.
- Quality assurance
- Preventive maintenance.
- Pull system approach to manufacturing execution.
- Producing product to plant load level.
- Development of a focus factory i.e. manufacturing cells or GT cells, etc.

### 3.8 QUALITY AND QUANTITY PRINCIPLES OF JIT

- The primary quality JIT Principles.
- Training the employee's in the organization on quality aspects.
- Make continuous improvement towards Zero—defect and make defect visible.
- Control quality at the Source by making each production worker responsible for quality and eliminate inspection.

- Make every worker responsible for his or her own work.
- Establish preventive maintenance.
- Encourage teamwork and worker involvement in decision-making.
- Reduce multiple work classification.
- Simplify product design so that it incorporates
  1. Production
  2. Simplicity
  3. Standardization
  4. Flexibility
  5. Quality.
- Emphasize on TQC (Total quality control)
- Quality vendors and validation requires before delivery

### 3.9 THE PRIMARY QUANTITY JIT PRINCIPLES

- Improve plant layout by designing for flow, emphasizing flexibility and responsiveness.
- Reduce lot sizes
- Reduce inventory levels to approach zero errors.
- Make continuous improvement towards eliminating Setup time.
- Develop a uniform load and avoid over loading capacity
- Avoid over loading capacity.
- Eliminate high safety stock required.
- Part scheduling should be based on finished parts due date.
- Training of shop supervision

### 3.10 BENEFITS OF JIT

- Material flow improvement.
- Reduced product development time.
- Increase in production cycle at each step.
- Decrease the amount of time that of a stock of raw material and a finished products.
- Implementing JIT manufacturing plan can achieve a wide range of benefits and relative ranges consists of
  - (i) Reduction in path movement.
  - (ii) Reduction in manufacturing lead-time.
  - (iii) Reduction in Material bundling
  - (iv) Reduction in Scrap and Rework
  - (v) Reduction in Setup time and machine down time
  - (vi) Reduction in direct and indirect labor.

### 3.11 JIT IMPLEMENTATION

Successful implementation of JIT requires a number of important decisions to be made. These include

1. What do we start with?
2. Where do we start?
3. Who should do it?

Factors for implementation are:

- Simplifying the process
- Eliminating Waste
- Making problems visible
- Creating a climate for continuous improvements

### 3.12 KANBAN/CARD SYSTEM

#### 3.12.1 Introduction

The purpose of this report is to explain what a Kanban system is, how it works, and how it can be implemented. The theory will then be applied to the “Stirling Engine” Manufacturing Cell and a suggestion for implementation is to be proposed. The proposal for implementation will include explaining the requirements for a kanban system and designing the containers required for the system. The scope of the project ends with a summary of the report and other recommendations useful to the instructor.

### 3.13 WHAT IS KANBAN?

Kanban (kahn-bahn) is Japanese word that when translated literally means “visible record” or “visible part”. In general context, it refers to a signal of some kind. Thus, in the manufacturing environment, kanbans are signals used to replenish the inventory of items used repetitively within a facility. The kanban system is based on a customer of a part pulling the part from the supplier of that part. The customer of the part can be an actual consumer of a finished product (external) or the production personnel at the succeeding station in a manufacturing facility (internal). Likewise, the supplier could be the person at the preceding station in a manufacturing facility. The premise of kanbans is that material will not be produced or moved until a customer sends the signal to do so.

The typical kanban signal is an empty container designed to hold a standard quantity of material or parts. When the container is empty, the customer sends it back to the supplier. The container has attached to it instructions for refilling the container such as the part number, description, quantity, customer, supplier, and purchase or work order number. Some other common forms of kanban signals are supplier replaceable cards for cardboard boxed designed to hold a standard quantity, standard container enclosed by a painting of the outline of the container on the floor, and color coded striped golf balls sent via pneumatic tubes from station to station.

Kanbans serve many purposes. They act as communication devices from the point of use to the previous operation and as visual communication tools. They act as purchase orders for your suppliers and work orders for the production departments, thereby eliminating much of the paperwork that would otherwise be required. In addition, kanbans reinforce other manufacturing objectives such as increasing responsibility of the machine operator and allowing for proactive action on quality defects. However, kanbans should not be used when lot production or safety stock is required because the kanban system will not account for these requirements.

### 3.14 PUSH VS. PULL SYSTEM

The kanban system described is a pull system. Traditionally, a push system is and has been employed. The push system is also more commonly known as the Materials Requirements Planning (MRP) system. This system is based on the Planning Department setting up a long-term production schedule, which is then dissected to give a detailed schedule for making or buying parts. This detailed schedule then pushes the production people to make a part and push it forward to the next station. The major weakness of this system is that it relies on guessing the future customer demand to develop the schedule that production is based on and guessing the time it takes to produce each part. Over-estimation and under-estimation may lead to excess inventory or part shortages, respectively.

One of the major reasons kanbans are used is to eliminate or reduce the above mentioned wastes throughout an organization due to the pull system that is employed. Waste can come from over-production (inventory) and therefore, the need for a stockroom. This waste is eliminated. Part shortages (under-production) are also eliminated. Costs are reduced by eliminating the need for many of the purchasing personnel and the paperwork associated with purchasing. The planning department's workload is also reduced, as they no longer need to produce work orders.

### 3.15 TYPES OF KANBAN

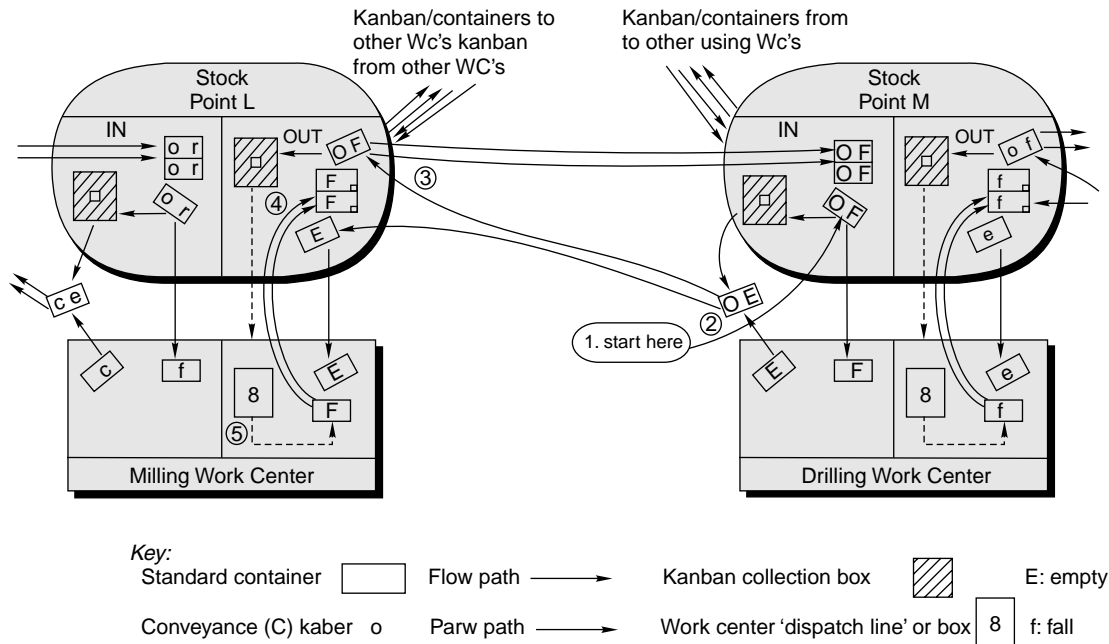
#### 3.15.1 Dual-Card Kanban

This kanban system is more commonly referred to as the Toyota kanban system as Toyota was the first to employ this system in full-scale use. It is a more useful kanban technique in large-scale, high variety manufacturing facilities. In this system, each part has its own special container designed to hold a precise quantity of that part. Two cards are used: the production kanban, which serves the supplier workstation and the conveyance kanban, which serves the customer workstation. Each container cycles from the supplier workstation to its stock point to the customer workstation and its stock point, and back while one kanban is exchanged for another. No parts are produced unless a P-kanban authorizes it.

There is only one C-kanban and one P-kanban for each container and each container holds a standard quantity (no more, no less).

Figure 3.1 clearly explains this process using the Milling (supplier) and Drilling (customer) processes.

1. Find the note "Start here". The C-kanban is detached and placed in a collection box for Stock Point *M*.



**Fig. 3.1** Dual card Kanban for milling and drilling process

2. The container that is most recently emptied in Drilling is taken to Stock Point *M* and a C-kanban is attached to it.
3. The empty container and C-kanban are taken to Stock Point *L* where the C-kanban is detached and re-attached to a full container, which is taken back to Stock Point *M*.
4. The full container taken to Stock Point *M* had a P-kanban attached to it. Before leaving Stock Point *L*, the P-kanban was detached and placed in the Stock Point *L* collection box.
5. The P-kanban in the Stock Point *L* collection box are taken to Milling hourly where they go into a dispatch box and become the list of jobs to be worked on next at the Milling Station.
6. For every job that is completed, parts go into an empty container from Stock Point *L*, and a P-kanban is attached. The full container is then moved back to Stock Point *L*.

### 3.15.2 Single-Card Kanban

The single-card kanban system is a more convenient system for manufacturing facilities requiring less variety in their parts. Essentially, the single-card kanban system is simply a dual-card kanban system with the absence of the production kanban and designated stock points. This system is demonstrated using the following diagram and the same workstations as the dual-card example (where the stock points shown are the work stations themselves but are shown separately for explanation purposes):

1. Find the note "Start here". A container has just been emptied at the drilling station. The kanban is placed in the kanban collection box.

2. The full containers at milling, with kanbans attached to them, are transported to drilling and the kanbans in the collection box are taken back to milling.
3. Milling continues to fill containers depending on the demand from Drilling.
4. Empty containers are collected from drilling periodically.

Due to the inherent simplicity of the single-card kanban system and its applicability to the purposes of this report, the remainder of the report shall assume this technique is employed.

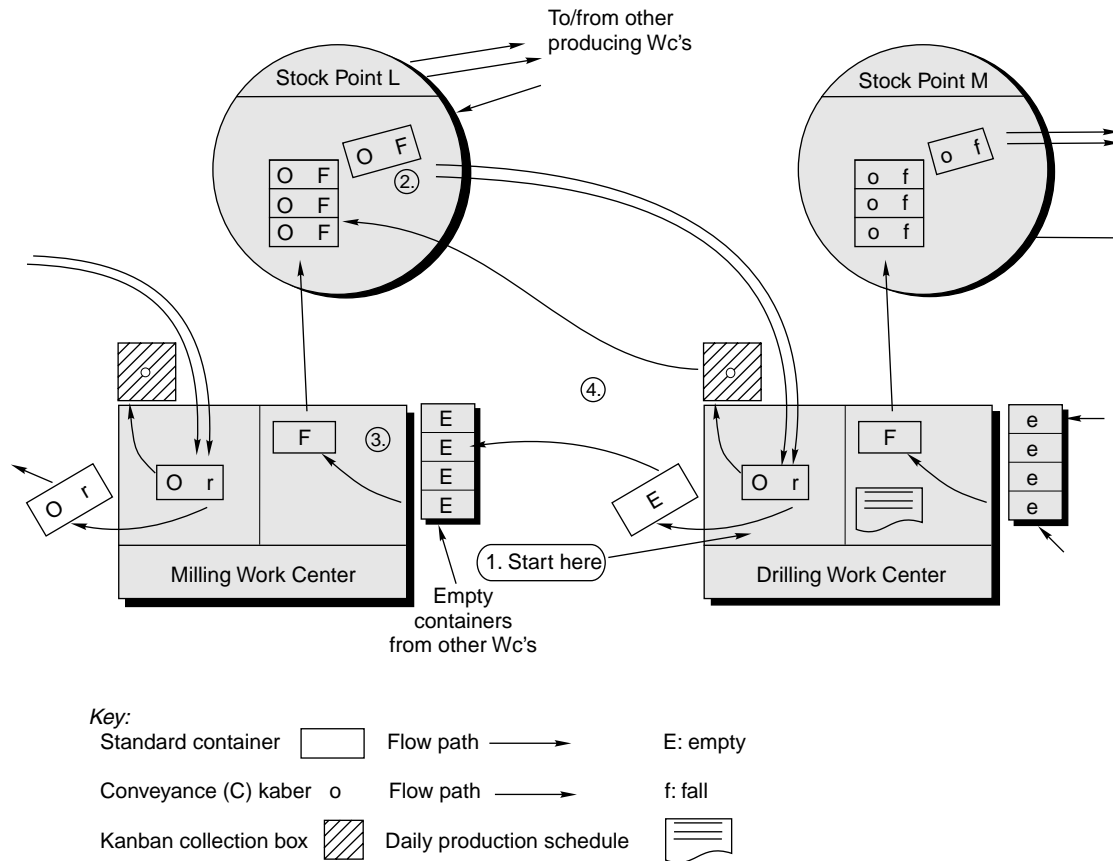


Fig. 3.2 Single card kanban system

# 4

## Group Technology

### 4.1 INTRODUCTION

Group Technology is the concept, which has been around since World War 2, and received wide attention due to close association with cellular manufacturing, FMS, CIM, etc. GT is not simple the formation of machinery into manufacturing cells, but it involves bringing together and organizing common concepts, principles, problems, tasks, and technologies, to improve productivity.

Group technology, like JIT is a journey, not a destination. It involves continuous improvement and structured discipline and must be a fundamental building block of a cell or system if the real benefits of automation are to be achieved. And it must be approached and applied before, during and after automation.

### 4.2 DEFINITION

Group Technology involves grouping components having similar attributes in order to take advantage of their similarities in design or manufacturing phases of production cycle. It is implemented through the application of well-structured classification and coding systems and supporting software to take advantage of the similarities of components in terms of design attributes and processing sequences.

### 4.3 REASONS FOR ADOPTING GROUP TECHNOLOGY

Growing international competition and fast changing market demands have put considerable amount of pressure on industries to streamline their production. The marketing challenges can be successfully met by GT.

Today there is a trend in the industry towards low volume production of a wider variety of products in order to meet the raising demands for specially ordered products. The concepts of markets of yearly 20<sup>th</sup> century as vanished. The share of batch type production is growing every day and it is accepted that 75 per cent of all manufactured parts will be in small batch quantities.

As a result of first factor, the conventional shop layout i.e. types or functional layout is becoming very inefficient and absolute because of messy routing paths of the products between the various

machined tool departments. Modern management concepts like business process and reengineering highlight the need for breaking barriers between departments of an industry. GT and cellular manufacturing streamline material flow and reduced non-value adding activities.

There is need to cut short the lead time, thus winning a competitive situation in the international market.

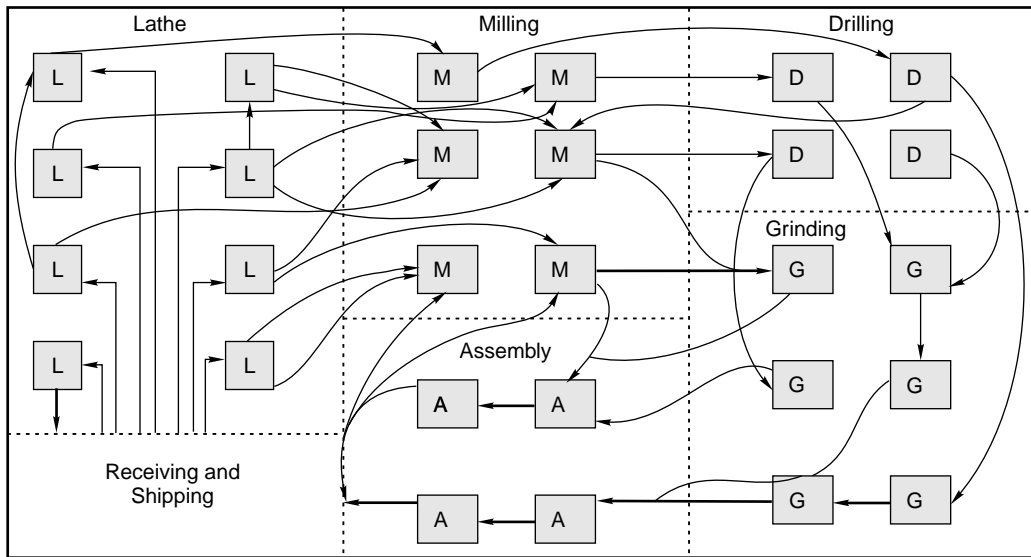


Fig. 4.1 (a) Process type layout

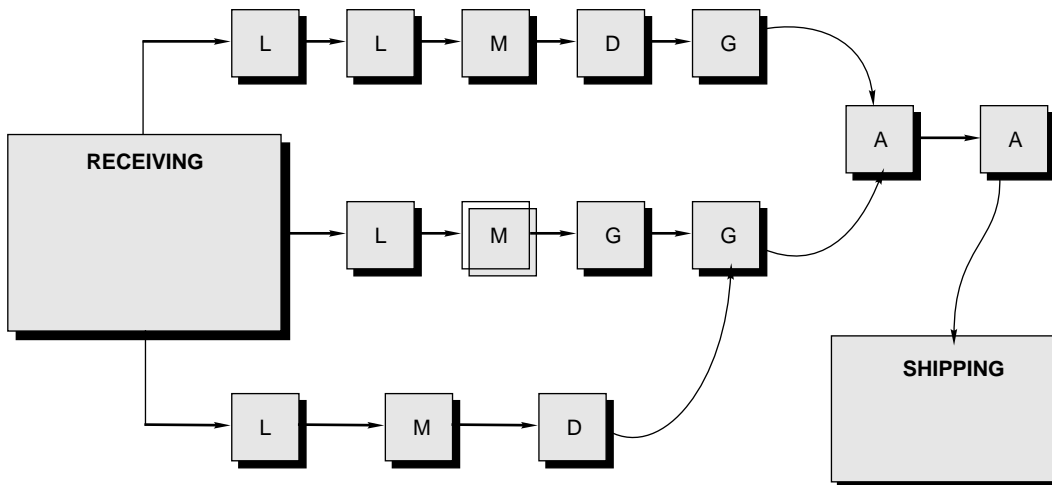


Fig. 4.1 (b) Group technology layout

The Fig. 4.1 (b) shows a group technology layout of equivalent capacity of process type layout, but machines are arranged in cells. Each cell is organized to specialize in production of a part from

a particular family. From this type of layout there are advantages of reduced work pieces handling, lower set up times, less in process inventory and shorter lead-times.

The main problem in switching over from conventional layout to GT layout is grouping parts into part families.

GT gives the idea that many parts have similar geometric features, and by combining those design requirements a common part solution can be found. Parts may be arranged or grouped for GT technology through

- I. Design characteristics or features.
- II. Manufacturing process

For grouping parts into part families there are three methods. They are

1. Visual Inspection.
2. Part Classification and coding.
3. Production flow analysis.

### 4.3.1 Visual Inspection

This method is the least sophisticated and least expensive method. It involves the classification of parts into part families by looking at either the physical parts or their photo groups and arranging them into groups having similar features.

### 4.3.2 Part Classification and Coding

For parts to be grouped based on design characteristics and features and manufacturing processes, they must be classified into predetermined categories and coded for retrieval and use. Classification and coding are computerized tools used to capture the design and manufacturing features of part. They provide the ability to retrieve and analyze the data by desired feature. This is essentially the system of arrangement much like zip code or classification system used in library.

#### 4.3.2.1 Development of Coding System

A coding system may be based only on number or only on alphabets, or it can also be alphanumeric. When using alphanumeric codes, each position can have 26 different alternatives, but the values of alternatives are only limited to 10 per cent when numerical codes are used. Consequently alphabets are used to widen the scope of a coding scheme and make it more flexible.

There are basically two types of coding systems.

1. Mono codes,
2. Poly codes

##### 4.3.2.1.1 Mono code

Mono codes, which are also referred to as hierarchical or tree-structured codes, are based on the approach that each digit amplifies the information given in the preceding digit. It is therefore essential that these codes are short and shape oriented. However the mono codes don't directly

indicate the attributes of components because of their hierarchical structure. They are normally used for design storage and retrieval and not very useful for manufacturing application.

#### 4.3.2.1.2 Ploy code

Unlike in mono code, the meaning of each digit in ploy code is completely independent of any other digits and provides information that can be directly recognized from code. Ploy code generally manufacture oriented, because its easily identifiable attributes help the manufacturing engineer to determine the processing requirements of parts. Never the less, poly codes tend to be long and digit location must be reserved whether that particular feature applies to a part or to a family of codes. It is therefore, a common industrial practice to use a hybrid construction combining the advantages of each of the two basic codes while eliminating their disadvantages. In a combination type, the first digit is the whole group of parts into sub groups

### 4.3.3 Production Flow Analysis

Production flow analysis is a method in which part families are identified and machine tools are grouped based on the analysis of the sequence of operations for the various products manufactured in the plant. Parts, which may not be similar in shape but require similar sequence of operations, are grouped together to form a family. The resulting families are then used to design or establish machine cells. PFA employs clustering algorithms to manufacturing cells.

After gathering the needed data, i.e. the part number and machine routing for every product, the computer is employed to sort out the products into groups, each of which contains parts that require identical process routings and is called a pack. Each pack is given an identification number, and packs having similar routings are grouped together. Next zoning is used to identify the machine tools form rational machine cell.

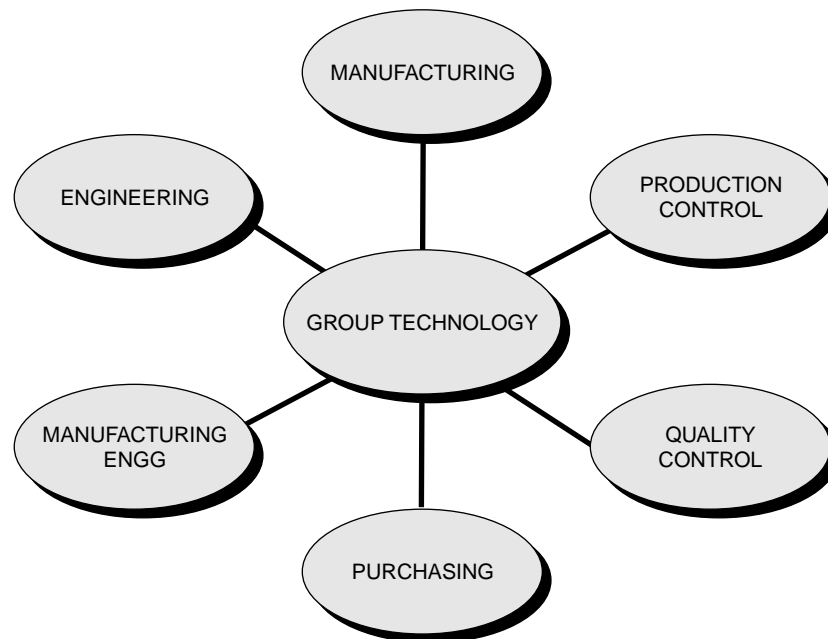


Fig. 4.2 Principle areas of a company benefited by group technology

#### 4.4 BENEFITS OF GROUP TECHNOLOGY AFFECTING MANY AREAS OF A COMPANY

The various benefits by functional area include:

##### 1. Engineering Design:

- Design Standardization and redundancy avoidance.
- Rapid design retrieval.
- Reduce number of new similar parts and elimination of duplicate parts.

##### 2. Manufacturing:

- Reduction of part steps and associative costs and time.
- Improve estimation of machine tool requirements.
- Improve quality and communication.

##### 3. Manufacturing Engineering:

- Standardization of routings.
- Use of common tooling and avoidance of new tooling.
- Reduced tools and fixtures to be used.

##### 4. Production Control:

- Reduced in process inventory.
- Easier location of production difficulties.
- Improved equipment monitoring and scheduling.

##### 5. Quality Control:

- Improved opportunities for controlling quality at source.
- Reduced time to locate part defects.
- Reduced sampling and inspection time.

##### 6. Purchasing:

- Grouping parts for quality buys at lower cost.
- Establishing vendor capabilities by code to built bid lists.

#### 4.5 OBSTACLES TO APPLICATION OF GT

- Problems associated with rearrangement of physical equipment.
- The Large amount of development work needed.
- Resistance to change.

**Example 4.1** Four machines will constitute a GT cell. The from-to data for the machine is as follows:

<i>To</i> →	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
↓ <i>From</i>				
<i>1</i>	0	5	0	45
<i>2</i>	0	0	0	0
<i>3</i>	50	0	0	0
<i>4</i>	0	45	0	0

Determine the most logical sequence of machines for these data according to/from ratios

**Solution:** By hollier's method

	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>"From" Sum</i>
<i>1</i>	0	5	0	45	50
<i>2</i>	0	0	0	0	0
<i>3</i>	50	0	0	0	50
<i>4</i>	0	45	0	0	45
<i>"To" sum</i>	50	50	0	45	

The minimum sum value is the "To" sum for machine 3. Hence machine 3 is placed at the beginning of the sequence. Eliminate the row and column of the corresponding to machine 3.

	<i>1</i>	<i>2</i>	<i>4</i>	<i>"From" Sum</i>
<i>1</i>	0	5	45	50
<i>2</i>	0	0	0	0
<i>4</i>	0	45	0	45
<i>"To" sum</i>	0	50	45	

The minimum sum value is the "To" sum for machine 1. Hence machine 1 is placed at the second of sequence. Eliminate the row and column of the corresponding to machine 1.

	<i>2</i>	<i>4</i>	<i>"From" Sum</i>
<i>2</i>	0	0	0
<i>4</i>	45	0	45
<i>"To" sum</i>	45	0	

Since the minimum sum value is "To" sum for machine 4, the machine 4 is placed in the sequence.

Therefore the machine sequence is 3-1-4-2

**Example 4.2** Four machines will constitute a GT cell. The from-to data for the machine are as follows.

		<i>From</i>			
		<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>
<b>To</b>	<b>1</b>	0	5	0	25
	<b>2</b>	30	0	0	15
	<b>3</b>	10	40	0	0
	<b>4</b>	10	0	0	0

- Determine the sequence of machine according to/from ratio
- Construct a flow diagram
- Where do the parts enter cell and exit the cell

50 parts enter at machine 3, 20 parts after machine 1 leaves and 30 parts after machine 4 leaves.

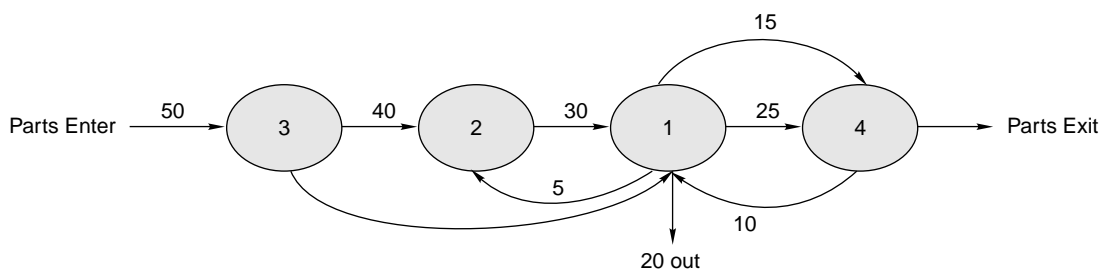
**Solution:**

	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	"From" Sum	To/From Ratio
1	0	5	0	25	30	$50/30 = 1.667$
2	30	0	0	15	45	$45/45 = 1$
3	10	40	0	0	50	$0/50 = 0$
4	10	0	0	0	10	$40/10 = 4$
"To" sum	50	45	0	40		

Since it is To/From ratio, arrange the machines in ascending order.

The machine sequence is 3-2-1-4

The flow diagram is given by



**Fig. 4.3** Flow diagram

Machine 3 – 50 parts enter	40 moves out to machine 2
	10 moves out to machine 1
Machine 2 – 45 parts enter	30 moves out to machine 1
	15 moves out to machine 4

**Example 4.3** Four machines belong to a GT machine cell. An analysis of 50 parts which are processed on these machines provides the following from-to chart (machines are identified by number).

<i>To</i> → ↓ <i>From</i>	1	2	3	4
1	0	5	0	25
2	30	0	0	15
3	10	40	0	0
4	10	0	0	0

Additional information is: 50 parts enter the machine grouping at machine 3, 20 parts leave after processing at machine 1, and 30 parts leave after machine 4. Determine from-to ratios and suggest a logical machine arrangement.

**Solution:** Summing up the “from” trips to “to” trips for each machine gives the following:

	1	2	3	4	“From” Sum
1	0	5	0	25	30
2	30	0	0	15	45
3	10	40	0	0	50
4	10	0	0	0	10
“To” sum	50	45	0	40	

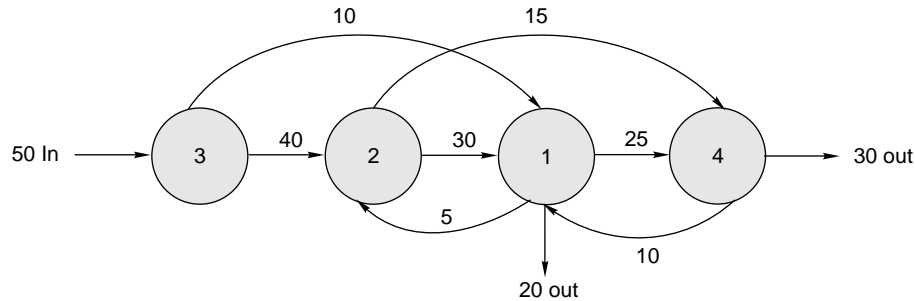
The to/from ratios can be calculated.

Machine	To	From	To/From Ratio
1	50	30	$50/30 = 1.667$
2	45	45	$45/45 = 1$
3	0	50	$0/50 = 0$
4	40	10	$40/10 = 4$

Based on these relative values, the machines in the cell should be arranged as 3 – 2 – 1 – 4.

The workflow is mostly in-line; however, there is some back flow of parts, which has to be considered in the design of any material handling system that may be used by the cell. As a percentage this backflow constitutes only  $15/135 = 11.1\%$  of the total material handling activity. A conveyer or might be used for the forward flow between machines, with less mechanized handling system for the back flow.

The flow diagram for machine layout is as shown in Fig. 4.4.



**Fig. 4.4** Flow diagram

## Problems

**4.1** Four machines will constitute a GT cell. The from-to data for the machine is as follows:

<i>To</i> → ↓ <i>From</i>	1	2	3	4
1	0	10	0	65
2	0	0	0	0
3	70	0	0	0
4	0	65	0	0

Determine the most logical sequence of machines for these data according to/from ratios.

**4.2** A GT cell consists of 5 machines. The from-to data for the machines are as follows.

		<i>To</i>				
		1	2	3	4	5
<i>From</i>	1	0	10	80	0	0
	2	0	0	0	85	0
	3	0	0	0	0	0
	4	70	0	20	0	0
	5	0	75	0	20	0

- (i) Determine the logical sequence of machines according to/from ratios
- (ii) Construct a flow diagram
- (iii) Where do the parts enter cell and exit the cell? How many parts in each place?"

**4.3** Four machines belong to a GT machine cell. Machine 1 and machine 2 are identical and are used to feed machine 3, which is the main machine in the cell. The output of machine 3 feeds into machine 4. The cell is set up to produce a family of 5 parts (*A*, *B*, *C*, *D* and *E*). The operation times for each part at each machine are given in the following table.

<i>Part</i>	<i>Operation time (min.)</i>		
	<i>Machine 1 and 2</i>	<i>Machine 3</i>	<i>Machine 4</i>
1	4	15	10
2	15	18	7
3	26	20	15
4	15	20	10
5	8.0	16	10

The products are produced in the ratio 4:3:2:2:1. If the hours worked per week are 35, determine how many of each product will be made by the cell? What are the utilization of the main machine and the utilization of the cell.

# 5

## Machining Centers

### 5.1 INTRODUCTION

Known in the 1960s ATCs or automatic tool changers, machining centers originated out of their capability to perform variety of machining operations on work piece by changing their own cutting tools. Thus began a tool change and additional feature/capability revolution among machine tool builders that continues to escalate by adding improvements and enhancements to the staggering array of machining center choices.

### 5.2 TYPES OF MACHINING CENTERS

Machining centers are classified as either vertical or horizontal. Vertical machining centers continue to be widely accepted and used, primarily for flat parts and where three-axis machining is required on a single part face such as in mold and die work. Horizontal machining centers are also widely accepted and used, particularly with large, boxy and heavy parts and because they lend themselves to easy and accessible pallet shuttle transfer when used in a cell or FMS application.

Selection of either a vertical or horizontal machining center mainly depends on the part type, size, weight, application, and in many cases, personal preference. Each has its own specific advantages and disadvantages.

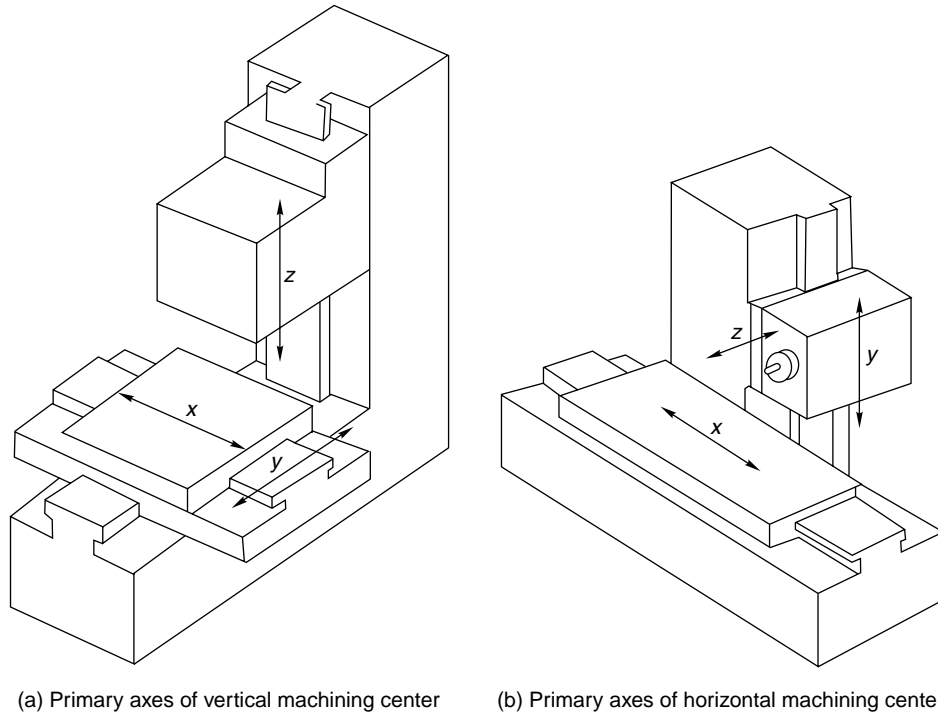
#### 5.2.1 Machining Center Innovations and Developments have Brought About the Following Improvements

- Improved flexibility and reliability
- Increased feeds, speeds, and overall machine construction and rigidity
- Reduced loading, tool-changing and other non-cutting time
- Greater MCU (machine control unit) capability and compatibility with systems
- Reduced operator involvement
- Improved safety features and less noise

## 5.3 MACHINING CENTERS

### 5.3.1 Axes and Format Information

The primary axes of both vertical and horizontal machining centers are  $X$ ,  $Y$  and  $Z$  as shown in Fig. 5.1 (a) and Fig. 5.1 (b) respectively. Generally, in vertical machining centers, the  $X$ -axis provides the longitudinal table travel, the  $Y$ -axis provides in and out saddle movement, and the  $Z$ -axis provides up and down movement of the head or spindle.



**Fig. 5.1**

In horizontal machining centers  $X$ -axis movement is accomplished by the longitudinal table travel.  $Y$ -axis movement is up and down, provided through movement of the machine tool's knee or spindle carrier.  $Z$ -axis positioning is through in and out movement of the machine tool's saddle, table or spindle carrier.

### 5.3.2 Merits of Horizontal Machining Center

1. Table indexing capability enables multiple sides of a work piece to be machined in one setting and clamping.
2. Chips drop out of the way during machining providing an uncluttered view of the cut and preventing re-cutting of chips.
3. Operators station is to one side of the column, providing good line of sight control
4. Pallet shuttle/exchange mechanisms are open, accessible and easy to service

5. Ideally suited for large, boxy heavy parts
6. Overall, more flexible.

### 5.3.3 Demerits of Horizontal Machining Center

- Difficult to load and unload large, flat, plate type work pieces
- High thrust may be absorbed by tombstones, fixtures or right angle braces
- Heavy tools can deflect
- Generally more costly

### 5.3.4 Merits of Vertical Machining Center

- Thrust is absorbed directly into the machine table during deep tool thrust operations such as drilling or pocketing
- Ideal for large, flat plate work and single surface, three-axis contouring.
- Heavy tools can be used without concern about deflection
- Generally less costly.

### 5.3.5 Demerits of Vertical Machining Center

1. As work piece size increases it becomes more difficult to conventionally look down into the cut
2. Extensive chip buildup obstructs view of the cut and re-cuts chips
3. On large verticals, head weights and distance from the column can cause head drop, loss of accuracy and chatter
4. Not suitable for large, boxy, heavy parts

### 5.3.6 Automated Features and Capabilities of Machining Center

Three principal developments in the 1960 are led to the increased acceptance and use of machining centers.

1. The capability of machine tool to change its own cutting tools on command
2. An indexable work table permitting machining on multiple sides of a work piece in one clamping (increased versatility of horizontal over vertical machining centers)
3. Calling up interchangeable pallets from an of line bank for machining center, part processing

Today's trend is to incorporate many diverse functions in a single machining center, such as tilt tables, swivel spindles and touch trigger probing. The result is the emergence of the flexible manufacturing cell resident is a single machine; the machining center.

Machining center automated features and capabilities perform various functions that now automates what was previously performed manually in several separate operations and on variety of different machine tools.

The principal automated machining center features and capabilities are

1. Torque control machining
2. Surface sense probe
3. Automated tool delivery
4. Multiple and angled spindle heads
5. Broken tool detection

#### **5.3.6.1 Torque Control Machining**

It is also referred to as adaptive control, this feature was developed to speed up or slow down a cutting tool while the tool is engaged in actual cutting operation. The functions of torque control machining are to sense machining conditions and adjust the feeds and speeds to suit the real time condition. Sensing devices are built-into the machine spindle to sense torque, heat and vibration. These sensing devices provide feed back signals to the MCU, which has the preprogrammed safe limits. If the preprogrammed safe limits are exceeded, the MCU alters the feeds and speeds.

*Note:* MCU → Machine Control Unit.

#### **5.3.6.2 Surface Sensing Probe**

Probing is used extensively on machining centers in stand-alone cell and FMS applications. Just as in rotational cells and systems, probing is of critical importance to the successful operation of our automated cell or system for prismatic parts. A probe is a multidirectional precision electronic switching device that can be held in the tool storage matrix, until called for by the part program. It is then positioned in the machine spindle just as if it were a standard tool with appropriate CNC—resident software and part programming.

#### **Machining center probes can**

1. Check for part presence and alignment on single to multi part loaded pallets
2. Calculate the center position of a hole by averaging measured points taken around the hole or boss.
3. Compute and store offset data in the fixture-offset table.
4. Detect stock variations or cored hole shifts and automatically re-grid the machine

Probing improves machining accuracy by feeding back offsets to fine tune the program in the range of 0.0001 inches or finer. This technique by passes the need for extremely fine (and costly) drives and position measuring devices in the machine tool.

#### **5.3.6.3 Automated Tool Delivery**

Automated tool delivery to a machining center as part of an automated cell or system offers big gains in productivity and machine utilization rates, since machines cannot be stopped for tool replacement.

Generally delivered on an AGV to the rear of the machine and tool matrix, new cutting tools can be exchanged with used tool without interference with the ongoing machining process.

Although, generally controlled by the help of a cell controller or mini computer, the automated tool delivery and exchange capability add considerably to a machining centers overall uptime and performance.

#### **5.3.6.4 Multiple and Angled Spindle Heads**

When cycle time can be improved by drilling or tapping several holes at once, multiple spindle or cluster heads may be used. Multiple spindle heads, which can be loaded like an ordinary tool, drive a cluster of tools through their internal gearing mechanisms. The head during contains a fixed number of driven spindles, but the location of each spindle relative to the others is determined by the purchaser, who can configure each individual spindle location to suit a repetitive hole pattern 90 and 45 angle. Heads are used on machining centers in highly specialized apparatus. In most cases, they are used where the investment in an angled spindle head to drill a few holes for example, may save another complete setup and part handling, just to drill a few difficult to get to holes.

#### **5.3.6.5 Broken Tool Detection**

This feature throughout the NC part program permits offsetting each tool to a fixed probe to check for tool breakage before beginning the cut sequence. If a tool is broken, the machine will automatically replace it with a duplicate stored in the tool matrix. If the duplicate does not exist, a machine stop condition will occur and operator action is required. Broken tool detection adds to increased machine productivity and utilization and decrease operator involvement and attention.

# 6

## Deburring and Wash Stations

### 6.1 INTRODUCTION

In almost all forming and machining operations very fine burrs of metal are invariably left on the work piece. These burrs are undesirable, particularly for precision components, as they may break loose and disturb a delicately balanced mechanism. They are also dangerous for the fingers. The work piece will also contain some oily unwanted substances such as grease, dust, and etc. The finished work piece with these unwanted materials cannot be a final finished product. So in order to deliver final finished products, the above-mentioned problems have to be overcome. These problems can be overcome by the techniques like deburring and cleaning.

Actually, cleaning and deburring equipment do perform post-machining operations, but the automated processes add value, save time, and free employees to perform more meaningful work elsewhere. Parts must be cleaned and deburred before they can ever attempt to be accurately inspected, stocked or assembled.

Although sometimes challenged because simple processes require high priced equipment, how parts are cleaned and burrs removed are important factors to be considered in the planning of many flexible cells and systems.

### 6.2 DEBURRING

Deburring is a process of removal of burr from the machined work piece. In past, deburring was purely a manual, repetitive process that was highly labor intensive. In many instances today, circumstances still require extensive manual effort for part deburring. However, over the last several years, various high-tech methods have emerged or have been perfected to deal with the problem of automating and reducing the manual effort required for burr removal.

The 4 most common types of automated deburring are:

1. Mechanical
2. Vibratory
3. Thermal energy
4. Electrochemical

### 6.2.1 Mechanical Deburring

Mechanical deburring involves the use of industrial robots in an automated cell or systems. In this method deburring is done by supplying rotational power to the wire brush or grinding wheel which is held at the end effector of the robot, while the robot's articulated arm positions the deburring tool in all its proper positions to remove the burrs.

In many cases, conventional robots are not ideally suited for burr removal. This is because the robot's articulated arm doesn't provide enough rigidity and accuracy for heavy burr removal applications. Also many work pieces require different parts of the work piece.

### 6.2.2 Vibratory Deburring

This is designed for relatively small rotational or prismatic work pieces. Parts systematically enter a large bowl container filled with ceramic pebbles commonly referred to as media. The size of the ceramic pebbles commonly referred to as media. The size of the ceramic media can vary depending upon the type, size and material of the parts to be deburred. As the parts enter the bowl (via conveyor), the bowl is rapidly vibrated back and forth, this motion agitates the parts in the ceramic media, removing burrs, and gently polishing the parts. Here eccentric weights are mounted on each end of the bowl support shaft to vibrate the bowl in a controlled and adjustable manner.

### 6.2.3 Thermal Deburring

In this method intense heat is used to deburr work pieces. The parts to be deburred are sealed in a chamber, which is pressurized with a mixture of combustible gas and oxygen. This mixture completely envelops the parts and surrounds the burrs, regardless of external internal or blind hole location. This gaseous mixture is then ignited by a spark plug, which creates an instant burst of intense heat, and burrs, because of their high ratio of surface to area mass, burst into flames. Burrs and flash are instantly oxidized and converted to powder in approximately 25 to 30 seconds. Parts are then cleaned with a solvent. This process removes undesired material from all surfaces and eliminates follow-up inspection necessitated by inconsistent hand deburring operations. This process is effective for wide range of dissimilar parts of both ferrous and nonferrous materials.

### 6.2.4 Electrochemical Deburring

Electrochemical deburring machines can deburr contour parts through an electrochemical reaction that dissolves metal from a work piece into an electrolyte solution.

In this process an electrode is positioned close to area of workpiece (made of conducting material to be deburred). The electrode is connected to the negative, and the work piece to the positive terminal of a D.C. source. An electrolyte is made to flow between electrode and workpiece. Thus electrochemical reaction takes place and burrs are removed. In this the current passed is directly proportional to burr removal rate.

This process has several advantages like tool never touches the part, so no tool wear occurs. No heat is created during the process; therefore, thermal or mechanical stress cannot distort the part.

## 6.3 WASH STATIONS

Wash stations play an important role in the flexible manufacturing system. Wash stations are automated high-tech washing machine that uses high-pressure coolant to remove the dirt, grease and chips from the part, fixture and pallet. Wash stations can accommodate a variety of different parts as long as the parts can fit within the required size limitations.

### 6.3.1 Classification of Wash Stations

Wash stations are classified into two major types. They are

- Batch type wash stations
- In-line type wash stations

#### 6.3.1.1 Batch Type Wash Stations

Here, the batch washers handle work pieces weighing thousands of pounds and as large as 72-inch cube. Batch wash stations are generally used in low-to mid-volume applications to provide a clean work piece for downstream inspection, assembly or further processing.

#### 6.3.1.2 In-line Type Wash Stations

In-line washers are used for high-volume production where high and rapid production rate is required. In an in-line washer, workpieces are loaded at one end of a system, the work pieces are cleaned as they pass through the machine, and removed at the opposite end. Separate roller conveyors can be added at the load-unload sections for interfacing. Multiple stages can be added for rinsing, rust prevention, or part blow-dry.

Selection of either a batch or In-line wash stations is a function of:

- Workpiece type, size, weight, material and configuration.
- Production rate required.
- Material to be removed (chips, cutting oil, tapping compounds, etc.).
- Succeeding operation type (inspection, stocking, assembly).
- Method of part loading unloading, transport and delivery.

For this Batch or In-line wash stations requires spray nozzle, which is to be properly sized, located and directed to clean exterior and interior areas of workpiece.

In batch or in-line wash stations an adequate volume and pressure are required for complete flushing of chips from the workpiece fixture and pallet. These high-pressure wash stations operate at a 28bar or even more. This high pressure is capable of sharing of encrusted dirt and grease, resulting in a well-cleaned workpiece.

Some heavy-duty batch wash stations are capable of automatically locking the pallet assembly to an internal machine circular rail carriage and rotating the entire assembly around the rail during the cleaning and blow-dry cycle. This allows better access to recessed areas, improved drainage and increased blow-dry coverage.

Blow-off is one of the most important wash station options. This reduces drying time of the washed workpiece by blowing off the excess coolant or wash solution, prevents spillover to other machines and other areas of the cell, and helps keep the area clean and neat. Some machines use convector heated air blow-off generated by gas, steam, or electricity in order to speed up the blow-off and part drying cycle and to remove moisture.

In-line wash stations generally have their own individual and cleaning solution storage tanks equipped for chip recovery and coolant or cleaning solution recirculation, where as in batch wash station the chip and coolant flow directly into the flume system trough to be circulated back to the central coolant storage tank.

A sludge conveyor can be used on any type of wash station to handle any volume of dirt, chips. A sludge conveyor basically carries the waste material up to a slope to be deposited in a sludge container for disposal, while the liquid drains back into the central storage tank.

Wash stations, like the other equipment in a FMS, receive instructions for the host computer or cell controller to their individual programmable controller. These instructions consists of signals primarily to:

- Open and close the entry door.
- Position pallet and internal locks before beginning the wash cycle.
- Monitor, control and feed back tank coolant and cleaning solution levels to the host computer.

A typical batch wash stations operational scenario in an FMS would be:

- A fixture pallet is delivered via AGV to the wash station shuttle mechanism.
- The entire pallet assembly is shuttled to the front of the wash station.
- Wash station doors open and the pallet assembly moves into the wash zone, where internal locks are activated to lock the pallet to the overhead rail carriage and the doors are shut.
- The locked fixture assembly begins its 360-degrees overhead rotational path.
- High-pressure coolant begins to flood the entire pallet assembly through many nozzles, causing chips, dirt, and grease to fall into the flume system.
- After a timed period and with the assembly still rotating, the coolant flush is shut off and the heated air blow-off cycle begins.
- The blow—off fans continue for a timed period, and the cycle ends as the carriage returns to its original positions.
- Pallet locks are released, the wash-station doors open, and the fixture pallet assembly is returned to the shuttle position for disposition to another area.

## 6.4 IMPORTANCE TO AUTOMATED MANUFACTURING

Planning the design and implementation of any cell or system requires careful, systematic study of the many factors that affect final results. Among these key factors is the method for removal of burrs, chips, dirt, grease, tapping compound, and coolant from parts, fixtures and pallets. It is important to consider deburring and wash stations processes in an automated cell or system because they can:

- Eliminate the manual move, queue, labor and piece-handling time.
- Improve part flow and production output.

- Provide a cleaner and safer work environment.
- Reduce potential part damage as a result of the extra manual part handling.
- Free personnel for more meaningful tasks.
- Add more control to the total part manufacturing process.

Of the two processes, cleaning and deburring, cleaning is more flexible and generally easier to add to a cell or system than deburring. Depending on part characteristics and other factors, it may not always be cheaper.

Deburring has limited flexibility of operation, as we have already seen. Different types of deburring may be required for different parts of similar work-pieces. If work piece requirements change, the method and type of deburring may have to change.

Wash stations, on the other hand, can accommodate a variety of different parts, as long as the parts can fit within the required size limitations. And batch wash stations must be able to accommodate the height and weight of tombstone fixtures. Consequently, how large a part and tombstone fixture can be accommodated by a particular wash station is an important factor to be considered in purchasing.

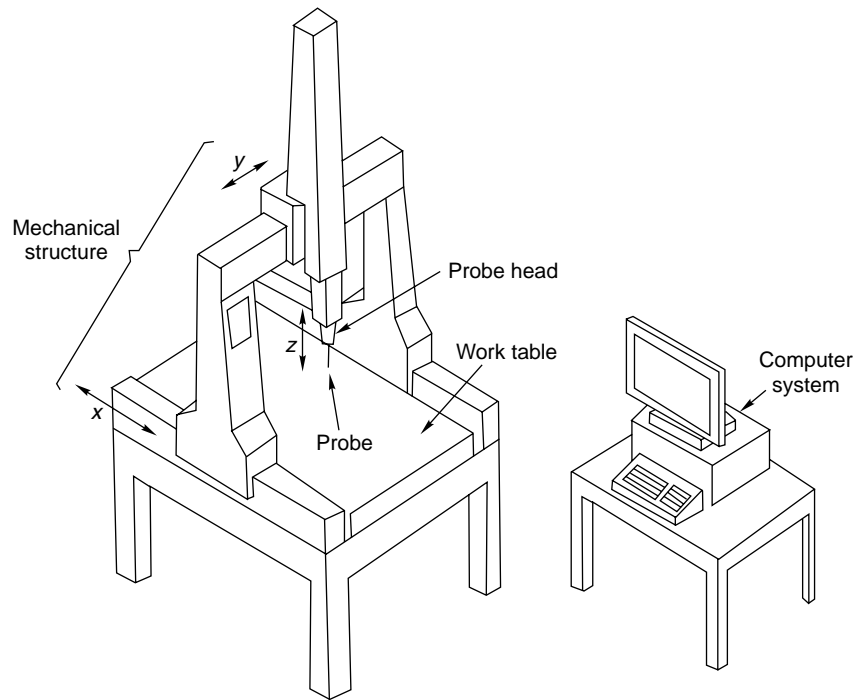
# Coordinate Measuring Machine

## 7.1 INTRODUCTION

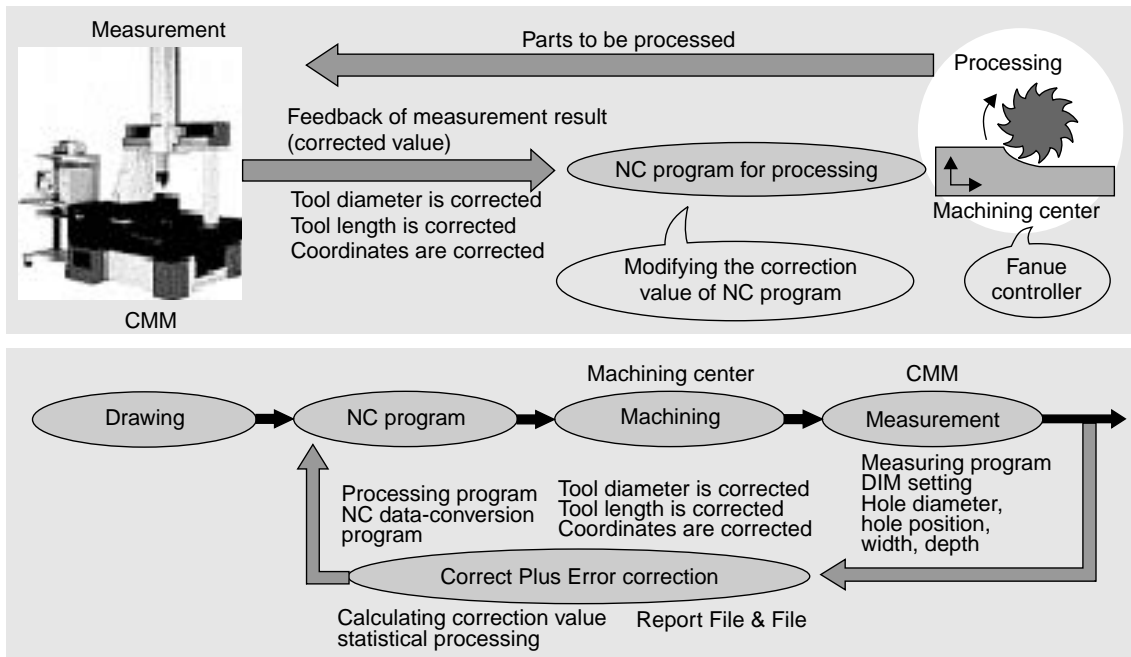
Traditional measuring instruments can provide excellent solutions for the measurement of features such as length, height, width, inside and outside diameters, flatness, roundness, angles, and so on. The problem with traditional measurement techniques is that each measured feature may require individual inspection instruments and individual setups, as well as allowing for increased human error. A coordinate measuring machine (CMM) can fill a valuable role in precision measuring because a surface plate, height gage and indicator inspection procedure are combined to provide a fast, accurate and more convenient alternative to the conventional methods for measuring complex parts.

The CMM can also be fully automated and linked to a CAD system as well as used to measure and verify Geometric Dimensioning and Tolerancing (GD&T) call outs. It seems that CMMs offer the answer to all our dimensional measurement problems, but is that really true? Will we get precisely the same results as the traditional methods? Measurement with a CMM is a complex process that requires the right training and interruption of data collected.

Coordinate measuring machine is an electromechanical system designed to perform coordinate metrology. Coordinate metrology is concerned with the measurement of the actual shape and dimensions of an object and comparing these with the desired shape and dimensions, as specified by the part drawing. CMM evaluates the location, orientation, dimensions, and geometry of the part or object. A CMM consists of a contact probe that can be positioned in 3-D space relative to the surfaces of a work part. The  $x$ ,  $y$  and  $z$  coordinates of the probe can be accurately and precisely recorded to obtain dimensional data concerning the part geometry (See the Fig. 7.1).



**Fig. 7.1** Coordinate measuring machine



**Fig. 7.2** CMM in action

## 7.2 CMM CONSTRUCTION

CMM consists of two basic components:

1. Probe
2. Mechanical structure

### 7.2.1 Probe

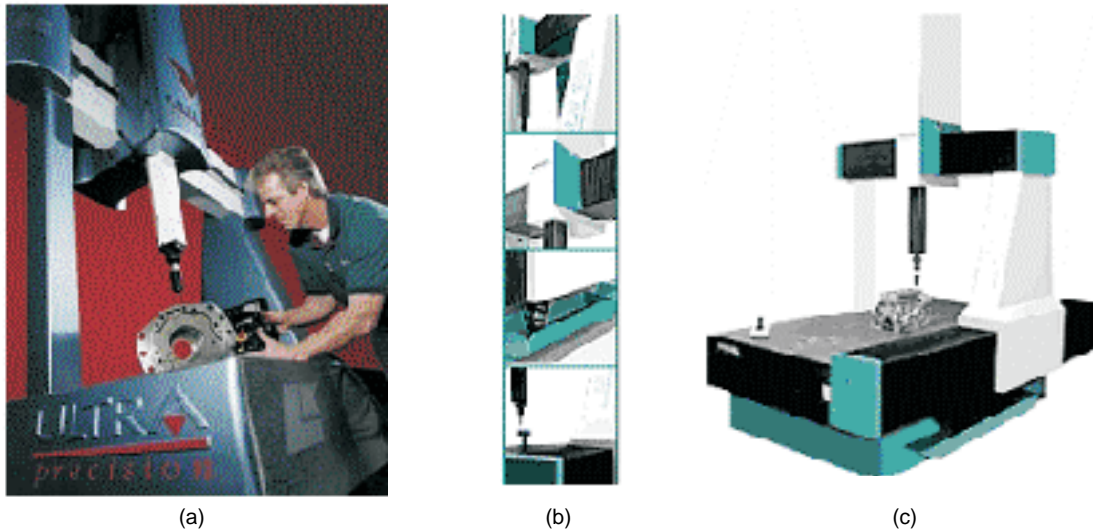
Probe is a key component of CMM. The tip of probe is usually a ruby ball, which is used to make contact with the part surface during measurement. Ruby ball is usually made of corundum (aluminum oxide), whose properties are high hardness for wear resistance and low density for minimum inertia. Probes can have either a single tip or multiple tips. Most probes today are touch-trigger probes, which actuate when the probe makes contact with the part surface. When contact is made between the probe and part surface, the coordinate positions of the probe are accurately measured by displacement transducers associated with each of the three linear axes and recorded by the CMM controller.

### 7.2.2 Mechanical Structure

There are various physical configurations for achieving the motion of the probe, each with its relative advantages and disadvantages. Nearly all CMMs have a mechanical configuration that fits into one of the following six types:



**Fig. 7.3** Horizontal CMM on inspection work



**Fig. 7.4** Inspection of a component using vertical CMM

### 7.2.2.1 Cantilever

In the cantilever configuration, the probe is attached to a vertical quill that moves in the  $z$ -axis direction relative to a horizontal arm that overhangs a fixed worktable. The quill can also be moved along the length of the arm to achieve  $y$ -axis motion, and the arm can be moved relative to the worktable to achieve  $x$ -axis motion.

The advantages of this construction are:

- Convenient access to the worktable
- High throughput
- Capacity to measure large work parts
- Relatively small floor space requirements

### 7.2.2.2 Moving Bridge

In the moving bridge design, the probe is mounted on a bridge structure that is moved relative to a stationary table on which the part to be measured is positioned. This provides a more rigid structure than cantilever design. One of the problems encountered with the moving bridge is yawing (walking) in which two legs of the bridge move at slightly different speeds resulting in twisting of bridge. This can be reduced by installing dual drives and position feedback controls for both legs.

### 7.2.2.3 Fixed Bridge

In this configuration, the bridge is attached to the CMM bed, and the worktable is moved in the  $x$ -direction beneath the bridge. This bridge eliminates the yawing effect, hence increasing rigidity and accuracy.

### 7.2.2.4 Horizontal Arm

The horizontal arm configuration consists of a cantilevered horizontal arm mounted to a vertical column. The arm moves vertically and in and out to achieve  $y$ -axis and  $z$ -axis motions. It allows

good accessibility to the work area. Large horizontal machines are suitable for measurement of automobile bodies.

### 7.2.2.5 Gantry

This construction is generally intended for inspecting large objects. The probe quill moves relative to the horizontal arm extending between the two rails of the gantry.

### 7.2.2.6 Column

This configuration is similar to a machine tool. The  $x$ -axis and  $y$ -axis motions are achieved by moving the worktable, while the probe quill is moved vertically to achieve  $z$ -axis motion.



Fig. 7.5 Gantry type CMM

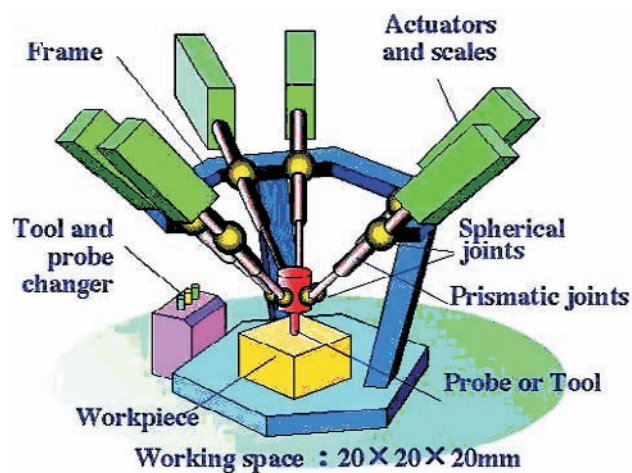
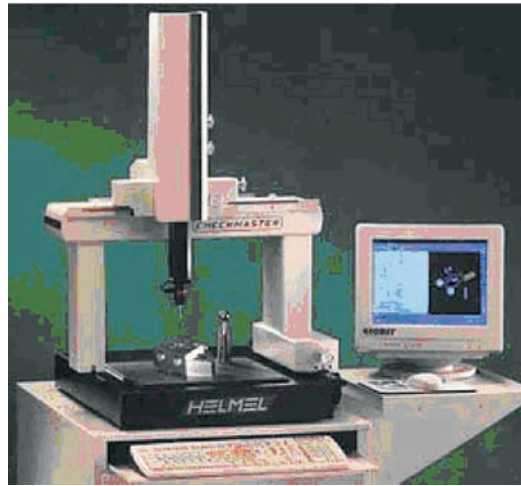


Fig. 7.6 Tool action on work piece using various parts and joints

### 7.3 TYPES OF CMM

CMM comes in variety of types, sizes, and models. Just like CNC machine tools CMMs are classified either as vertical or horizontal. Vertical CMMs are referred to as bridge models, while horizontal CMMs are referred to as cantilever models. Both types have various manufacturers and range in size from small tabletop models to the very large and expensive floor-mounted kind. CMMs are available with various computer peripherals and offer a variety of improved software packages, making systems integration of this equipment more practical.



**Fig. 7.7** Vertical type of CMM



**Fig. 7.8** Horizontal CMM

The materials used for CMM construction have been improved considerably in recent years. The measuring table and all the guide ways for example are constructed of high quality granite. Increased use of ceramics is also gaining wide acceptance.

Floor preparation of coordinate measuring machines is also very important. Solid reinforced concrete foundations are required for vibration dampening. Sometimes CMMs require environmental control. Measured dimensions can only be as accurate and reliable as the stability of their surrounding environment.

## 7.4 FUNCTIONS OF CMM COMPUTER

CMM inspection programs are prepared and proved out in advance of actual use just like the CNC part programs that machine the parts. Axes movements in  $x$ ,  $y$  and  $z$  are similar to other vertical and horizontal CNC equipment. During the automated inspection process, part dimensions are recorded with the help of probe. The CMM compares the result measurement with the previously input manufacturing tolerances allowed for each dimension and conveys this information to either the host or CMM computer.

The CMM computer is interfaced with the FMS host computer for uploading and down loading inspection data and CMM part programs. The CMM computer plays an important role in operation of coordinate measuring machine. In general its primary functions include:

- Control of graphical display and hard-copy output of measured data
- Storage and retrieval of measured data
- Determination of dimensional deviations
- Transfer of dimensional data files to the host computer
- Generation of SPC data
- Storage of machine calibration data
- Measurement comparison with test data parameters
- Operation of the CMM through manual or part program control

## 7.5 OPERATIONAL CYCLE DESCRIPTION

Parts that are manufactured are delivered to the inspection station after completion of the wash cycle via an AGV. The docking procedure at the inspection station is controlled and monitored by a (PLC) Programmable logic controller.

The parts to be inspected require preprogrammed inspection programs for each different work piece. These reside at the host computer level in an FMS. Inspection programs are downloaded in demand to the CMM computer.

Pallet and part identification are verified and the proper CMM inspection programs are automatically downloaded to the CMM computer.

Inspection data from the CMM are automatically compared with pre-established tolerance bands in the CMM part programs. Inspection includes diameter, hole depth, flatness and depths of machined area.

If a single work piece is rejected by a CMM, that pallet is automatically routed to material review station. An operator can then visually review the inspection results and dispatch the rejected

work piece pallet to make a second pass through the CMM. If the part is rejected second time, the rejection is recorded in the associated work piece history file on the host computer and the pallet continues its predetermined routing.

Deviations can be plotted to provide both graphical (SPC) and analytical inspection results with the appropriate quality and statistical process control software.

## 7.6 CMM APPLICATIONS

Coordinate measuring machines are most appropriate for applications possessing the following characteristics:

1. **Many inspectors performing repetitive manual inspection operations.** If the inspection function represents a significant labor cost to the plant, then automating the inspection procedures will reduce labor cost.
2. **Post-process inspection.** CMMs are applicable only to inspection operations performed after the manufacturing process.
3. **Measurement of geometric features requiring multiple contact points.** Geometric features like angle between planes, flatness, etc. are identified and available CMM software facilitates evaluation of these features.
4. **Multiple inspection setups are required if parts are manually inspected.** Manual inspections are generally performed on surface plates using gage blocks, height gages, and similar devices and a different setup is often required for each measurement. The same group of measurements on the part can usually be accomplished in one setup on a CMM.
5. **Complex part geometry.** If many measurements are to be made on a complex part, and many contact locations are required, then the cycle time of a DCC (Direct Computer Control)CMM will be significantly less than the corresponding time for a manual procedure.
6. **High variety of parts to be inspected.** A Direct Computer Control CMM is a programmable machine, capable of dealing with high parts variety.
7. **Repeat orders.** Using a Direct Computer Control CMM, once the part program has been prepared for the first part, subsequent parts from repeat orders can be inspected.



**Fig. 7.9** DCC (Direct Computer Control) CMM

## 7.7 CMM ADVANTAGES

1. **Reduced inspection cycle time:** Because of the automated techniques included in the operation of a CMM, Inspection procedures are speeded and labor productivity improved.
2. **Flexibility:** A CMM is a general—purpose machine that can be used to inspect a variety of part configurations with minimum changeover times.
3. **Reduced operator errors:** Automating the inspecting process has an obvious effect of reducing human errors in measurements and setups.
4. **Greater inherent accuracy and precision:** A CMM is inherently more accurate and precise than the manual surface plate methods that are traditionally used for inspection.
5. **Avoidance of multiple setups:** Traditional inspection techniques often require multiple setups to measure multiple part features and dimensions. In general, all measurements can be made in a single setup on a CMM, thereby increasing throughput and measurement accuracy.

# Automated Material Movement and Storage System

## 8.1 INTRODUCTION

Automated Guided Vehicles (AGVs) are vehicles that are equipped with automatic guidance systems and are capable of following prescribed paths. Unlike traditional robots, AGVs are not manipulators, they are driverless vehicles that are programmed to follow a guide path. In automated factories and facilities AGV's move pallets and containers. In offices they may be used to deliver and pick up the mail. They are even used to transport patrons around in airports.

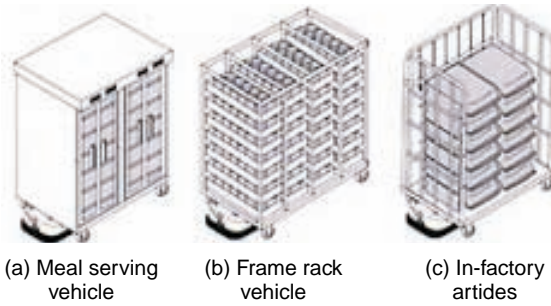
AGVs have been around since the 1950's. The technology was first developed by Barret Electronics from Grand Rapids, Michigan. One of the first AGVs was a towing vehicle that pulled a series of trailers between two points. AGV systems did not catch on at that time; however, they were not well received by unions and were never allowed to perform to their full potential. The Europeans expanded AGV technology in the 1970's. The market has now grown to include the United States.

The main benefit to AGVs is that they reduce labor costs. But in material handling facilities there is another benefit. Material handling has always been dangerous. Injuries occur due to lack of driver attention, driver's driving too fast, or personnel not paying attention. Obstacle detection is therefore a key to allowing AGVs to interact with personnel safely while optimizing vehicle speeds.

AGV technology has been moving forward. There have been advances in navigation systems. Until about 10 years ago most AGVs followed electromagnetic wires buried in the floor. Then laser-guided systems came into the market. These navigation systems allowed the AGV to determine its position in the plant based on the location of reflectors within the area. The future may be the in-plant equivalent of a global positioning system. Obstacle detection systems, has largely consisted of mechanical bumpers, giant E-stops that stop the AGV if it contacts a person or obstacle. Now, new advanced "virtual" bumpers may eliminate "driver error" injuries and allow AGV's to operate at optimum speeds.



**Fig. 8.1** Reach type (automated guided vehicle)



(a) Meal serving vehicle

(b) Frame rack vehicle

(c) In-factory articles

**Fig. 8.2**



**Fig. 8.3** FW-S30PMXZ

## 8.2 TYPES OF AGVS

- **Automated guided vehicle systems** consists of the computer, software and technology that are the “brains” behind the AGV. Without computer software systems and communications networks, only the simplest AGV functions can be performed.
- **Camera guided AGVs** are used when precise guidance accuracy is needed, such as in crowded environments and smaller sized facilities. An on-board camera focuses and guides the AGV while performing.
- **Forked AGVs** are used to pick up and deliver various loads, such as pallets, carts, rolls and others. These can be manually driven as well as used automatically, and have the ability to lift loads to many levels.
- **Inertial guided AGVs** use a magnet sensing device, a gyroscope that measures the unit’s heading and a wheel odometer that calculates the distance traveled. Magnets mounted beneath the floor are detected by the on-board magnetic sensing device and combine with the first two readings to give an accurate positional location.
- **Large chassis/unit load AGVs** are used to transport heavier loads with various transfer devices such as roller beds, lift/lower mechanisms and custom mechanisms.
- **Laser guided AGVs** use mounted laser scanners that emit a laser and reflect back from targets. The vehicle’s location can be determined based on distance to the target and time of reflection information.
- **Optical guided AGVs** use a latex-based photosensitive tape on a facility’s floor for guidance. Distance is measured by use of wheel odometers, which establish stop locations for the AGV along the course.
- **Outrigger AGVs** have two horizontal stabilizing legs (outriggers) to provide lateral support, and are used to handle pallets, rolls and racks.
- **Small chassis AGVs** are able to maneuver through crowded workplaces through laser sensing, while transporting smaller loads.
- **Smart vehicle AGVs** are capable of determining their own traffic control and routing without necessitating a central controller.
- **Tug/tow AGVs** are used to pull trailers and are usually manned by an operator who adds and removes the trailers at designated stops. These can follow a basic loop or a more complicated path.
- **Wire guided AGVs** use a charged wire that is buried beneath the floor for proper guidance and has a small antenna composed of metal coils mounted on their bottoms. The stronger the field between the buried wire and antennae, the higher the voltage induced to the coils.

### 8.2.1 Unit Load Carriers: Low Built Vehicle 3 Types A and C

- Unit handler, which can be fitted with any type of load handler on top. Roller or chain conveyor, fixed load table, lifting load table or arms, telescopic fork, etc.
- Load capacity up to 12,000 lbs.
- Three or five wheel version

- Single or fully bi-directional
- Ideal for material delivery and manufacturing



**Fig. 8.4** Unit load carrier

### 8.2.2 Side Loading and High Lifting Types

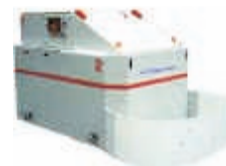
- Side loading vehicle with telescopic fork for load handling on both sides.
- Load capacity up to 3,000 lbs.
- Lift heights up to 20 feet
- Seven wheels with one spring loaded drive wheel and four castor wheels
- Support feet that lower to the floor and supports the vehicle for extra stability on high lifts
- Bi-directional motion
- Ideal for material delivery and finished goods warehousing



**Fig. 8.5** Side loading and high lifting type

### 8.2.3 Tugger Systems

- Rugged design, for hostile conditions
- Towing capacity up to 12,000 lbs.
- Wide variety of loads can be accommodated with standard or custom trailer types
- Custom vehicles with higher towing capacities



**Fig. 8.6** Tugger systems

### 8.2.4 Automated Guided Transport Carts

- Proven design, easy to install magnetic tape guidance
- Load capacity up to 1,100 lbs.
- Wide variety of loads can be accommodated with standard or custom attachments
- Ideal for distribution of bulk mail, large packages, material and parts



**Fig. 8.7** Automated guided transport carts

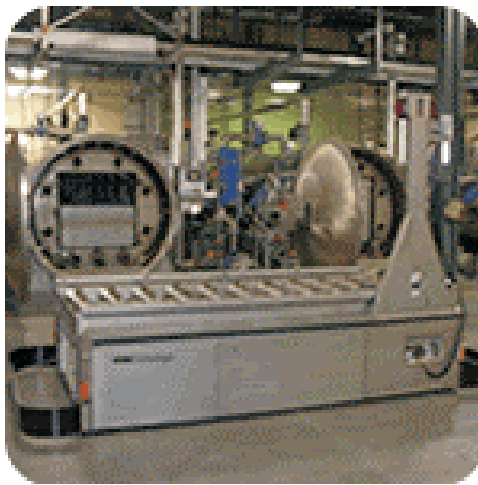


(a) AGV in plastics industry handle raw materials and finished



(b) AGV in chemical industry to handle raw materials are goods finished goods

**Fig. 8.8**



**Fig. 8.9** Food/Beverage—AGVs for movement of materials in the process or in the warehouse...



**Fig. 8.10** Pharmaceutical—AGVs support cGMP and validation requirements

Amerden's Automatic Guided Vehicles use proven, reliable and user-friendly operating systems in every facet of the AGV system's usage. Again, a modular approach can be taken in all communication and reporting systems to aid in diagnostics and reduce the overall downtime.

ACE AGV Onboard control language is used for all automatic functions of the vehicle.

The De'Carte Advanced Control System easily integrates with inventory and production control systems and works wonderfully in retrofit projects. And the Layout Development Kit speeds up the work of developing a new system, especially in Laser Guidance scenarios.



**Fig. 8.11** Amerden's AGV

**Features**

- Speed settings variable up to a maximum speed of 60 m/min
- Up to 256 travel patterns can be stored.
- Touch panel type easy-to-operate box
- Emphasis is placed on safety. Two-step detection of non contact collision prevention sensor



**Fig. 8.12** Laser guided AGV

The detailed specifications are given in the following Table 8.1

**Table 8.1** FW-C50S/FW-C55S/FW-C65S Specification

<i>Model number</i>	<i>FW-C50S</i>	<i>FW-C55S</i>	<i>FW-C65S</i>
Max. Load Capacity	Including the conveyor weight (If a conveyor is added, the permissible load capacity is decreased by its weight.)		
Vehicle weight	62 kg	65 kg	73 kg
Dimensions	885L × 550W × 260H		1090L × 640W × 260H
Guidance system	Optical guidance system/Optical guidance and magnetic maker system + magnet guidance system: Use our company's specified travel tape (Aluminum or stainless steel/magnetic tape)		
Max. rated speed	Set at an arbitrary low medium, and high speed in the range of 6 to 60m/min. in addition, the speed can be set directly		
Travel Function	Front-single-wheel steering, Forward travel, branching*3	Front-single-wheel steering, Rear-two-wheel steering (at spin turn or sliding)	
Stop repeatability	± 10 mm On level surface		
Min turning radius	400 mm	600 mm	
Battery	Lead sealed battery 24V 17Ah		
Safe device	Non contact collision prevention sensor (personal, impersonal) Non contact collision prevention blocking (Panawagon merge) Warning alarm (traveling music, warning alarm) Traveling direction indicator lamp (winker lamp) Address recognition: Marking tape counting up system No. of travel pattern:256 patterns (8000 marks in total) (It varies depending on the number of marks per route.)		
PLC function	Input: 16 points, Output:12 points (Optionally, 8 input points and 4 output points can be expanded.) Program: Ladder diagram language, Programming with the GCP (option), max. 2000 steps Storage system: RAM (battery-back up), IC card (mounted on the GCP: option)		
Communication system	Fixed point, optical communication, SS radio system (option: For the specifications and date of delivery, please contact us)		
Operation environment	0~40°C (Indoor, Free of dew condensation and freezing) Slope: Max. 1 degree, Bump: Max.5 mm		
Others	Touch panel type operation box (option)		

### 8.3 ASRS SYSTEMS AVAILABLE



**Fig. 8.13** ASRS systems

### 8.4 ANALYSIS OF AGV SYSTEMS

The analysis of AGV systems is used to determine

- (i) the number of AGV's required
- (ii) cycle times
- (iii) handling system efficiency

It is assumed that the vehicle operates at a constant speed of  $V$ . The acceleration, deceleration and other effects that influence the speed are ignored.

The time for a typical delivery cycle in the operation of the vehicle includes

- loading at the pick up station
- unloading at the drop off stations
- travel time to the drop off station
- empty travel time of the vehicle between deliveries

Therefore the total cycle time per delivery per vehicle is given by

$$T_v = T_l + T_u + Ld/v + Le/v \quad \dots (8.1)$$

Where,  $T_v$  = Delivery cycle time (min./delivery)

$T_l$  = Pick up time (min.)

$T_u$  = Drop off time (min.)

$T_h = T_l + T_u$  = Handling time (min)

$Ld$  = Distance the vehicle travels between load and unload station (m)

$L_e$  = Distance the vehicle travels empty until the start of next delivery cycle (m)

$v$  = velocity (m/min.)

The delivery cycle time can be used to determine the rate of deliveries per vehicle and number of vehicles required.

The hourly rate of deliveries per vehicle is 60 minutes divided by the delivery cycle time  $T_v$ , with adjusting for any time losses during the hour.

The possible time losses include *availability, traffic congestion and efficiency of manual drivers*.

$\therefore$  Traffic factor ( $F_t$ ) accounts and lies between 0.85 and 1.

$\therefore$  Number of deliveries per hour per vehicle =  $60 F_t/T_v$  ... (8.2)

or

Number of deliveries per hour per vehicle =  $(60 E_h)/(L_d/v)$  ... (8.3)

Where  $E_h$  = handling system efficiency

=  $\{(L_d/v) \times F_t\}/(L_d/v + T_h + L_e/v)$  ... (8.4)

$\therefore$  Number of AGVs required =  $\frac{\text{Number of deliveries required per hour}}{\text{Number of deliveries/hour/vehicle}}$  ... (8.5)

**Example 8.1** Following are the data of AGV system:

Vehicle Velocity = 45 m/min.

Average distance traveled/delivery = 135m

Pick up time = 45 sec.

Drop off time = 45sec.

Average distance traveling empty = 90 m

Traffic factor = 0.9

Determine the number of vehicles required to satisfy the delivery demand if the delivery demand is 40 deliveries per hour. Also determine the handling system efficiency.

**Solution:**  $L_d = 135$  m,  $L_e = 90$  m,  $T_l = 45$  sec = 0.75 min,  $T_u = 45$  sec = 0.75 min,  $T_h = T_l + T_u$

= 0.75 min. + 0.75 min

= 1.5 min.,

$v = 45$  m/min. and  $F_t = 0.9$

Total cycle time per delivery per vehicle is given by

$T_v = T_h + L_d/v + L_e/v$

=  $0.75 + 0.75 + 135/45 + 90/45$

= 6.45 min.

The number of delivery per hour per vehicle =  $60 F_t/T_v$

=  $60 \times 0.9/6.45$

= 8.37 deliveries/hour/vehicle

Number of vehicles required =  $\frac{\text{Number of deliveries required per hour}}{\text{Number of deliveries/hour/vehicle}}$

$$\begin{aligned}
 &= \frac{40 \text{ delivery/hour}}{8.37 \text{ deliveries/hour/vehicle}} \\
 &= 4.82 \\
 &= 5 \text{ vehicles} \\
 \text{Handling system efficiency} &= \{(Ld/v) \times Ft\} / \{(Ld/v) + Th + (Le/v)\} \\
 &= \{(135/45) \times 0.9\} / \{(135/45) + 1.5 + (90/45)\} \\
 &= 0.4154 \\
 &= 41.54 \%
 \end{aligned}$$

**Example 8.2** In order to determine the number of vehicles required to meet the demand for a particular automated guided vehicle system. The system must be capable of making 40 deliveries per hour. The following are the data of performance characteristics of the system:

- Vehicle velocity = 150 m/min.
- Average distance traveled per delivery = 450 m
- Pick up time = 0.75 min.
- Drop off time = 0.75 min.
- Average distance traveling empty = 300 m
- Traffic factor = 0.9

Determine the number of vehicles required to meet the demand of delivery. Also determine the handling system efficiency?

**Solution:** The total time per delivery per vehicle is given by

$$\begin{aligned}
 T_v &= T_h + Ld/v + Lc/v \\
 &= T_l + T_u + Ld/v + Le/v \\
 &= 0.75 + 0.75 + 450/150 + 300/150 \\
 &= 3 + 1.5 + 2 \\
 &= 6.5 \text{ min.}
 \end{aligned}$$

$$\begin{aligned}
 \text{The number of deliveries per hour per vehicle} &= 60 Ft/T_v \\
 &= 60 (0.9)/6.5 \\
 &= 8.3077 \text{ deliveries/hour/vehicle}
 \end{aligned}$$

Therefore, the number of vehicles required

$$\begin{aligned}
 &= \frac{\text{Number of deliveries required per hour}}{\text{Number of deliveries/hour/vehicle}} \\
 &= 40/8.3077 \\
 &= 4.81 \text{ vehicles} \\
 &= 5 \text{ vehicles}
 \end{aligned}$$

The handling system efficiency,

$$\begin{aligned}
 E_h &= \{(Ld/v) * Ft\} / \{(Ld/v) + Th + (Le/v)\} \\
 &= \{(450/150) * 0.9\} / \{(450/150) + 1.5 + (300/150)\} \\
 &= 0.41538 \\
 &= 41.54 \%
 \end{aligned}$$

## Problems

**8.1** An AGVS has an average travel distance per delivery = 500 m and an average empty travel distance = 300m. The system must make a total of 75 deliveries per hour. The load and unload times are both 0.5 min and the speed of the vehicles = 150 m/min. The traffic factor for the system = 0.85. Determine the average total time per delivery, the handling system efficiency and the resulting average number of deliveries per hour for a vehicle. How many vehicles are needed to satisfy the indicated deliveries per hour?

**8.2** In order to determine the number of vehicles required to meet the demand for a particular automated guided vehicle system. The system must be capable of making 60 deliveries per hour. The following are the data of performance characteristics of the system:

Vehicle velocity = 50 m/min.

Average distance traveled per delivery = 150 m

Pick up time = 0.45 min.

Drop off time = 0.45 min.

Average distance traveling empty = 100 m

Traffic factor = 0.8

Determine the number of vehicles required to meet the demand of delivery. Also determine the handling system efficiency?

## 8.6 AUTOMATED STORAGE AND RETRIEVAL SYSTEMS (AS/RS)

Automated Storage and Retrieval Systems (ASRS) are means to high density, hands free buffering of materials in distribution and manufacturing environments. There are several classes of Automated Storage and Retrieval (AS/RS) that are characterized by weight and size handling characteristics.

- Unit Load AS/RS
- Mini Load AS/RS
- Carousel AS/RS

### 8.6.1 Unit Load AS/RS

Unit Load AS/RS machines are generally pallet-handling systems with capacities that vary much like lift trucks. Unit load AS/RS Systems are often quite tall and sometimes support the building shell that contains them. The density, security and labor/machinery savings they provide, make them a good choice in a variety of applications from cold storage to general warehousing.

### 8.6.2 Mini Load AS/RS

Mini Load AS/RS—operating on the same principles as the Unit Loads these mini load machines handle smaller and lighter loads.



**Fig. 8.14** Unit load AS/RS

These typically range from metal trays and totes to shipping cartons. Mini loads may be used in traditional stockroom applications but are also well suited as buffers to support manufacturing processes and shipping systems.



**Fig. 8.15** Mini load AS/RS

### 8.6.3 Carousel AS/RS

Carousel AS/RS, the industrial carousel may be integrated with a specific purpose robotic inserter/extractor for small load buffering. Very often, carousel AS/RS is applied in lights-out stockroom. This technology finds itself at the heart of systems varying widely in application from the food industry to the manufacturing floor.



**Fig. 8.16** Carousel AS/RS

## 8.7 ADVANCED AUTOMATED STORAGE AND RETRIEVAL SYSTEM

Stores and retrieves production parts for aging, testing, or optimization of production flow. Allows parts to be grouped into multiple batches; internal database handles all part information including time stamp for accurate retrieval by age



**Fig. 8.17** Advanced AS/RS



**Fig. 8.18** Buffered manufacturing inserter/extractors addressing 2-wide double high carousels

Storage and Retrieval (SR) Systems combine high-density storage of components, work-in-process storage or finished goods with automated storage, retrieval and handling. In addition to a complete line of conveyors, transfers and ergonomic devices, Industrial Kinetics, Inc. manufactures and integrates a wide variety of Storage and Retrieval machines. Our innovative equipment can interface with carousels, live or static rack installations, and custom configured work cells. Industrial Kinetics, Inc. provided systems include the most current inventory control technology



**Fig. 8.19** Transfer car distributing product from inventory to work cells and, ultimately shipping



**Fig. 8.20** ASRS Crane—High-rise storage of work in process, including weighing and profiling of loads before storage

*Courtesy: Industrial Kinetics, Inc.*

## 8.8 ANALYSIS OF AS/RS

The analysis of AS/RS is used in order to determine the transaction cycle time. The transaction cycle involves retrieval of load out of storage or delivery of a load in to the storage or both of the activities in a single cycle.

The two types of transaction cycles are:

1. Single command cycle: It involves either retrieving a load from the storage or entering a load into the storage but not both in a single cycle.
2. Dual command cycle: It involves both entering a load into storage and retrieval of the load from storage in the same cycle. It represents the most efficient way to operate the AS/RS since two loads are handled in a single transaction.

In order to compute the transaction cycle time based on the formulas derived by Bozer and White following assumptions have to be made

- Randomized storage of loads in AS/RS
- Storage compartments are of same size
- Pickup and delivery station is located at the base and end of the aisle
- Horizontal and vertical speed of the storage/retrieval (S/R) machine are constant
- Simultaneous horizontal and vertical travel

For single command cycle, the transaction time is given by,

$$T_{sc} = T (Q^2/3 + 1) + 2 Tpd \quad \dots (8.6)$$

For dual command cycle, the transaction time is given by,

$$T_{dc} = T (4/3 + 0.5 Q^2 - Q^3/30) + 4 Tpd \quad \dots (8.7)$$

Where,  $L_s$  = Length of aisle

$H_s$  = Height of aisle

$V_h$  = Average horizontal speed of S/R machine

$V_v$  = Average vertical speed of S/R machine

$Tpd$  = shuttle time to perform pickup and deposit.

The time required for horizontal and vertical travel in full length and height of the storage system are given by

$$t_h = L_s/V_h \quad \dots (8.8)$$

and

$$t_v = H_s/V_v \quad \dots (8.9)$$

Using these travel times, the following parameters are defined,

$$T = \max (t_h, t_v) \quad \dots (8.10)$$

$$Q_{\min} = \min (t_h/T, t_v/T) \quad \dots (8.11)$$

## 8.9 QUANTITATIVE ANALYSIS

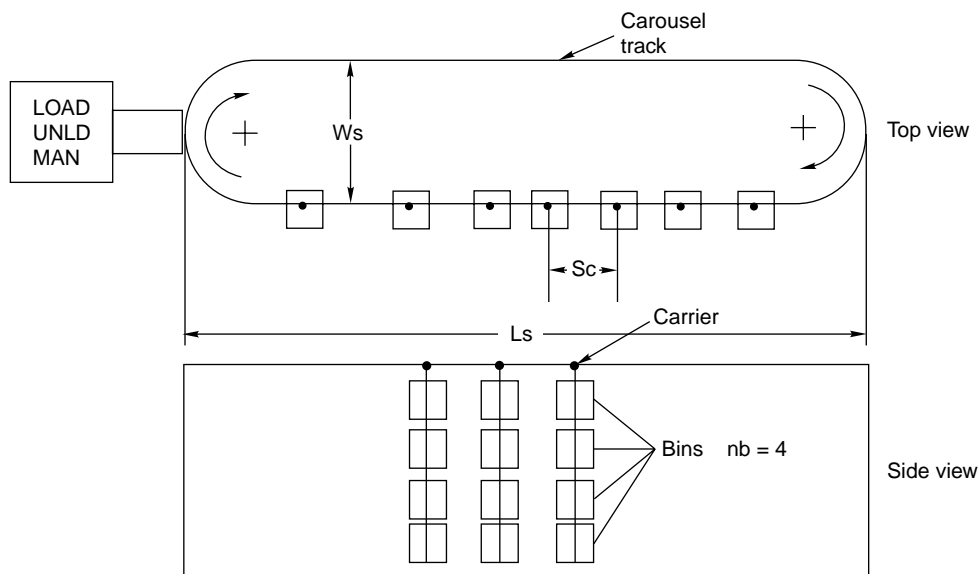
The size and capacity of a storage carousel can be determined with reference to the given Fig. 8.21. The individual bins are hung on carriers that revolve around the carousel track. The circumference of the carousel track is given by

$$C = 2(L_s - W_s) + \pi W_s \quad \dots (8.12)$$

Consider the spacing between carriers around the track be given by  $s_c$  and the number of carriers be symbolized as  $n_c$ .

$$\text{Hence } n_c s_c = C \quad \dots (8.13)$$

If the number of separate bins hung from a carrier is  $n_b$ , the total number of bins that is storage compartments on the carousel =  $n_c n_b$  ... (8.14)



**Fig. 8.21** Layout and elevation drawing of a typical storage carousel

Assumptions made to derive the time to perform a transaction are

- Transaction cycle consists of either a storage or retrieval, but not both that is single command transactions can be performed
- Speed ( $V_c$ ) of the carousel is constant
- Random storage is used in the carousel (i.e., any point around the carousel is equally likely to be selected for a storage or retrieval transaction).

Let us consider a retrieval cycle and the storage transaction is performed under the same assumption of random storage would be equivalent to a retrieval transaction.

The average distance that the carousel has to travel to move randomly located bin to the unload station at the end of the carousel depends on whether the carousel revolves in only one or both directions.

For the single direction, the average travel distance is given by

$$Lr = 0.5C \quad \dots (8.15)$$

And the corresponding time complete a retrieval transaction,

$$Tr = (0.5C/Vc) + Th \quad \dots (8.16)$$

Where  $Th$ —handling time of the picker to remove the item or items from the bin. For the carousel capable of bi-directional travel, the corresponding average travel distance and retrieval transaction time are

$$Lr = 0.25C \quad \dots (8.17)$$

$$Tr = (0.25C/Vc) + Tc \quad \dots (8.18)$$

**Example 8.3** Consider an operation of unit load AS/RS, which uses an S/R machine for each aisle of the system. The length of storage aisle is 300 m and its height is 50 m. Horizontal and vertical speeds of S/R machine are 400 m/min. and 75m/min. respectively. The S/R require 30 seconds to accomplish pickup and delivery. Determine the single and dual command cycle times.

**Solution:** The values of  $th$  and  $tv$  are

$$\begin{aligned} t_h &= Ls/Vh \\ &= 300 \text{ m}/400 \text{ m/min} \\ &= 0.75 \text{ min.} \end{aligned}$$

$$\begin{aligned} t_v &= Hs/Vv \\ &= 50 \text{ m}/75 \text{ m/min} \\ &= 0.667 \text{ min.} \end{aligned}$$

The parameter  $T$  and  $Q$  are determined as

$$\begin{aligned} T &= \max(th, tv) \\ &= \max(0.75, 0.667) \\ &= 0.75 \text{ min.} \\ Q &= \min(th/T, tv/T) \\ &= \min(0.75/0.75, 0.667/0.75) \\ &= 0.889 \text{ min.} \end{aligned}$$

Therefore single command transaction cycle time is given by:

$$\begin{aligned} Tsc &= T(Q^2/3 + 1) + 2 Tpd \\ &= 0.75 \{(0.889)^2/3 + 1\} + 2(30/60) \\ &= 1.9475 \text{ min.} \end{aligned}$$

**Example 8.4:** The oval of a top-driven carousel track has a length = 50m and width = 4m. The speed of the carousel = 75 m/min. There are 100 carriers around the carousel and each carrier has 5 bins suspended from it. For a single direction carousel and a bidirectional carousel, compare how long it take it takes to retrieve 20 parts from the carrier if each part is in different storage bin and random storage is used in the carousel. Also determine the spacing between carriers and carousel. The handling time associated with retrieval is 20 seconds.

**Solution:** The circumference of the carousel track is

$$\begin{aligned} C &= 2 \times (50 - 4) + 4\pi \\ &= 104.57 \end{aligned}$$

For single direction carousel, the retrieval of 20 parts would require

$$20Tr = 20 \times (0.5 \times (104.57/75) + 0.333)$$

$$Tr = 20.61 \text{ min.}$$

For a bidirectional carousel, the retrieval of 20 parts would require

$$20Tr = 20 \times (0.25 \times (104.57/75) + 0.333)$$

$$Tr = 13.63 \text{ min}$$

The spacing between carriers along the carousel is given by

$$Sc = 104.57/50 = 2.091 \text{ m.}$$

The dual command cycle, the transaction time is given by,

$$\begin{aligned} Tdc &= T(4/3 + 0.5 Q^2 - Q^3/30) + 4 Tpd \\ &= 0.75(4/3 + 0.5(0.889)^2 - (0.889)^3/30) + 4(30/60) \\ &= 3.278 \text{ minutes.} \end{aligned}$$

## Problems

**8.3** The length of an AS/RS is 400 m and its height is 100 m. horizontal and vertical speeds are 250 m/min. and 80 m/min. respectively. The  $P$  and  $D$  time is 0.6 min. Determine the average single command and dual command transaction times for the storage system.

**8.4** A mechanized storage carousel has a length of 40 m and a width of 4.5 m. The velocity of the carousel is 60 m/min., and the part handling time at the unload station is 0.40 min. Compute the average time to retrieve a part from the system:

- (a) Assuming that the system revolves in a single direction
- (b) Assuming that the system revolves in both direction

**8.4** A storage system serving electronics assembly plant consists of 3 storage carousels, each with its own  $P$  and  $D$  station. Each carousel has a track that is 60 m long and 3.5 m wide. The speed at which the system revolves is 75 m/min. The  $P$  and  $D$  handling time is 0.40 min. Determine the throughput rate of the storage system if the storage transaction and retrieval transactions are 4 equally divided during the shift. Assume bidirectional travel of the carousel.

## 8.10 INDUSTRIAL ROBOTS

The primary concern of the manufacturing industries since the early 70's was to find ways to increase productivity and reduce the cost of manufacturing products. Since the early 80's, the major industries have looked at such technologies as numerical control (NC) systems, computer aided design (CAD), computer aided manufacturing (CAM), computer numerical control (CNC), and computer integrated manufacturing (CIM). Computer integrated manufacturing utilizes CAD, CAM, CNC and robots to create work cells that perform a series of operations from the design of the part to its complete creation without the use of human labor. The tasks of selecting a piece of raw material, placing the material in a machine, selecting a machine tool, removing the partially completed part, placing the

part in another machine, and eventually placing the finished part in a storage bin are performed by one or more robots. Robots are also well suited for doing heavy, dangerous and repetitive tasks.

The first industrial robot, created by a company called Unimat, was purchased by Ford Motor Company in 1961. An inventor by the name of George C. Devol conceived the idea and with the help of Joe Engelberger, a manufacturing executive, the robot became a reality. Since the robot replaced human workers, organized labor resisted the move by major companies to incorporate these devices on the assembly lines. In addition, the cost of early produced robots was in the hundreds of thousand of dollars so only the largest manufacturing concerns could justify their use. Decreasing productivity and increasing labor costs eventually forced companies to use robots. With the demand for robots increasing, more companies began to build newer and better robots and the cost of robots dropped rapidly.

The number one user of robots in the U.S. is the automotive industry followed by electric machinery, electronic components, plastic molding products, sheet metal, iron and steel products. Welding, loading, unloading, machining, moving and painting are the principal tasks of existing robots with gluing, cleaning, checking, inspecting, and packaging as the newer jobs facing robots. In the near future, the fast food industry is hoping to use robots to prepare, cook and serve food items as well as dispense beverages automatically in response to customer selections. Robots are useful in industry for a variety of reasons. Installing robots is often a way business owners can be more competitive, because robots can do some things more efficiently than people.

1. Robots never get sick or need to rest, so they can work 24 hours a day, 7 days a week.
2. When the task required would be dangerous for a person, they can be do the work instead.
3. Robots don't get bored, so work that is repetitive and unrewarding is no problem for a robot.

### 8.10.1 Definition of an Industrial Robot

“A robot is a reprogrammable, multifunctional machine designed to manipulate materials, parts, tools, or specialized devices, through variable programmed motions for the performance of a variety of tasks.”

Or

“An **industrial robot** is officially defined by as an *automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes.*”

### 8.10.2 Basic Components of a Robotic System

The basic components of a robot are,

1. **Structure:** The mechanical structure (links, base, etc.). This requires a great deal of mass to provide enough structural rigidity to ensure minimum accuracy under varied payloads.
2. **Actuators:** The motors, cylinders, etc. that drive the robot joints. This might also include mechanisms for a transmission, locking, etc.
3. **Control Computer:** This computer interfaces with the user, and in turn controls the robot joints.

4. **End of Arm Tooling (EOAT):** The tooling is provided by the user, and is designed for specific tasks.
5. **Teach pendant:** One popular method for programming the robot. This is a small hand held device that can direct motion of the robot, record points in motion sequences, and begin replay of sequences. More advanced pendants include more functionality.

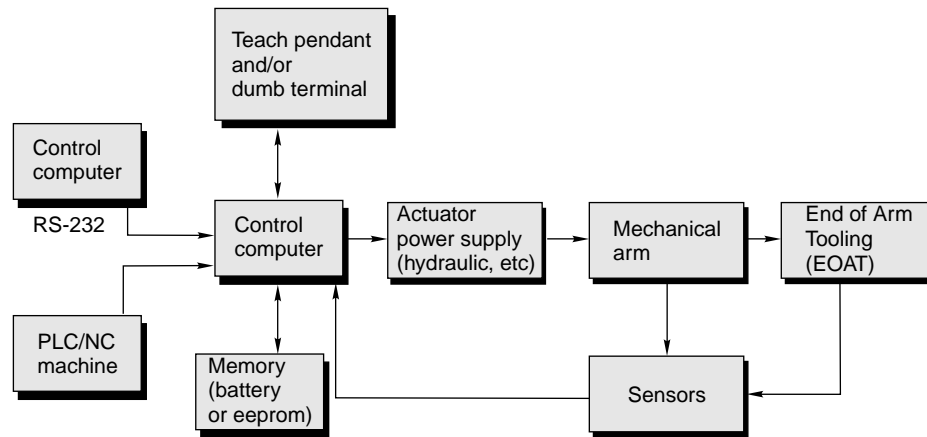


Fig. 8.22 Basic Robotic system

### 8.10.3 Types of Robots

Robots come in a wide variety of shapes, and configurations. The major classes of robots include,

- *Arms* fixed in place, but can reach and manipulate parts and tools
- *Mobile* these robots are free to move

### 8.10.4 ROBOTIC ARMS

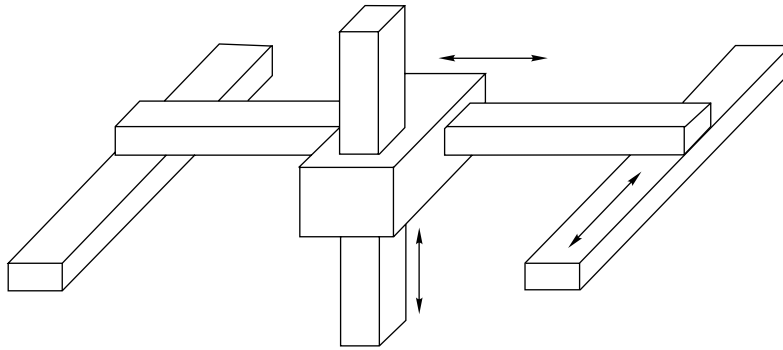
Typical joint types are,

1. *Revolute* rotary joints often driven by electric motors and chain/belt/gear transmissions or by hydraulic cylinders and levers.
2. *Prismatic* slider joints in which the link is supported on a linear slider bearing, and linearly actuated by ball screws and motors or cylinders.

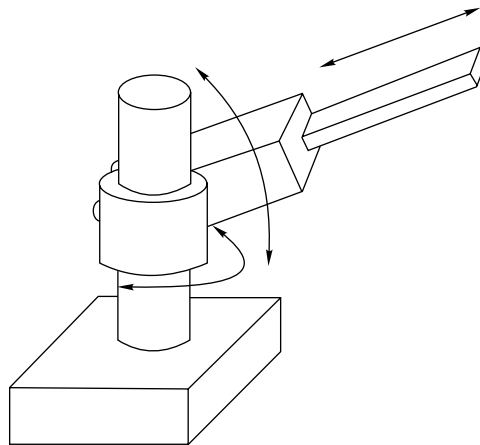
### 8.10.5 Basic Configurations Are

1. *Cartesian/Rectilinear/Gantry:* Positioning is done in the workspace with prismatic joints. This configuration is well used when a large workspace must be covered or when consistent accuracy is expected from the robot.
2. *Cylindrical:* The robot has a revolute motion about a base, a prismatic joint for height and a prismatic joint for radius. This robot is well suited to round workspaces.

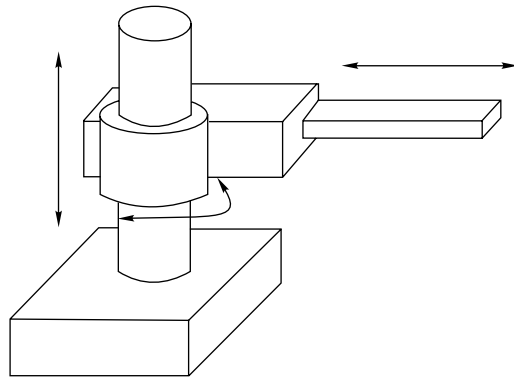
3. **Spherical:** Two revolute joints and one prismatic joint allow the robot to point in many directions, and then reach out some radial distance.
4. **Articulated/Jointed Spherical/Revolute:** The robot uses 3 revolute joints to position the robot. Generally the work volume is spherical. This robot most resembles the human arm, with a waist, shoulder, elbow, and wrist.
5. **SCARA (Selective Compliance Arm for Robotic Assembly):** This robot conforms to cylindrical coordinates, but the radius and rotation is obtained by a two planar links with revolute joints.



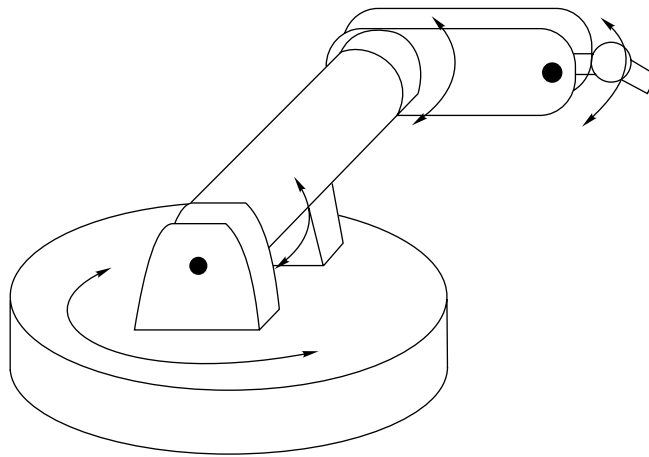
**Fig. 8.23** Cartesian/Rectilinear/Gantry



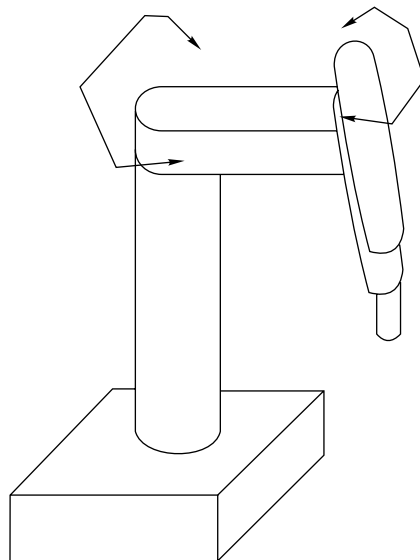
**Fig. 8.24** Spherical



**Fig. 8.25** Cylindrical



**Fig. 8.26** Articulated/Revolute/Jointed spherical



**Fig. 8.27** Scara

### 8.10.6 Applications of Industrial Robots

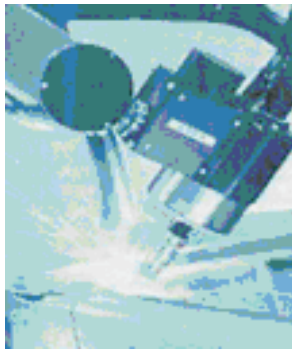
Robots are used in a wide range of industrial applications. The earliest applications were in materials handling, spot welding, and spray painting. Robots were initially applied to jobs that were hot, heavy, and hazardous such as die-casting, forging, and spot welding.

- Welding Applications
- Spray Painting Applications
- Assembly Operations
- Palletizing and Material Handling
- Dispensing Operations
- Laboratory Applications
- Water Jet Cutting
- Work Cell

#### 8.10.6.1 Welding

Perhaps the most popular applications of robots are in industrial welding. The repeatability, uniformity quality, and speed of robotic welding are unmatched. The two basic types of welding are spot welding and arc welding, although laser welding is done. Some environmental requirements should be considered for a successful operation.

The automotive industry is a major user of robotic spot welders. In 1985 Chrysler Motor Corporation's plants had a robot population of 900, 670 of which were used for spot welding.



**Fig. 8.28** Robot performing welding



**Fig.8.29** Robot performing spot welding

The total number was about 2,350 in 1990. The other major welding task performed by robots is arc or seam welding. In this application two adjacent parts are joined together by fusing them, thereby creating a seam.

#### 8.10.6.2 Spray Painting Applications

Another popular and efficient use for robots is in the field of spray painting. The consistency and repeat-ability of a robot's motion have enabled near perfect quality while at the same time wasting no paint.

The spray painting applications seems to epitomize the proper applications of robotics, relieving the human operator from a hazardous, albeit skillful job, while at the same time increasing work quality, uniformity, and cutting costs.



**Fig. 8.30** Robot performing spray painting

#### **8.10.6.3 Assembly Operations**

Robots lend themselves well to the tedious and repetitive nature of assembly tasks provided that the proper planning and design have been done. In addition, their high level of repeatability has allowed the development of some new technologies in electronic assembly.



**Fig. 8.31** Robot performing assembly operation

#### **8.10.6.4 Palletizing and Material Handling**

Palletizing is the act of loading or unloading material onto pallets. The newspaper industry has been particularly hard hit by increased labor costs. Part of the solution to this problem was to use robots like Cincinnati Milacron Robot being used to palletize advertising inserts for a newspaper.

Many companies in the United States and Canada have been forced to close in such areas as die casting and injection molding because they could not compete



**Fig. 8.32** Cincinnati Milacron Robot

with foreign firms. The introduction of robotics into this process has allowed the same companies to remain viable.



**Fig. 8.33** Robot performing material handling



**Fig. 8.34** Robot used in semiconductor industry

In semiconductor industry's IC chip manufacturing facilities, various processes take place within a clean room. This requires that personnel as well as robots not introduce dirt, dust, or oil into the area. Since robots do not breathe, sneeze, or have dandruff, they are especially suited to the clean room environment demanded by the semiconductor industry.



**Fig. 8.35** Industrial robots doing vehicle underbody assembly (courtesy: KUKA).

# 9

## Cutting Tools and Tool Management

### 9.1 INTRODUCTION

Some of the cumbersome and difficult issues to deal with relative to FMS are managing, co-ordination and controlling the wide variety of cutting tools. This includes not only having and maintaining the required number of cutting tools to process the required parts through the FMS but also managing and coordinating other elements such as

- Replacement of tools.
- Tool Assembly Component requirements.
- Tool storage.
- Reconditioning and present considerations.
- Tool life monitoring.
- Broken tool detection and other factors.

*Getting Control of cutting tools:*

Controlling the cutting tools involves good tooling policies, cost-effective part programming strategies on the machine, and sound tool-related practices in tool rooms, manufacturing and other off-line operations.

The following items should be considered as cost-effective, optimizing tactics to begin to augment and enhance the full impact of FMS productivity effectiveness.

- Review cutting tool and indexable insert inventory and get control of usage.
- Review cutting tool purchasing practices.
- Reduce dependency on specialized, nonstandard tooling.
- As perishable tools are checked out from in-house tool-stores, they ultimately find their way into operators tool cabinets carried to extremes. Such out of control activities can resort to unnecessary and costly extra perishable tool purchases.

- Guidelines for tool assembly preparation and reconditioning must be established and reinforced.
- Programming personnel must also work to impose guidelines and restrictions relative to tool proliferation.

## 9.2 TOOL MANAGEMENT

Regardless of how “flexible” a flexible manufacturing system is, the system is still only capable of processing a finite number of parts. The overall flexibility or “randomness” of an FMS is typically constrained by two support resources

- Palletized fixtures that control the rate of workflow coming into and going out of the system.
- Tool storage capacity.

The main problems caused by tool capacity constraints and a lack of tool management are:

1. Insufficient redundant tool backup at the machine during tool breakage and tool wear conditions.
2. Insufficient use of present tools and excess tool inventory.
3. Conflicting priorities with other areas outside the FMS over tool availability and reconditioning.
4. A limited number of workpieces being available to process due to insufficient tool, matrix capacity.
5. Under-utilized machines and low production rates caused by too many tools and extensive tool changing.

Generally, tool management is getting the right tool to the right place at the right time. Having an acceptable tool management system to fulfill the tooling requirements of an FMS means adequately addressing the following four areas:

### 9.2.1 Tool Room Service

Providing adequate tool room service does not directly affect the machine tools that make up an FMS, but is essential to system effectiveness.

Tool room service is a necessary support function dealing principally with preparing, servicing, organizing and controlling the vast array of perishable tools, inserts, tool holders and tool components.

The principal elements of tool room service are:

- Buildup and teardown of tool assemblies.
- Inventors of tools, tool components and related tool assembly instructions
- Control of idle (returning and least used) tool assemblies along with
- Determining tool disposition (what to do with these tools).
- Actively maintaining machine tool data for the remaining tool life of returning and idled tool assemblies.

### 9.2.2 Tool Delivery

Tool delivery addresses the tool management function relative to moving the tools between the tool room and the various tool magazines of each machine tool in the FMS. This includes transporting the tools to and from the machine tool requiring those tools, and loading and unloading the tool magazines once the tool arrive at the machines. If the demand for tools based on the variety of part mix is high enough, complete automation of the tool delivery and distribution function may be necessary.

### 9.2.3 Tool Allocation and Data Flow

Tool allocation and data flow are two of the most difficult aspects of tool management to manage and control.

Tool allocation is essentially assigning and controlling the total number of tools required for each machine to process the previously defined FMS part spectrum. It is based on specific part process plans, machine programs and machining methodology along with the varying part mix and volumes that could be running through the system at any given time.

Controlling the tool data flow relative to the allocated tools requires that the MCU (Machine control unit) would assume tool data transfer from the present area as tools are automatically gauged, identified and entered into the FMS tool system data base.

### 9.2.4 Fault Sensing

Fault sensing is monitoring and detecting cutting tool problems at each machine. This involves electromechanical and optical sensing and detection of worn and broken tools along with absence of tools or misplacements. Each tool is offset to a contact and non-contact sensor. Each time it is used in order to validate tool presence, correctness and condition. Replacements should be available for the broken tools.

## 9.3 TOOL STRATEGIES

Various tool strategies exist within the framework of tool management that requires examination. Each has its advantages and disadvantages as well as particular application for an FMS.

The tool strategies employed in FMS are:

- Mass Exchange
- Tool sharing
- Tool migration
- Assigned tools

### 9.3.1 Mass Exchange

The mass exchange strategy is removing all the tools in each machine tool matrix at the completion of specific production requirements and replacing them with the new part required for tooling.

Mass exchange permits tool exchange control to be minimized at the expense of an increase in tool inventory. The mass exchange strategy is logical and attractive for FMS applications only where high volume and low part variety workpiece exists.

### 9.3.2 Tool Sharing

The tool-sharing concept permits the logical sharing of tools within the framework of affixed production period and workpiece requirements. Common tooling among the fixed production requirements is recognized, identified and shared among the various parts to be manufactured in the fixed production period. After fulfilling part requirements within the fixed production period, a new set of tools for the next production is loaded and common tooling is again identified. The tool strategy requires computer software to implement due to merging of tool lists and matching requirements to identify the common tooling.

### 9.3.3 Tool Migration

The tool migration strategy is basically an extension of the mass exchange and tool sharing theory. Both consider the workpiece to be manufactured within the fixed production period and tool matrix capacity available to support it.

As parts are completed, many tools used to manufacture those parts become available for removal from the tool matrix. Removing the tools frees tool points in the tool matrix and permits other tools needed for new arriving parts to be loaded.

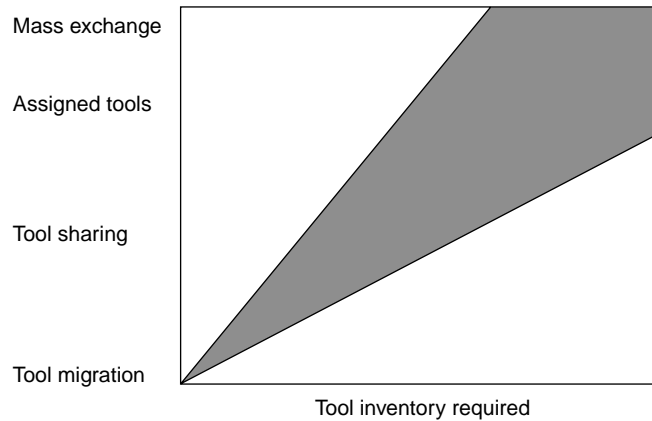
Tool migration exchanges must be done in an effort to minimize spindle interruption is of primary importance.

Consequently, tools completing their manufacture service are removed from the matrix at the tool matrix, while needed new tools are inserted in available tool pockets. Tool delivery is accomplished through various means such as AGV.

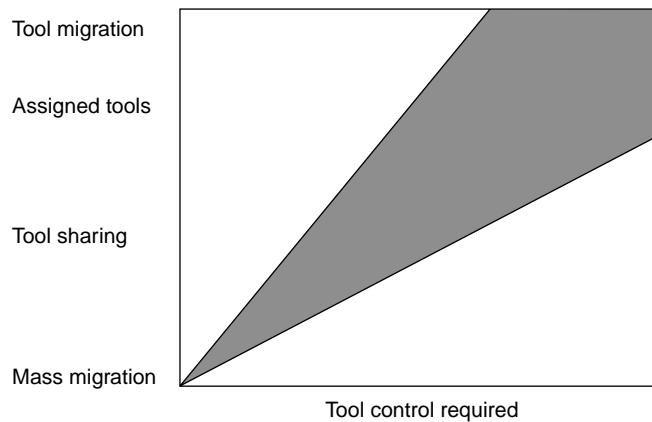
The Strategy requires sophisticated computer software and decision logic in order to determine the removal of tools, adding of this tool.

### 9.3.4 ASSIGNED TOOLS

The above 3 strategies previously discussed assumed that a given set of workpiece be machined at a specific machine tool. The reality of manufacturing operation forces consideration of production schedule changes, machine breakdowns, tooling and material unavailability, flexibility among processing equipment becomes high priority. Thus, the assigned tool strategy can address the need for increased flexibility among a set or group machine tools. This strategy identifies the most used tools for the production requirements and part mix and assigns permanent residence to those tools in each machine tool matrix for the full production run.



**Fig. 9.1** Graph indicating the relationship between tool inventory and the various tool management strategies



**Fig. 9.2** Graph indicating the level of control required relative to tool management strategies

#### 9.4 TOOL PRESET, IDENTIFICATION AND DATA TRANSFER

Tool presetting can easily be performed with simple height gauges and micrometers. However, time consuming and most importantly open to human error as touch sensitivity is highly subjective. Therefore, many presetting machines are based on touch-readout tool gauges and optical projection systems that magnify the tool point.

Sophisticated identification systems are available and are being used in FMS and other factory automation applications but have much broader and long-range potential. Automated identification systems are important because they are reliable, save time and reduce human error. The most common of these identification systems are:

### 9.4.1 Bar Code Scanning

Bar coding is the most popular form of automatic identification as evidenced by supermarket check-out lanes and with machine (FMS), bar codes are imprinted on paper or Mylar and fastened to the tool holder with adhesive and engraved in the tool. The control unit remembers the pocket where each unique coded tool was placed. Bar codes are made up of binary digits arranged so that the bars and spaces in different configurations represent numbers, letters and other symbols. Scanners that read bar codes contain a source of intense light produced by a laser or light emitting diode and aimed at the pattern of black bars and spaces of varying widths. The black bars absorb the light and the spaces reflect it back into the scanner. The scanner then transforms the patterns of light and dark into electrical impulses that are measured by a decoder and translated into binary digits for transmission to the computer. Bar codes are made up of binary digits arranged so that the bar and spaces in different configurations represent number.

### 9.4.2 Machine Vision

Machine vision is an imaging process involved with scanning and interpreting objects, documents and labels. Although the imaging process itself is more complex than that of bar code scanning, the technology has potential for a large number of applications, many of which are FMS related. Application would include character reading, sorting by shape of markings and locating defective parts or pallets.

### 9.4.3 Radio Frequency Identification

This form of automatic identification employs bi-directional radio signals as encoding medium and is widely used to provide hands free access control. Radio frequency identification offers solution to application problems in industrial automation and material handling where there is no line of direct sight between the scanner and the identification plate or tag.

### 9.4.4 Optical Character Recognition

Optical character recognition utilizes human readable letters and numerals rather than the lines and bars of bar coding, which are scanned with a light source. When the scanner recognizes a particular pattern, the data are converted to electronic impulses for transmission to the computer.

### 9.4.5 The Microchip

Microchip identification employs the use of a microchip embedded in a sealed capsule that can be inserted in the tool holder. This system uses a non-contact read-only head that can be attached to tool changers, presetting fixtures or tool grippers. Reading can occur at a distance of up to 0.080 inch and the read time is less than 50 milli-seconds. With an allowable 0.120 inch misalignment. The microchip can also be programmed offline with the tool identification and other dimensional data.

## 9.5 DATA TRANSFER

Once cutting tools have been assembled, gauged and identified the associated tool dimensional data must now be transferred to the host computer for application use. The tool-preset operator assigns an identification number to the entire physical collection of tools. This identification associates the physical collection of cutting tools with the data that are collected on each of the tools. If an electronic tool gauge is being used, the gauged values of tool length and diameter are automatically read from the gauge and transferred and stored in a tool collection file on the FMS computer.

## 9.6 TOOL MONITORING AND FAULT DETECTION

Cutting tools can be monitored in stand-alone machine cell and FMS application for tool life. Tool life refers to the time during which a cutting tool produces acceptable parts in a machining operation. A cutting tool is considered to have reached the extent of its useful life when any of the following occur.

- Losses of dimensional part accuracy due to cutter wear or deflection.
- Loss of required surface finish due to tool wear, material buildup or chatter.
- Tool breakage or chipping due to excessive wear.
- Excessive torque from increased feeds and speeds heavy stock removal application.

Tool monitoring therefore becomes a comparison of how much useful life should exist on a given tool measured against the actual cutting time of the tool.

When the actual cutting tool time as tracked by the host computer in FMS application expires, the FMS can be set up to perform one of the following actions:

- Select a duplicate and redundant tool, continue operation and notify the FMS computer.
- If no duplicate tool has been provided stop the machine in a “feed hold” condition and notify the FMS computer.
- Flush the part requiring that specific tool from the active machine queue and go on to another part (if different).

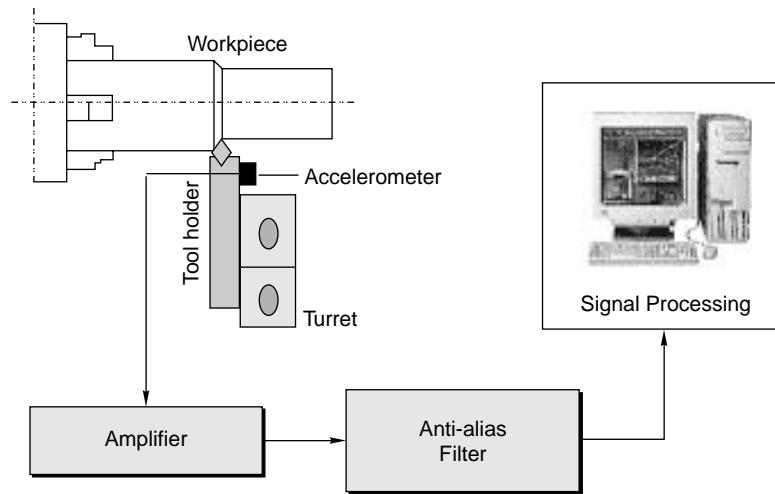
Tool monitoring measures normal tool wear against a predetermined standard stored on the FMS host computer and excludes recognition and detection of major tool failures or breakage. An important first step of tool monitoring is to build an accurate and reliable tool database because of the vast differences in user’s interpretations of tool life. The gathering and compiling of machinability information for a tool life data-box should be the responsibility of each user.

In a random user FMS, it is possible to run parts consisting of different material types. Care should be exercised when setting up the tool life data-box to categorize tools by part material type. Tool life monitoring places heavy emphasis on copies of redundant tools, related components and holders must be available to provide for a constantly changing mix of parts to machine.

## 9.7 EXPERIMENTAL SETUP AND DATA COLLECTION

Cutting tests were performed on a 30hp CNC lathe. An accelerometer was mounted on the cutting tool holder attached to the turret, as shown in Fig. 9.3 to measure vibration in the feed direction.

This is because preliminary results have shown the vibration signal in the feed direction to be more sensitive than those in the cutting and radial directions in detecting tool wear. The vibration signals were first amplified using a charge amplifier and low-pass filter with cut-off frequency of 6 kHz, and then sampled at 100 kHz using a 12-bit data acquisition card. Every data set was 0.1s in length, equivalent to 50k data points. Cutting started with a sharp insert and was stopped after every minute for tool wear measurement using a toolmaker's microscope. When the cutting edge develops an average flank wear height of at least 0.3mm or the maximum wear height of 0.6mm, it is considered to be a worn out edge.



**Fig. 9.3** Accelerometer was mounted on the cutting tool holder attached to the turret to measure vibration in the feed direction

### 9.7.1 The Need

Why is it important to know when to change out a tool on an automatic machine? There are many reasons for this. By monitoring tools, you can get more parts per tool. Tool costs are lowered because you are using the tool properly and sharpening it only when needed. This will also reduce machine downtime, labor to change out the tools and grinding costs.

Rather than changing out tools randomly and disrupting production, it is done only when it is needed by using the tool monitoring system's forecasting ability. In addition, tool inventory can be reduced. Instead of having many duplicate tools, because you never know when the tool needs changing or will fail, you can develop your inventory around set parameters that a monitoring system offers.

You can also get faster new part process development. If you have a history of tooling from a monitoring system, then when identical or near identical parts are processed, it's easy to see which tooling should be used on the new part for maximum productivity.

With tool monitoring, labor can be reduced, because fewer tool inspections and changes will be needed. Also, because the tools are being monitored second by second, highly skilled operators can be better used for machine setup and planning jobs. Lower skilled operators can watch the machines,

because the tool monitor alerts them to tool changes, and they don't have to guess when a change is needed.

Scrap can be significantly reduced because dull tools that produce scrap have been taken out of service before they can cause problems. Catastrophic failures will be reduced or eliminated with appropriate tool changes.

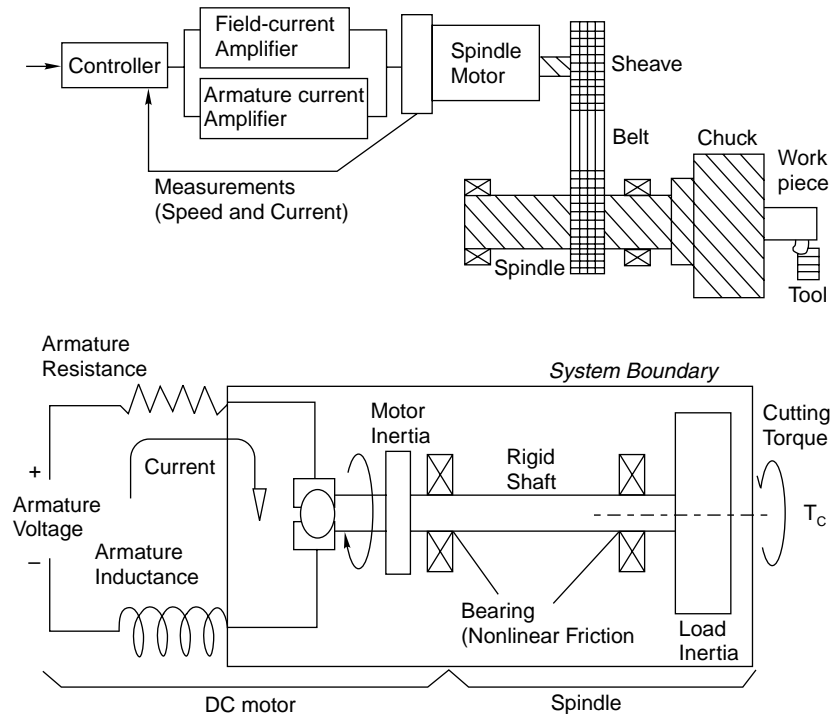
If a vendor wants you to try out new tooling, you can monitor that tool and compare it to the old one. In doing so, you'll have a concrete comparison to see if the new tool is cost effective.

Also, when a shift change occurs, the second shift would not have to communicate with the first shift to find out what tools need to be changed. A tool monitoring system would provide the information.

With control over tooling costs and labor usage, a company can have higher overall efficiency along with improved part quality. Accurate cost estimating both for the part and tooling can also be achieved by using historical reports. This all boils down to increased profit for a company and greater overall cost control.

### 9.7.2 Monitoring Model Derivation

A monitoring model for the spindle drive is derived to represent the dynamic relation between the cutting force signal and other easily measurable quantities. A system boundary chosen for modeling the spindle drive involves part of the DC motor and the spindle as shown in Fig. 9.4. There are several reasons for this choice:



**Fig. 9.4** A system boundary chosen for modeling the spindle drive involving part of the DC motor and the spindle

The spindle motor speed, armature current and cutting force are the only variables/inputs of the system. The armature current and motor speed can be easily measured. That leaves only one unknown, the cutting force that can be estimated from the model and the measurements.

Measurement of the high frequency voltage signal from an SCR amplifier can be avoided. The motor current is easier to measure than the armature voltage because the inductance and resistance of the armature windings filter much of the high frequency noise.

The parameters of the armature windings are excluded from the system. This means that the motor resistance, which changes with temperature, does not have to be considered.

An Eigen value analysis of the linear model in Fig. 9.2 shows that the belt compliance is not necessary for the model given the 20 Hz bandwidth requirement ~assumed for this monitor. Thus a first order model is obtained, which includes the dynamic effects induced by the system inertia and the effects of the energy losses in the system due to the bearing friction.

$$J_s \cdot \frac{d\omega_s}{dt} = K_{as} \cdot I_s - B_s \cdot \omega_s - T_{ts} \quad \dots (9.1)$$

Where,

$\omega_s$  = angular speed of the spindle motor,

$J_s$  = equivalent inertia seen by the motor,

$B_s$  = equivalent viscous damping coefficient seen by the motor,

$T_{ts}$  = total external torque applied to the spindle motor,

$I_s$  = armature current of the spindle drive,

$K_{as}$  = motor constant of the spindle motor.

A subscript “s” means the entire spindle drive.  $T_{ts}$  is not just the cutting torque applied to workpiece. Instead,  $T_{ts}$  is the total torque seen by the motor due to Coulomb friction and the cutting torque, and is given by

$$T_{ts} = T_{fs} + \delta T_{bs} + T_c \quad \dots (9.2)$$

Where

$T_{fs}$  = coulombic friction torque ( $5T_{fs} \ 1dT_{fs}$ ),

$T_{fs}$  = coulombic friction torque at idle states,

$dT_{fs}$  = additional Coulombic friction torque increase due to cutting load,

$dT_{bs}$  = additional viscous friction torque increase due to cutting load,

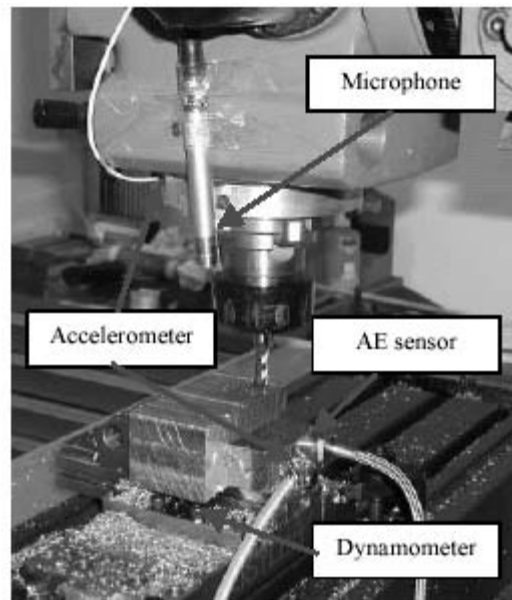
$T_c$  = normal cutting torque due to normal cutting force on the workpiece.

Stein and Shin showed that the actual spindle drive is a nonlinear system because  $dT_{fs}$  and  $dT_{bs}$  are nonlinear functions of  $T_c$  and  $\omega_s$  the spindle angular speed!. To calculate the normal cutting force from the estimated total external torque applied to the spindle motor, detailed information about the components of  $T_{ts}$  is necessary. This can be done through off-line tests. The parameters that do not change during cutting operations can be determined by off-line tests. Those parameters

are: Coulomb friction without cutting ( $T_{fs}$ ); total equivalent inertia of the spindle system as seen by the spindle motor ( $J_s$ ); and parameters for the nonlinear friction model. Only one parameter needs to be determined on-line ~during cutting!—the damping coefficient  $B_s$ . This parameter is dependent on temperature and operating conditions.

### 9.7.3 Monitoring by Sensors

Sensors are the key components in the accurate measurement of strategic quantities in the machining process. The quantities that can be monitored include power consumption, torque, force, vibration, acoustic emission, tool wear, tool temperature, etc. The eTCM employs multiple sensors to monitor the machining process condition. The monitoring sensors include accelerometer, dynamometer, microphone, and acoustic emission (AE) sensor. Integration or fusion of data from multiple sensors improves the detection accuracy and provides several advantages over data from a single sensor in tool condition monitoring.



**Fig. 9.5** Experimental setup of milling process monitoring using multiple sensors

Figure 9.5 shows the experimental setup of milling process monitoring using multiple sensors. A Kistler quartz 3-component platform dynamometer was mounted between the workpiece and machining table to measure the cutting forces. Two Kistler piezo-accelerometers were used to measure the machine tool vibrations in cutting, one accelerometer was mounted to the spindle quill and the other one was applied to the work-piece fixture. A B&K type 2671 microphone was used for precision sound level measurement. An AE sensor was mounted on the fixture. The outputs of these sensors were conditioned through corresponding signal conditioning accessories such as charge amplifiers or couplers, and then were passed to the data acquisition module.

# 10

## System Hardware and General Functionality

### 10.1 INTRODUCTION

FMS computer hardware is the visible computing element in a system installation. It includes the central FMS computer, its related peripheral equipment, programmable controllers, and a backup computer, in some cases, for traffic and/or material management.

The computer can do nothing, however, without the required application software, people, and the necessary communication links to the various workstations. The computer requires proven application software, competent and trained personnel, and backup resources in order for the entire system to perform at acceptable levels.

The FMS computer is a tool and functional component like any other element in a flexible manufacturing system. Although it is simply a means by which the FMS application software and initiates system activity, it is, in essence, the heart of an FMS.

General functions and manufacturing usage:

- Sales records and forecast data.
- Accounting, payroll, and cost control information.
- Design engineering data consisting of drafting, analysis, revision history and bills of materials.
- Shop floor control.
- Tool inventory and design information.
- Work-in-process inventory and scheduling control.
- Capacity planning or process planning.
- Shipping and receiving data.
- Quality control information.

These data groups, although listed as independent pieces of information and designed for convenience of the user, must be able to interface through one from or another and exchange files and records.

The information resides in one central computer and in one database. This is the centralized-decentralized argument of computers and computer control. Each has its advantages and disadvantages.

As installation size and complexity increases, reliability and responsiveness decreases. In the case of major computer failure, if the entire system breaks down, all plant communication would be lost. However, having large central computers provides more consolidated control of computer charges and expenses, while reducing duplication of new application programming effort within the overall organization.

Decentralized computers (those handling pockets of applications within an organization) gives users more control of their own destiny for improved responsiveness and may be connected to other computers or to a central mainframe for data distribution. Centralized control of expenses and computation charges is difficult to obtain due to local or departmental control of the decentralized computers.

**Table 10.1** Principal differences in centralized versus a decentralized computer environment

<i>Centralized</i>	<i>Decentralized</i>
1. High hardware cost	1. Lower hardware cost
2. High software cost	2. Lower software cost
3. High in-plant wiring and connection costs	3. Lower in-plant wiring and connection costs
4. Software complex, time consuming and difficult to change and maintain	4. Software application specific designed for local use, easy to write, modify and maintain.
5. Easy to trace overall operating costs and control expenses	5. Harder to track overall operating costs and control expenses
6. Low computer transaction response time, priorities assigned and controlled by corporate data processing	6. Fast computer response time user controls own application environment and assigns own priorities
7. Expandability difficult and hard to justify cost	7. Expandability easy, less expensive and less difficult to justify
8. All plant communications shut down with computer failure	8. Only isolated location shut down with computer failure
9. Expensive backup resources required	9. Less expensive backup resources required, spare computer can be available as standby
10. Application program changes is time consuming to implement, central data processing must evaluate, prioritize, analyze, and determine system impact	10. Application changes easy to make and in control of local users

## 10.2 PROGRAMMABLE LOGIC CONTROLLERS

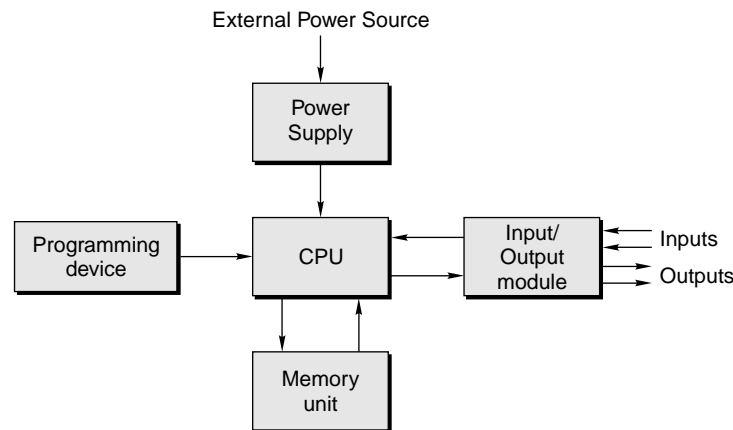
Programmable computers often referred to, as PLC's or PCs are electronic devices or small computers that are used to control machinery, actuated devices, and assist in the control of advanced automation

systems. PLC's are the technological replacements for electrical relay systems that are rapidly replacing the hardware circuits that have controlled the process machines and driven equipment of industry in the past.

The functions of a PLC are to examine the status of an input or set of inputs and based on this status, acute or regulate an output device or devices. Input to a PLC may be either discrete or continuous. Discrete PLC inputs typically come from photocells, proximity and limits, push buttons, micro switches and pressure switches. Continuous PLC inputs come from voltmeters, potentiometers, solenoid valves, and motor starters, and in the case of FMS to initiating some activity at the various workstations.

A PLC is composed of four primary elements:

- Central processing Unit (CPU)
- Power supply
- Memory
- Input and Output (I/O) signal-handling equipment



**Fig. 10.1** Components of a PLC

Generally, the CPU is a microprocessor and supplies the brainpower for the PLC. Most PLCs now being offered are microprocessor based and have more logic and control capabilities than the earlier electronic logic circuit models. The CPU scans the status of the various input devices continuously, applies the input signals to the memory control logic, and produces the required output responses needed to activate and control the equipment or workstation entry-exit points.

PLCs are generally grouped by size, based on the number of I/O handling capabilities, functional attributes, and memory capacity. Micro and mini PLCs are usually modern replacements for relay systems. Larger units may have the functional capabilities of a small computer and be able to handle computational functions, generate and output reports, and provide high-level communications capabilities.

Instructions are input to a PLC in the form of programs, just as for other computers. Four major programming languages are generally used with PLCs. These include ladder diagrams, Boolean mnemonics, functional blocks and English statements. Some PLC systems even support high-level programming languages such as BASIC and Pascal.

The PLCs function in an FMS is to receive signals to monitor and activate the I/O queues of each workload station. This includes each of the individual workstations for part processing, inspection, cleaning and others. Additionally, PLCs are used to control loading/unloading and fixture build stations, queuing stations and carousels, automatic storage and retrieval systems (ASRS), and control coolant-chip reclamation systems. Signals are passed back and forth between each of the PLCs in the FMS and the host computer in order to activate and verify pallet shipment, movement, registration, and receipts and to initiate activity of other FMS system functions.

### 10.3 CELL CONTROLLERS

Cell controllers are devices responsible for the coordination of multiple workstations, machines, or operations that offer information and communications processing and coordination capability; they combine the capabilities of PLCs and mini computers.

Cell controllers are generally factory hardened to exist on the shop floor but are not used to directly control shop equipment. Cell controllers are generally used to control PLCs or PCs, which in turn control a manufacturing cell or a series of machine tools. Cell controllers provide computerized supervision and coordination of multiple controllers along with data collection and concentration for the factory floor. Cell controllers also provide a distributed database and communication capabilities to higher-level computers, such as the factory host or the inventory control system computer.

Cell controllers are generally used for small-scale FMS or cellular systems where the full range of system decision-making capabilities is not required to support diverse part mix and lot size requirements. This would include mid- to higher-volume applications with some part type and mix variety but high cell coordination and data management requirements.

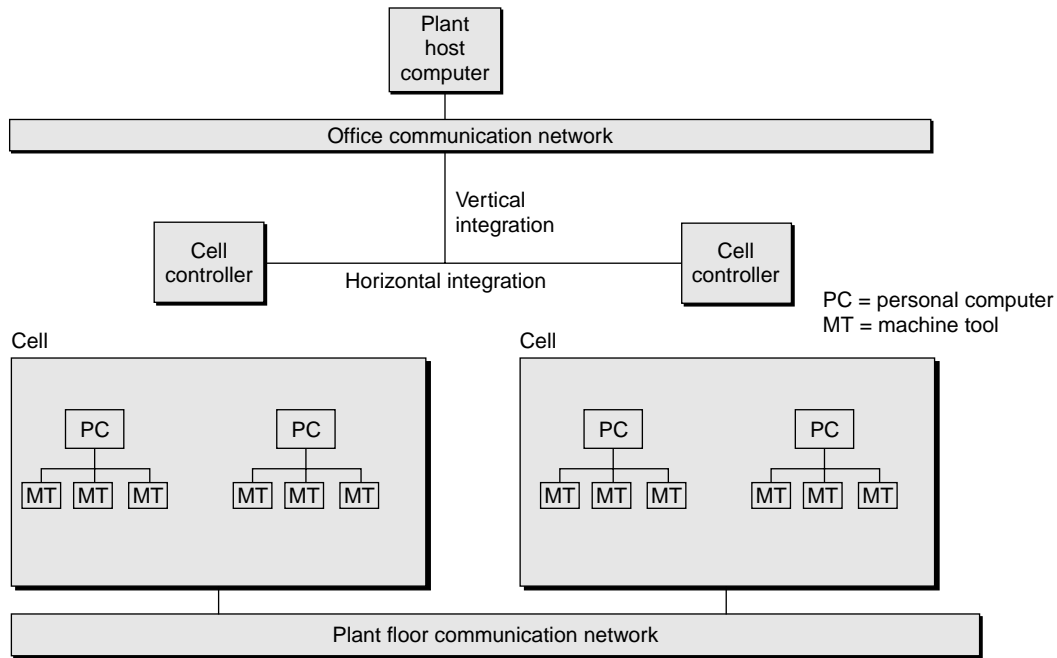
The primary difference between cell controllers and PLCs is the computer language and knowledge required to program and maintain them. Little computer knowledge is necessary to program PLCs. Cell controllers, on the other hand, require some degree of computer knowledge, along with more operator knowledge and training to use than programmable controllers.

Electronic repair personnel, if easily replaced, may stock repair parts for PLCs, in cases or they may be obtained from distributors. Cell controller maintenance or repair generally requires skilled in-house engineering skills or the original equipment manufacturer's (OEM) field service technicians. How quickly a manufacturer can react to cell or system trouble is an important consideration when selecting a cell controller vendor.

Communications between various cells, other plant computers, and the factory floor can be either horizontally or vertically integrated. Communication between the islands of automation or manufacturing cells is horizontal integration and should be considered as primary building block of CIM. This level of integration may be sufficient if automation is the only goal. This level of communication establishes the foundation for vertical communications.

Vertical communications are integrated upward and downward between the plant host computer and office level and the cell and plant floor level. However, it is important to note that, without horizontal communication integration, vertical integration cannot be fully achieved in a CIM network.

Many cell controller applications do not require the functionality or the price of larger systems. Smaller-scale cell controllers, for example, can be used to automate towards CIM in a logical step by step or phased in approach. Such an approach can hold down the price of distributed cell controller architecture, thereby lowering the overall implementation cost of CIM.



**Fig. 10.2** Cell controller architecture illustrating vertical and horizontal integration

## 10.4 COMMUNICATION NETWORKS

Communication Networks are the information highways of an automated manufacturing system. Selection either of the network or computer, in many cases, may determine the other. Some networks are closer to being standardized and supported by computer vendors than others.

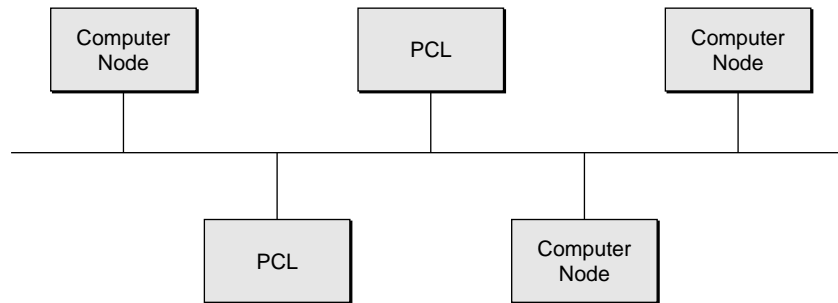
Networks are generally localized based on the elements that need to be linked together in a given area. Consequently, the acronym LAN (Local Area Network) is used in many cases to designate the network or data transfer line. Local Area Networks (LANs) fit Local Area Networks may be limited to a room, a building, an automated system, or a series of closely connected systems or buildings.

Network topology is the road map of the entire network. Although the word topology is basically a misuse of the word topography, it is the geometric layout of the data links and the computers that require linkage. Network topology can have many forms, but the two most common are point-to-point and multidrop.

Point-to-point topology is a circuit connecting two points or computer nodes without passing through an intermediate point. The primary use is for very simple or sub networks. A multidrop network is a single line that is shared by two or more computer nodes. Multidrop networks reduce overall line costs, but increase in the complexity of data transfer in the network, as well as the cost of the line connection. The method of data control and priorities in either a point-to-point or multidrop application is the control topology.



**Fig. 10.3** Point-to-point circuit connecting two points without passing through intermediate point



**Fig. 10.4** A multidrop network shares a line with two or more points

## 10.5 Networks

Networks are generally classified in three types:

1. Star or Radial
2. Ring or Loop
3. Bus

### 10.5.1 Star or Radial

Control of a star or radial network remains at the node where two points are joined. The connecting point would be called the slave. This is a simple master-slave relationship. This type of network controlled by the net master in a master-slave relationship is shown in the Fig. 10.5.

### 10.5.2 Ring or Loop

Ring or Loop networks may be classified in two types depending on control type. Centralizing control in one node of the network creates what is generally referred to as a loop network. Sub nodes in a network can only communicate with other sub nodes when permitted by the controlling master node.

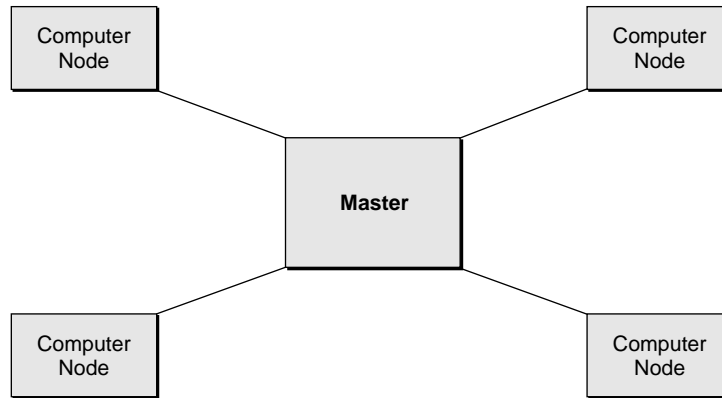
Ring networks are distributed control. In this case, each node can communicate with every other node without direction from a controlling master node. This method is more complex more than loop arrangements, but in either case (Ring or Loop) data may be passed from node to node round the ring. Each node must have an active repeater to transmit the data to the next node. Ring or loop network is shown in the Fig. 10.6.

### 10.5.3 Bus

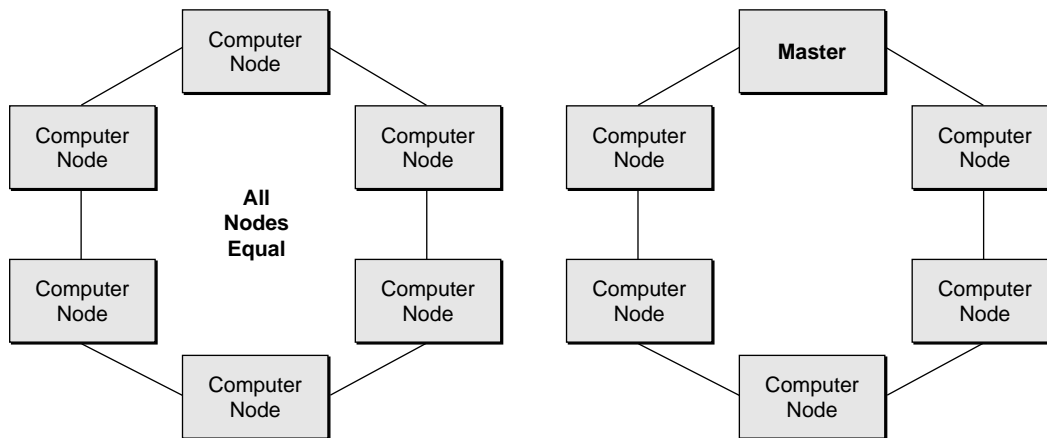
One of the most commonly used forms of control topology is the bus network. A bus network is significantly different from the other arrangements in that data may be sent to all nodes at the same time, as opposed to passing data from node to node around a ring. This is shown in the Fig. 10.7.

The efficiency of a bus network in an FMS or any other automation application depends on the following factors:

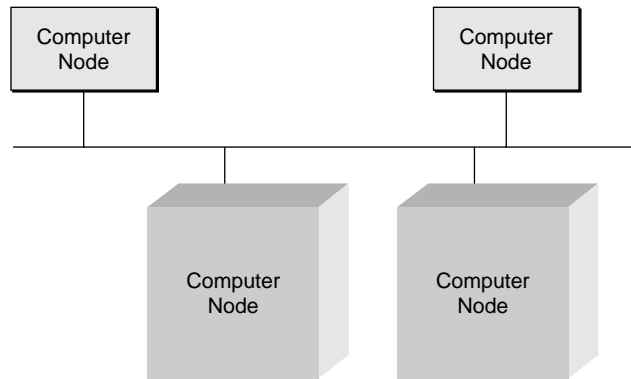
- Reliability, fault tolerance, and availability.
- Data transmission rate and maximum distance between nodes.
- Time delay to respond to interrupts and data requests.
- Geographic distribution of components requiring node connection.



**Fig. 10.5** Star or radial network controlled by the net master in a master-slave relationship



**Fig. 10.6** Ring or loop network

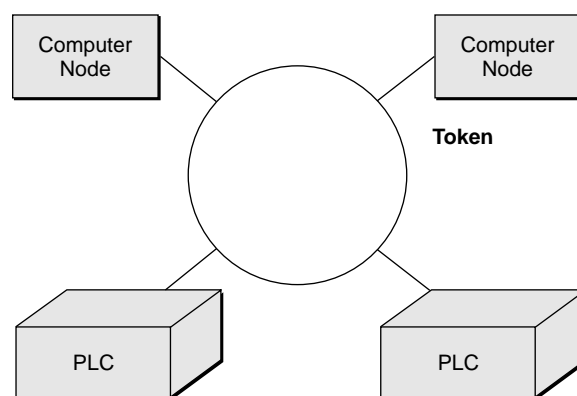


**Fig. 10.7** Bus network, where data can be sent to all nodes at the same time

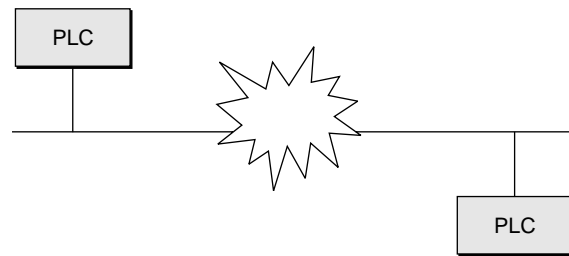
Channel access is a means of determining who controls the network. Polling is a technique in which each nodes access to the network is determined by the master node.

If a centralized polling scheme is used, the central node will query each sub node and ask if it has access to the network. Each nodes frequency of access depends on how much other data traffic needs to be passed between the other nodes in the network and the total number of nodes on the network. Some polling schemes can assign priority to selected nodes by querying them more often.

Figure 10.8 shows the token passing in a distributed polling. A common form of distributed polling is called token passing. Token passing is generally associated with ring or loop networks and functions by passing a packet of bits called token around the loop until it reaches am node that requires access to the network. That particular node will grab and hold the token while it sends its data. Once a message is on the ring, it is passed from node to node until received by the destination node. Messages usually circulate back to the sending node to control receipt. When the sending node has completed its transmission, it puts the token back in circulation. Figure 10.9 illustrates a detection of collision in order to prevent the two nodes attempting to take control of bus at the same time.



**Fig. 10.8** Token passing is a common form of distributed polling



**Fig. 10.9** Collision detection prevents two nodes from attempting to take control of the bus at the same time

# FMS Software Structure, Functions and Description

## 11.1 INTRODUCTION

Flexible manufacturing system is made up of various elements. The major elements consist of a variety of processing, quality assurance, computer hardware, and system support equipments, all of which are visible and tangible.

Software is an invisible element, it is the essential glue that binds the visible FMS equipment together and forms a system. Without these highly developed and sophisticated computer routines, an FMS is a mere collection of individually automated equipments on the factory floor.

FMS software drives the entire system, calling various equipments to action through command driven operator and system manager input. If the FMS computer is the “HEART” of FMS, then the software is “LIFE BLOOD”.

## 11.2 GENERAL STRUCTURE AND REQUIREMENTS

As we have discussed earlier, FMS software is an invisible element, that drives the FMS, which has two levels of software required for FMS to run, they are

1. *Operating system software* is the highest level, computer manufacturer specific, and executes supervisory control over the application software.
2. *Application Software* is usually developed and supplied by the system supplier and includes all the FMS specific programs and routines.

Application Software for an FMS is complex, highly proprietary. It is generally composed of several modules. Each module is made up of a series of computer programs and routines relating to various functions performed within the system.

These include

- NC part program downloaded from FMS host Computer to machine tool controller.
- Traffic and material-handling management.

- Work order generation
- Work piece scheduling,
- Simulation
- Tool management.

All these software modules must be well designed and function predictably, reliably and interactively in order for FMS to perform at peak operating efficiencies and acceptance levels. These software modules should be structured and coded properly, tested rigorously and functioning adequately. All these individually developed modules interact together to run the entire system.

### 11.3 ADVANTAGES OF MODULAR SOFTWARE DESIGN AND DEVELOPMENT

Segmenting the required software into modules for development permits simultaneous efforts, once overall system requirements and specifications are agreed on, there by saving time.

Modular software design and development permits “Phased Installation”, allowing the user to begin using the system while some portions are still in the development, testing, or implementing mode. Quicker and easier tracing and pinpointing for problem, enhancement, or modification changes.

### 11.4 ACTIVITIES AND FUNCTIONS TO BE PERFORMED BY FMS SOFTWARE, WITHIN THE SYSTEM

- Access to critical data for users customizable management and status reporting
- Operation data collection
- Scheduling and simulation of the system activities
- Workpiece load balancing for efficient utilization of processing equipment and tooling.
- Remote distribution of NC programs to machine control units.
- NC part processing at the remote site via telecommunication links.
- NC program library control and maintenance.
- Automated tool and Workpiece delivery
- Management of fixture, pallet, and tooling data.
- Definition and assignment of Workpiece operational sequence (routing).
- Automated Workpiece inspection.
- System control of Workpiece entry and exit.
- Overall control of system resource utilization.
- Error diagnostic output and display for system maintenance and troubleshooting.

### 11.5 REQUIREMENTS OF FMS SOFTWARE

- Complete installation and functionality of all FMS components and data lines.
- Thoroughly tested and complete operational software.
- Completed and proven NC and CMM part Programs

- Assembled and proven fixtures
- Available tooling and material
- Fixture and pallet assignment and identification.
- Completed work order creation.

## 11.6 TYPES OF FMS SOFTWARE MODULES

The various types of FMS software modules are:

### 11.6.1 Work—Order Processing

The primary functions are work piece production schedules and processing sequencing, which should be implemented and controlled and managed within the system.

All processing steps must be listed in sequential order and the resources to be utilized such as part programs, cutting tools, and fixtures,

It must be completed well in advance of the parts scheduled run-time. Any work piece introduction should be identified by the work order.

Identification of work piece generally includes defining the number of parts to be processed, start date, due date and, routing sequence.

#### 11.6.1.1 The Objectives

- Define an individual work order to the FMS and describe its station processing sequence
- Initiate entry and exit of workpieces within the system.
- Reserve system resources to ensure production and completion of in process work orders
- Start and stop processing of work orders in response to changing production requirements, bottlenecked machine groups or machine breakdown situations
- Establish and control multiple Workpiece processing sequences and priorities for parts completing for the same resource at the same time.
- Permit alternate routing creation and system entering for parts due to changing production requirements or catastrophic failures.
- Collect and report current and historic information regarding completed and in-process work.
- Interact with various other FMS software modules to provide for Workpiece movement and delivery and other resources availability and allocation.

### 11.6.2 Data Distribution and Collection

This module basically sends data to and receives data from the machine control units. The primary function to retrieve NC data from FMS computer disk storage and transfer it to requesting machine control unit as required.

### 11.6.2.1 Other Functional Capabilities Includes

- Storage and retrieval of specific or cumulative cutting tool, machine tool, or other data collection information.
- To allow only authorized access to NC data files, and protection for the integrity of the data in the system.
- Data manipulation, prioritization, and file management capabilities for NC data transfer.
- Real time status of system resources and management report information; which show the current status of the system with respect to production, tooling and other system resource for short-term management decision-making.
- Send messages from a terminal or MCU in the system to any or all terminal in the system
- Uploading of APT source files from a remote site via the RJE option and transmission of the post processed NC output back to the FMS computer for storage and later use.
- Logging of all system transactions along with time of day and user identification.

### 11.6.3 System Diagnostics and Maintenance

This module provides diagnostics for scheduled and unscheduled maintenance and troubleshooting of system components. In some cases the menu driven sequence of diagnostic and recovery instructions is displayed to the system manager in the event of catastrophic failure or shutdowns.

The diagnostic and maintenance module will:

- Collect data stored at the MCUs to maintain a historical maintenance and cumulative run time log.
- Inform the system manager of regularly scheduled preventive maintenance for all system components.
- Notify the system manager when tool failure occur
- Detect and identify system failures, and notify the system manager when a failure is detected.
- Verify specific failure through comparison using library of diagnostic programs
- Communicate via telephone line with a vendors computers or remote diagnostic capabilities.
- Monitor the FMS equipment using feedback sensors in the material handling system and processing stations.
- Maintain up to date program libraries and diagnostic routines for maintenance and trouble shooting of system components and facilities.

### 11.6.4 Tool Management

This module is responsible for storing, managing, and updating cutting tool data files. It provides the capability to assign the necessary tooling to the various processing stations in the system. It also allows for entering, in advance, the associated data for required tooling, along with the ability to transport and load that tooling at the designated machine tools.

Tool management software generally will:

- Store, manage and update tool data files containing tooling data, which typically consists of tool length, cutter diameter compensation, feed rate and spindle override information. And tool cycle time expectancy
- Add new tool assemblies and tool groups to the system.
- Delete completed tool groups or time expired tool assemblies from the system.
- Authorize tool movement to and fro from the work stations
- Display, via system terminal, the complete list of tools for a specific part program
- Display specific tool or tool group's status information.
- Search the tool data file for specific tool groups or tool assemblies.
- Automatically enter tool data from tool gauging equipments.
- Permit editing of tooling data by authorized users
- Address and identify the specific machine tool and tool pockets that hold each tool
- Identify the pockets in each machine tool matrix from which tool has been exchanged.

### 11.6.5 Traffic Management and Control

This module monitors the movement of tools and palletized workpieces between processing, parking, and load-unload station in a FMS. It accepts signals from other software modules and initiates timely action of the material handling system. These consists of machine tools, queuing carrousel, load unload stations, wash stations, battery recharge stations, gauging and inspection stations.

The primary functions are:

- Issue commands to move tools and palletized workpieces between the various stations in the FMS.
- Control an AGV's registration, positioning, and lift mechanism via sensors for pallet pickup and delivery.
- Track and maintain current and historical part, pallet, and tool movement data between processing parking stations and load stations.
- Provide overall supervisory control of all AGVs in the material handling system.
- Provide operating personnel with software input commands to control AGV traffic.

### 11.6.6 Quality Control Management

This module provides the capability to collect, store, retrieve, and archive workpiece inspection data. Here, current machine tool cutting data are compared with workpiece specification, any deviation outside the part tolerance band will direct a message to the system manager and cause resultant action to begin.

This module will:

- Control and direct the CMM and compare inspection results with previously input workpiece tolerance specifications; so created programs are uploaded to FMS computer for storage and retrieval.

- Check that machining stations are processing parts to required specifications
- Identify the specific part, call for a download of the appropriate inspection program to the CMM, and initiate the measuring cycle.
- Store and archive inspection data, prepare the measurement report, and notify the FMS computer of the completion of measurement cycle.
- Ensure that only recent inspection program is stored on the FMS computer to avoid the risk of downloading a previous version.
- Associate each measuring program with the correct workpiece and specific routing subprogram for matching when retrieval is initiated.

### 11.6.7 Fixtures and Workpiece Control

This module works in conjunction with the work order-processing module. It is used to control the status of all fixtures and parts known to the system. System operator operates the workpiece loading and unloading at one or more fixture stations. A CRT message will instruct the operator to either store or disassemble a fixture and pallet assembly.

The various functions of this module are:

- Authorize fixture load-unload completion for workpiece entry and exit.
- Validate workpiece-to-fixture and fixture to pallet identity.
- Control and monitor fixture and workpiece activity from system entry to exit.
- Initiate the material handling system for workpiece movement to and from processing stations.
- Permit operator communication with the FMS computer and system manager as to load and unload workpiece-processing availability.
- Assign fixture identification to every fixture and fixtured pallet used in the system.
- Dispatch work pieces that have faced CMM inspection to a material review station for re-inspection and dispatch.

### 11.6.8 Planning Scheduling and Simulation

This module provides the user with the capability to do production planning and workpiece scheduling in advance of actual due dates and to simulate (mimic) the results. It provides for the selection and designation of system resources. This is most powerful and useful software module to the system user as they are involved in planning, scheduling, and balance load and production requirements

This module will:

- Provide predictable results of work order processing based on prior definition of production requirements and needed system resources.
- Provide the capability to assign operation sequences and tooling for processing operations on the various workstations in FMS.
- Simulate the results of production load situations based on input of work order release times, pallet allocation.
- Verify that existing or proposed production schedules will achieve the required throughput and results.

- Display system element utilization levels and provide production capacity data.
- Determine the most efficient workpiece batching and scheduling strategies
- Ensure the availability of system resources to achieve the expected production rates
- Obtain useful simulated results quickly by modeling the system under load conditions and analyzing its performance
- Analyze the impact of system expansion (increasing the no. of work stations or AGVs)

### 11.6.9 Computer Simulation

Simulation is a powerful analytical software tool that is used to mimic the behavior of a system. With simulation, a mathematical model is built of a particular process that allows users to observe the outcome of manufacturing operations without experimenting with the actual equipment. It allows the users the opportunity to know the consequences of system changes before they happen through the powerful routine's predictive, look ahead and what if capabilities. It is recognized as a fast and accurate analytical tool for studying complex manufacturing systems and operations.

Classifications of simulation languages according to different concepts, activities, or capabilities are:

- Event oriented
- Process oriented
- Transaction or Translation oriented
- Activity or Function oriented

Simulation permits close analysis of the manufacturing processes to be examined, as it consists of known and available resources, activities and alternative methods.

It can be done independent of other ongoing computer functions and without affecting existing operations.

System manager on the FMS Computer generally performs the simulation analysis to develop, model, and examine alternatives in order to:

- Optimize production schedules
- Maximize resource utilization
- Meet multiple part production due dates
- Maintain production requirements in the event of individual workstation downtime problems
- Increase production
- Balance machine load
- Balance tool requirements

Simulation may be used as an aid to plan a new facility or to change an existing one, to search for more efficient machine layouts to observe traffic and material conjunction and to test the effect of workstation failures through computer simulation. The consequences of these and other changes and alterations can be reviewed and the best alternatives selected to meet system and production goals and objectives.

## 11.7 GENERAL PHASES OF SIMULATION ANALYSIS

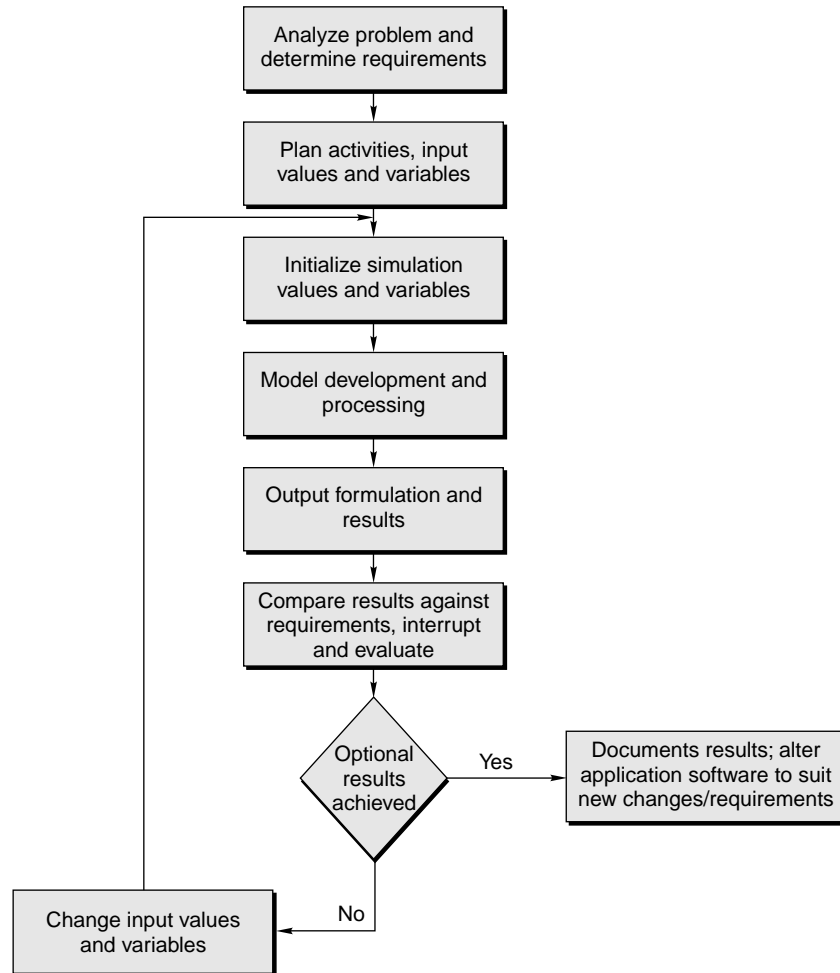


Fig. 11.1 Flowchart of general phases of simulation

## 11.8 REASONS TO INTEGRATE FMS COMPUTER SYSTEM TO A CENTRAL HOST COMPUTERS

The primary reasons to integrate FMS computer system to a central host computers are:

- Download material requirements planning (MRP) information directly to the FMS computer and avoid manual determination and entry.
- Process NC part program from an FMS terminal on the host computer and direct output results via the remote job entry (RJE) feature.
- Interface with other management information system (MIS) for data exchange, decision-making, and report generation.
- Interface with existing or expanding CAD/CAM systems to provide more globalized computer integrated manufacturing (CIM) capabilities.

### 11.9 FUNCTIONS OF AN FMS HOST COMPUTER

The main functions of an FMS host computer are

- Production capacity planning.
- Production preparation.
- Manufacturing control.
- Administration of production data.

### 11.10 THE MAJOR FMS HOST FUNCTIONS

<i>Integration method</i>	<i>Function</i>	<i>Use Decoupled</i>
Offline, inactive background Tool requirements Programs Operator-initiated	Planning	<ul style="list-style-type: none"> <li>● Machining/Process</li> <li>● Capacity</li> </ul> Transport units <ul style="list-style-type: none"> <li>● Pallets</li> <li>● Fixtures</li> </ul> Tools requirements
	Preparation	Tool - commission - setting - exchange Transport units <ul style="list-style-type: none"> <li>● setting</li> <li>● adjustment</li> </ul>
Coupled Online, active foreground Programs Event drive	DNC	NC program <ul style="list-style-type: none"> <li>● Supply</li> <li>● Deletion</li> </ul>
	Material flow	Transport orders <ul style="list-style-type: none"> <li>● Pallets for transfer</li> <li>● Machines needing work</li> <li>● Execution</li> <li>● Acknowledgement</li> </ul>
Monitoring		Tool lives <ul style="list-style-type: none"> <li>● Machine status</li> <li>● Order status</li> <li>● Shift lists</li> <li>● Utilization status</li> <li>● Report logging</li> </ul>

### 11.11 FMS MASTER HOST TASKS

The tasks that the master host computer can perform are

- Production order planning
- Tool planning
- Level 3 hosts status monitoring
- NC program administration
- System image mimic picture
- Tool setting (if centralized)
- Material flow (if centralized)
- System shift/utilization lists
- Connection to any level 4 or 5 computers

### 11.12 SUBORDINATE FMS HOST TASKS

The following tasks are those, which are an essential to an FMS host to organize the production of a group of work centers, and cannot be displayed to a coordinating master host

- Material flow
- Tool flow
- Machine control
- NC program administration
- Tool load/unload dialogue
- Competent load/unload dialogue
- System alarm report monitoring
- System image mimic picture (subsystem specific)
- Synchronization

### 11.13 AREA CONTROLLER HOST TASKS

The area controller plans the work to go into a manufacturing area's available capacity and may even provide the transport organization to physically arrange that the area's production facilities be provided with work. These facilities may well be one or several FMS. Either an FMS host or master host will interface to the area controller or corporate computer level. The data exchange carried out is to update the FMS host with new databases or to inform the corporate computer of the status of FMS.

### 11.14 DATA EXCHANGES

The data exchanges are:

- NC programs
- Creation on CAD systems

- Modification at CNC level
- Transfer to host's databases
- Production orders
- Sending of new production orders → production order pool (FMS host)
- Master data
- Holding of factory database
- Corporate database update → FMS database updating.
- System status data
- Production equipment status
- Receiving of machine utilization status
- Shift data and equipment status data
- Work calendar
- Changes in shift hours → perform realistic capacity planning.
- Process routings
- Transfer of new process routings to respective hosts
- Includes part number, fixture identification, operations and work centers.

# 12

## FMS Installation and Implementation

### 12.1 FMS INSTALLATION

#### 12.1.1 Introduction

The system must be physically be assembled, started and debugged during the FMS installation phase. During this period some training must be carried out while the system is being installed and some training occurs after the system is installed and in complete operation.

The extremely critical elements during this period due to high activity level are direction and communication. People must understand the installation plan and schedule and those who work, as a part of FMS team must begin to work together. Working together at this early stage alongside vendor personnel enables the FMS team to learn as much as they can about the equipment and helps in cultivating the ownership of the system and teamwork.

#### 12.1.2 System Installation

Most of the system installations follow a predetermined and structured sequence of events. There are no hard and fast rules for installation of FMS. However, logical and orderly occurrences must take place that are determined jointly and agreed ahead of time by the system purchaser and supplier.

Most of the purchasers prefer a phased installation approach, which allows them time to bring various pieces of equipment on line and in some cases into production as quickly as possible, as opposed to waiting for the entire system to be installed and become operational. Customer requirements, scheduling demands and various other considerations have to be kept in mind during the installation.

A typical FMS installation that might be accomplished in 4 phases are:

##### *Phase 1:*

Site excavation and central coolant and chip removal and recovery system installation occur at this early stage. Underground utilities would be laid and the chip bins and a chip compactor installed if

required. Machine foundation slabs and the main FMS manufacturing floor would be reinforced and concrete poured and cured

*Phase 2:*

At this time AGV lines are cut into the floor from the floor marking templates. Guidepath wire embedded in the floor cuts and epoxy sealed. The elevated computer room is erected, additional utilities and conduit are run to approximate locations and wiring is pulled. Compressed air and electricians are run to machine power drop locations and the overhead crane system is installed. Additionally a central coolant flume and chip recovery system, chip conveyor and chip compactor are run off and operationally checked.

*Phase 3:*

During this phase, machines that have been transported by truck to their destinations are unloaded and placed in their proper positions. Electrical and compressed air lines previously run to drop locations are hooked up. Machine tools are quickly aligned, and operational features (machine and control) are thoroughly checked out. Machine cutting tests, generally conducted, witnessed and approved by the purchaser project manager in the machine tool vendor's plant, are conducted again once machines are installed in the customer's plant. Again cutting tests are witnessed and approved by the purchaser project manager.

The FMS host and the AGV computer system are also installed during this phase and the operating and application software is installed. Installing the FMS computer and software at this stage permits early computer system testing and debugging. AGVs are installed, checked out, operated manually and linked to the computer system.

*Phase 4:*

Adding the inspection machine is one of the next important modules to add to the FMS. Other modules quickly added to the system, many of which are occurring at the same time, include installation of the queuing carousels for overflow parking, load-unload stations, fixture and tool build stations and the tool delivery module. If ASRS is included, this could be installed some time during this phase. Also during this phase, the purchaser would be installing perimeter guarding, eye wash stations, fire extinguishing equipments and other safety equipments along with painting guide path markings on the factory floor.

As each FMS machine or module is added to the system, its performance and conformance to specifications are checked out and verified on an individual or modular basis before linking it with other modules or FMS elements. Such rigid modular verification can help to eliminate specific problem determination confusion once the entire system is being tested for functionality and performance capabilities.

## **12.2 FMS IMPLEMENTATION**

### **12.2.1 Introduction**

FMS implementation involves making all the installed components work and function as a system. It must optimize and fine-tune each FMS component including computer hardware and software to get peak performance.

FMS implementation is the transition phase to decrease reliance on supplier and vendor personnel and increase reliance on in-house personnel and expertise. Supplier and original equipment manufacturer vendor personnel starts to withdraw as their equipment comes on-line and is accepted. Although the FMS equipment will be under warranty for some time, making the system perform to expectation and productivity levels is now squarely up to the system purchaser.

### 12.2.2 Acceptance Testing

Acceptance testing is making sure the entire system and all its processing modules run and perform to expected performance and specification levels as a complete and operational cycle. Generally bigger and more complex a cell or system is the longer the customer demand for a continuous, uninterrupted acceptance test.

The purpose of acceptance testing is to have the system purchaser conditionally accept the system. That is in order to be formally accepted the system must run and flawlessly perform for a specified number of continuous shifts. The number of continuous operating shifts can vary widely, but usually the required number is from 9 – 15. Acceptance testing is the time for fine tuning and honing the system to peak performance.

To make sure acceptance testing occurs on time and on schedule, many primary activities and tasks must have previously occurred and be entirely completed. These are:

1. Each equipment module has been singularly run off and individually performs to functional specifications
2. All computer hardware and software are installed, operational and functioning properly
3. Purchaser personnel have been trained and learning has occurred through demonstrable and observable competencies
4. The complete system has been started and tested for operation and functionality as an entire system
5. Work orders and other executable commands for the entire system have been tried and tested during the initial startup and debug phase.

Additionally the system purchaser and supplier will be checking, recording and verifying other aspects of system acceptance for specification compliance. Items to be checked and verified during acceptance testing include:

- Productivity and part throughput levels
- Equipment accuracy, functionality and utilization levels
- Tooling and fixturing availability and deployment
- Processing equipment downtime for maintenance and service
- Material handling performance reliability and dependability
- Part quality, accuracy and repeatability
- Incoming and outgoing system work flow
- Flume system capacity and dependability
- Computer software feature execution and verification

Software testing is under a variety of production situations during the allotted acceptance testing time may be difficult. However it is common practice on many system installations and acceptance tests for supplier personnel to actually run and perform the acceptance tests and user personnel to observe. This is because the installed system has not been formally turned over to the user until after the system has been accepted. However, a better idea is to have a new user to perform the acceptance test with supplier personnel observing, assisting and guiding. Such a change from the norm is important because:

- After final acceptance, the supplier team leaves. And even though the user team has been trained, they have little time functioning as a complete team with the new system and with complete system in actual production
- Adults learn by doing and having the user team run the acceptance test instead of the supplier team intensifies and lengthens the actual training time. This places and keeps the user in the student's role and the supplier in the instructor's role.

# 13

## Case Studies

### 13.1 CASE I: THE TOYOTA PRODUCTION SYSTEM

#### 13.1.1 Automobile Manufacturing

Forty years ago, Peter Drucker dubbed it “the industries of industries.” Today, automobile manufacturing is still the world’s largest manufacturing activity. After First World War, Henry Ford and General Motors’ Alfred Sloan moved world manufacture from centuries of craft production (led by European firms (into the age of mass production. Largely as a result, the United States soon dominated the world economy.

#### 13.1.2 Toyota Production System

After Second World War, Eiji Toyoda and Taiichi Ohno at the Toyota motor company in Japan pioneered the concept of Toyota Production System. The rise of Japan to its current economic pre-eminence quickly followed, as other companies and industries copied this remarkable system. Manufacturers around the world are now trying to embrace this innovative system, but they are finding the going rough.

The companies that first mastered this system were all headquartered in one country-Japan. However, many methods on the existing mass-production systems cause great pain and dislocation.

This essay, I believe, is an effort to explain the necessary transition from mass production to revolutionary production called Toyota production System. By focusing on the global auto industry, this essay explains in simple, concrete terms what the Toyota Production System is, where it came from, how it really works, and how it can spread to all corners of the globe Western companies now understand Toyota Production System, and at least one is well along the path of introducing it. Superimposing this for everyone’s mutual benefit. The global adaptation, as it inevitably spreads beyond the auto industry, will change everything in almost every industry-choice of customers, the nature of work, the fortune of companies, and, ultimately, the fate of nations.

What is Toyota Production System? Perhaps the best way to describe this innovative production system is to contrast it with craft production and mass production, the two other methods humans have devised to make things.

### 13.1.3 Production Methods

The craft producer uses highly skilled workers and a simple but flexible tool to make exactly what the customer asks for one item at a time. Few exotic sports cars provide current day examples. We all love the idea of craft production, but the problem with it is obvious: Goods produced by the craft method—as automobiles once were exclusively—cost too much for most of us to afford. So mass production was developed at the beginning of the twentieth century as an alternative.

The mass-producer uses narrowly skilled professionals to design products made by unskilled or semiskilled workers tending expensive, single-purpose machines. These churn out standardized products in very high volume. Because the machinery costs so much and is so intolerant of disruption, the mass-producer keeps standard designs in production for as long as possible. The result: The customer gets lower costs but at the expense of variety and by means of work methods that most employees find boring and dispiriting.

The Toyota motor corporation, by contrast, combines the advantages of craft and mass production, while avoiding the high cost of the former and the rigidity of the latter. Toward this end, they employ teams of multi-skilled workers at all levels of the organization and use highly flexible and increasingly automated machines to produce volumes of products in enormous variety.

The Toyota Production System is also defined as Lean Production because it uses less of everything compared with mass production—half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.

Perhaps the most striking difference between mass and Toyota production system lies in their ultimate objectives. Mass-producers set a limited goal for themselves—“good enough,” 1.3 Production methods, which translate into an acceptable number of defects, a maximum acceptable level of inventories, a narrow range of standardized products. Lean producers on the other hand, set their sights explicitly on perfection.

### 13.1.4 Toyota Production System

#### 13.1.4.1 Basic Idea and Framework

The Toyota production system is a technology of comprehensive production management the Japanese invented a hundred years after opening up to the modern world. The basic idea of this system is to maintain a continuous flow of products in factories in order to flexibly adapt to demand changes. The realization of such production flow is called Just-in-time production, which means producing only necessary units in a necessary quantity at a necessary time. As a result, the excess inventories and the excess work force will be naturally diminished, thereby achieving the purposes of increased productivity and cost reduction.

The basic principle of Just-in-time production is rational; that is, the Toyota production system has been developed by steadily pursuing the orthodox way of production management. With the realization of this concept, unnecessary intermediate and finished product inventories would be eliminated. However, although cost reduction is the system’s most important goal, it must achieve three other sub-goals in order to achieve its primary objective. They include:

- Quantity control, which enables the system to adapt to daily and monthly fluctuations in demand in terms of quantities and variety;
- Quality assurance, which assures that each process, will supply only good units to the subsequent processes.

Respect-for-humanity, which must be cultivated while the system utilizes the human resource to attain its cost objectives. It should be emphasized here that these three goals cannot exist independently or be achieved independently without influencing each other or the primary goal of cost reduction. All goals are output of the same system; with productivity as the ultimate purpose and guiding concept, the Toyota production system strives to realize each of the goals for which it has been designed. Before discussing the contents of the Toyota production system in detail, an overview of this system is in order. The outputs or result side as well as the inputs or constituent side of the production system are depicted.

A continuous flow of production, or adapting to demand changes in quantities and variety, is created by achieving two key concepts: Just-in-time and Automation. These two concepts are the pillars of the Toyota production system.

Just-in-time basically means to produce the necessary units in the necessary quantities at the necessary time. Automation (“Jidoka” in Japanese) may be loosely interpreted as autonomous defects control. It supports Just-in-time by never allowing defective units from the preceding process to flow into and disrupt a subsequent process. Two concepts also key to the Toyota production system include Flexible work force (“Shojinka” in Japanese) which means varying the number of workers to demand changes, and Creative thinking or inventive ideas (“soikufu”), or capitalizing on workers suggestions.

To realize these four concepts, Toyota has established the following systems and methods:

- Kanban system to maintain Just-in-time production
- Production smoothing method to adapt to demand changes
- Shortening of set-up time for reducing the production lead time
- Standardization of operations to attain line balancing
- Machine layout and the multi-function worker for flexible work force
- Improvement activities by small groups and the suggestion system to reduce the work force and increase the worker’s morale.
- Visual control system to achieve the Automation concept
- Functional Management system to promote company-wide quality control.

### 13.1.5 Just-in-Time Production

The idea of producing the necessary units in the necessary quantities at the necessary time is described by the short term Just-in-time. Just-in-time means, for example, that in the process of assembling the parts to build a car, the necessary kind of sub-assemblies of the preceding processes should arrive at the product line at the time needed in the necessary quantities. If Just-in-time is realized in the entire firm, then unnecessary inventories in the factory will be completely eliminated, making stores or warehouses unnecessary. The inventory carrying costs will be diminished, and the ratio of capital turnover will be increased.

However, to rely solely on the central planning approach, which instructs the production schedules to all processes simultaneously, it is very difficult to realize Just-in-time in all the processes for a product like an automobile, which consists of thousands of parts. Therefore, in Toyota system, it is necessary to look at the production flow conversely; in other words, the people of a certain process go to the preceding process to withdraw the necessary units in the necessary quantities at the necessary time. Then what the preceding process has to do is produce only enough quantities of units to replace those that have been withdrawn.

### 13.1.6 Kanban System

Many people think the Toyota production system a Kanban system: this is incorrect. The Toyota production system is a way to make products, whereas the Kanban system is the way to manage the Just-in-time production method. In short, the kanban system is an information system to harmoniously control the production quantities in every process. It is a tool to achieve just-in-time production. In this system what kind of units and how many units needed are written on a tag-like card called Kanban. The Kanban is sent to the people of the preceding process from the subsequent process. As a result, many processes in a plant are connected with each other. This connecting of processes in a factory allows for better control of necessary quantities for various products. The following supports the Kanban system:

- Smoothing of production
- Reduction of set-up time design of machine layout
- Standardization of jobs
- Improvement activities
- Automatisation

A kanban is usually a card put in a rectangular vinyl envelope. Two kinds are mainly used: Withdrawal Kanban and Production-ordering Kanban. A Withdrawal Kanban details the kind and quantity of product, which the subsequent process should withdraw from the preceding process, while a Production-ordering Kanban specifies the kind and quantity of the product, which the preceding process must produce.

The Withdrawal kanban shows that the preceding process which makes this part is forging, and the carrier of the subsequent part must go to position B-2 of the forging department to withdraw drive pinions. The subsequent process is machining. The Kanban shows that the machining process SB-8 must produce the crankshaft for the car type. The crankshaft produced should be placed at store F26-18. These cards circulate within Toyota factories, between Toyota and its many co-operative companies, and within the factories of co-operative companies. In this manner, the Kanban can contribute information on withdrawal and production quantities in order to achieve Just-in-time production.

Suppose we are making products *A*, *B*, and *C* in an assembly line. The parts necessary to produce these products are *a* and *b* which are produced by the preceding machining line. Parts *a* and *b* produced by the machining line are stored behind this line, and the production-ordering Kanbans of the line are attached to these parts. The carrier from the assembly line making product *A* will go to the machining line to withdraw the necessary part *a* with a withdrawal kanban. Then, at store, he

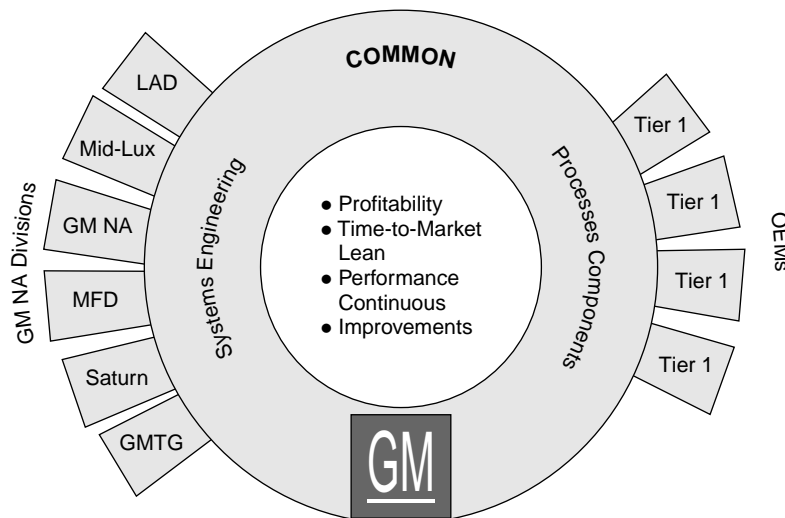
picks up as many boxes of this part as his withdrawal kanbans and he detaches the production-ordering kanban attached to these boxes. He then brings these boxes back to his assembly line, again with withdrawal kanbans. At this time, the production-ordering Kanbans are left at store of the machining line showing the number of units withdrawn. These Kanbans will be the dispatching information to the machining line. Part *a* is then produced in the quantity directed by that number of Kanbans. In this machining line, actually, parts *a* and *b* are both withdrawn, but these parts are produced according to the detached order of the production-ordering Kanbans.

### 13.1.7 Autonamation

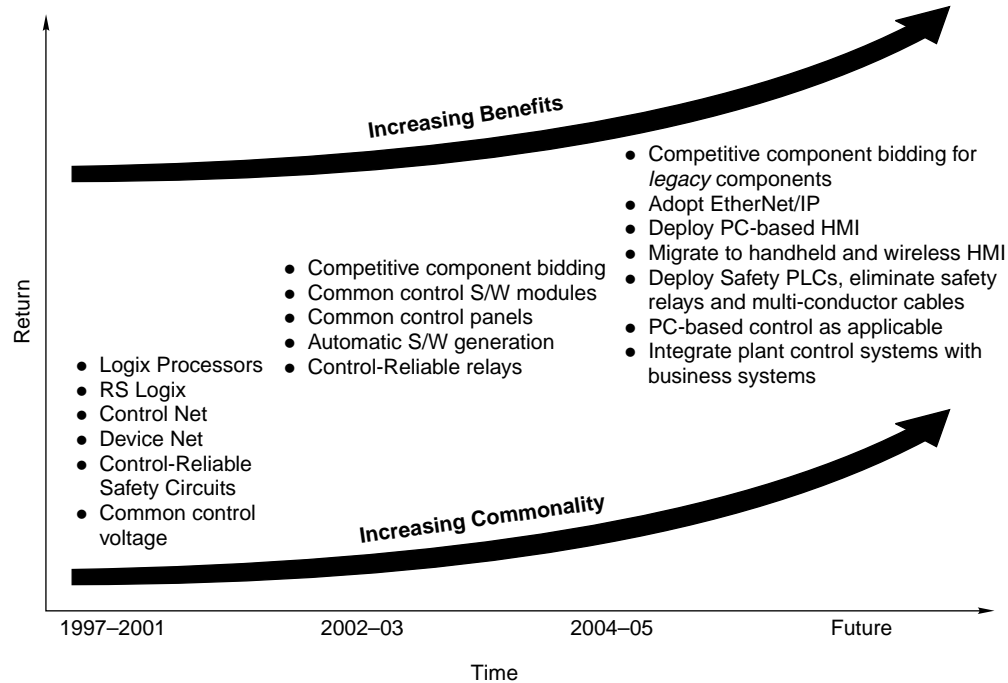
In order to realize Just-in-time perfectly, 100 per cent good units must flow to the prior process, and this flow must be rhythmic without interruption. Therefore, quality control is so important that it must coexist with the Just-in-time operation throughout the Kanban system. Autonamation means to build in a mechanism a means to prevent mass-production of defective work in machines or product lines. Autonamation is not automation, but the autonomous check of abnormality in the process.

The autonomous machine is a machine to which an automatic stopping device is attached. In Toyota factories, almost all the machines are autonomous, so that mass-production of defects can be prevented and machine breakdowns are automatically checked. The idea of Autonamation is also expanded to the product lines of manual work. If something abnormal happens in a product line, the worker pushes stop button, thereby stopping his whole line. For the purpose of detecting troubles in each process, an electric light board, called Andon, indicating a line stop, is hung so high in a factory that it can easily be seen by everyone. The Andon in the Toyota system has an important role in helping this autonomous check, and is a typical example of Toyota's "Visual Control System."

## 13.2 CASE II: GENERAL MOTORS LEVERAGES COMMON ARCHITECTURE TO STRATEGIC ADVANTAGE



**Fig. 13.1** ARC S GMs move to common processes, systems, and components eliminates costly and non-value-adding variations between different entities



**Fig. 13.2** GM is pursuing a phased migration to a common architecture

### 13.2.1 Executive Overview

Just a decade ago global automaker General Motors was teetering on the brink of bankruptcy. Plagued by a twenty-year legacy of shrinking North American market shares and bloated, slow, and unprofitable operations, the sun appeared to be setting on the world's largest automaker.

Today's GM boasts a rising global market share, profitable operations, and, as of 2001, the distinction of being Detroit's lowest-cost producer. The company is now targeting even higher profitability with a plan to triple earnings by 2005, while at the same time planning its largest-ever introduction of new model vehicles. Numerous factors contributed to this reversal, including an emphasis on core businesses and the resulting spin-off of non-automotive assets, but from a manufacturing perspective former GM chief Jack Smith's simple mantra of. Run Common, Run Lean and Fast, Grow, and Go Global has been a profound catalyst behind the increasingly lean and profitable performance of the company's North American Operations.

GM North America's (GM NA) response to this mid-90.s corporate edict was to pursue establishment of common engineering, common processes, common manufacturing systems, and common components throughout its operations. From a controls system perspective, this commonality was charged with enabling the outfit to overcome the impact of legacy activities that resulted in lengthy body style changes, slow program accelerations, low cost competitiveness, limited flexibility, limited learning opportunities, and limited reuse of designs and software.

Starting in 1997 with the formation of the Common Controls Architecture Team and the decision to adopt open network architecture, GM NA.s CRW (Controls, Robotics, and Welding) group has

been spearheading a step-by-step migration to a common architecture. This migration and its early results to date are indicative of the need for large manufacturers to be proactive in establishing their own core architecture standards, rather than leave it to OEMs and third parties, and the profound and positive impact this deceptively simple strategy can exert.

- Run Common
- Run Lean and Fast
- Grow
- Go Global
- Return 5% of Sales

## 13.2.2 GM Corporate Mantra

### 13.2.2.1 Common Benefits

As a corporate edict, the benefits of running common extend throughout the GM enterprise in areas such as improved profitability, time to market, and market responsiveness. While commonality on its own provides benefits numerous enough to justify the strategy, the dividends from the common strategy extend into enablement of companion strategies such as Lean Manufacturing. Further benefits are evident in the ability to use the common infrastructure as a platform for continuous improvement, which will provide dividends long after the common philosophy is established. Reducing variability as a means of reducing cost is a central tenet of GM's Lean Manufacturing philosophy. Simplicity in design, minimal variations, elimination of redundancy, use of common design tools, and other key aspects of the Common initiative will all contribute to achieving this reduced variability. The common philosophy also enables the responsiveness, low cost, and quality objectives inherent in Lean Manufacturing.

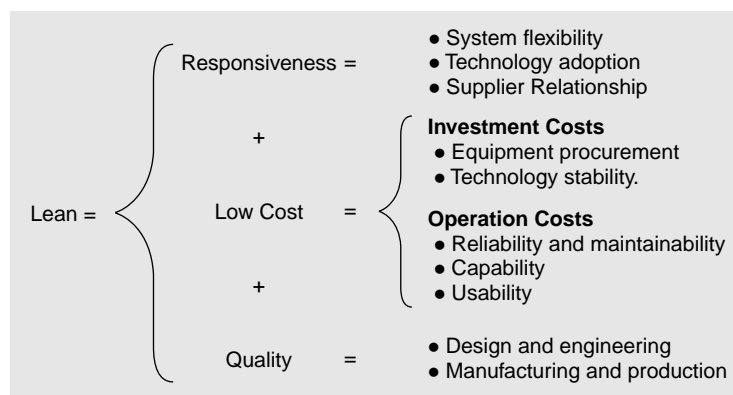


Fig. 13.3 Lean manufacturing

### 13.2.2.2 Lean Manufacturing Objectives

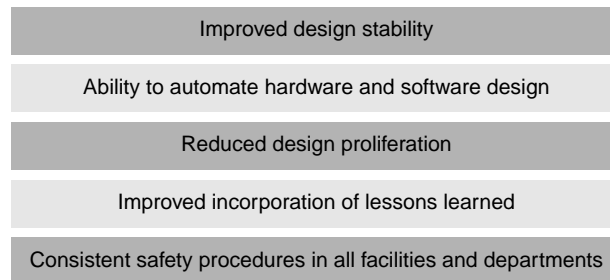
As a platform for continuous improvement, the common philosophy will pay dividends for years to come. No longer subject to the upheaval introduced as new systems are brought in with each product

launch, instead the stable environment specified in the common approach frees up resources to focus on continuous improvement rather than continual redoing of base tasks. GM NA.s adoption of the common philosophy is focused on engineering, manufacturing processes, manufacturing systems, and associated components.

Commonality in each of these areas results in optimization of the performance of each particular domain as well as contribution to the company's overall objectives.

### 13.2.3 Common Engineering Benefits New Initiatives

GM NA.s common approach in the engineering domain improves productivity by reducing the engineering costs and time associated with each new vehicle program. A core metric in this effort is the targeted 90 per cent reuse of the basic design and parts for new vehicle models built on existing platforms, while at the same time reducing proliferation of the number of platform designs in use. This objective is met by commonizing cars in noncustomer viewable ways and reusing the basic design and parts for vehicles built from the same platform.



**Fig.13.4** Common engineering benefiting new initiatives

Common Engineering Improves Productivity by Reducing Costs and Time Associated with Each New Program

CRW's primary objective was to completely commonize manufacturing engineering standards to accommodate widely varying product designs. Applying this strategy

to manufacturing engineering gives GM the ability to achieve a high level of engineering commonality and enables cost-saving and productivity-enhancing automation of both hardware and software. Lessons learned on prior programs are easily incorporated, eliminating the costly potential of making the same mistake twice. It further enables establishment of consistent safety applications across all of the organization's manufacturing operations. Commonality to this extent significantly reduces the time and cost associated with development and maintenance of separate divisional standards and specifications. This is not a small task for GM NA, which originally comprised six separate organizations that developed and maintained their own distinct control system specifications—even within the same plant! For GM NA, the move toward commonality allows these formerly disparate groups to share and benefit from lessons learned through common experience.

### 12.2.4 Common Processes Accelerate Time-to-Market

Successful establishment and execution of product launches have a direct impact on the company's competitiveness in the area of time-to-market. Formerly plagued by delays in its vehicle launches, GM's move to a common product development system has cut its time to market from 42 months to 18 and is still improving as it continues to benefit from lessons learned. This continuous improvement is vitally important for a company targeting introduction of one new vehicle every three weeks for the next five years. Not only are the launches faster, but common processes also enable the company to offer regionally-oriented cars at a reduced cost and/or low volume niche products at a profit.



**Fig. 13.5** Common processes accelerate time-to-market

Common Processes have helped GM cut its Time to Market from 42 Months to 18 months. From a production standpoint, common processes shorten program lead times and improve quality of the end product. Operational efficiency is continually improved as new vehicle launches approach the previously unheard-of status of a non-event. The shorter vehicle development cycle puts pressure on the manufacturing operation to have the vehicle assembly process ready to ramp-up to high volume, high quality production in less time.

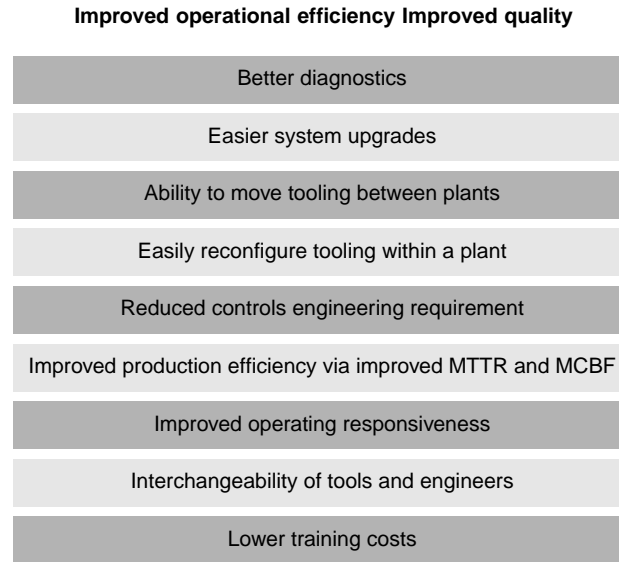
### 13.2.5 Common Manufacturing Systems Lower Costs

For GM NA's CRW group, the move to common manufacturing systems presents numerous opportunities. While certainly not achieved without pain, both internally-generated (the large number of constituencies represented in GM) and externally generated (the large number of OEMs involved in each vehicle launch), GM NA perceived that CRW's common philosophy can help the organization achieve key goals for its vehicle operations. Faster startups/shorter lead times Reduced time to market offer regional products at lower cost offer low-volume niche products at a profit

### 13.2.6 Common Manufacturing Systems Improve Production Efficiency and Lower Costs

Migration to a common controls architecture is expected to benefit GM NA's manufacturing systems in key areas such as improved production efficiency, lower structural costs, and easy interchangeability of tools and engineers. Improvements in production efficiency are achieved by

improvement in two key metrics: Mean Time to Repair (MTTR) and MCBF (Mean Cycles before Failure). Lower structural costs contribute to ongoing reductions in controls engineering requirements. The ultimate goal is that, through the combination of commonality and interchangeability, the controls engineering design requirement for each successive program is reduced significantly.



**Fig.13.6** Common processes that have helped GM to cut its time to market from 42 months to 18 months

### 13.2.7 Common Controls Architecture Lies at the Foundation of GM NA.s Strategy

GM NA is pursuing implementation of its common strategy in a phased fashion, and in the late 1990s the foundation elements of common controls architecture were first put into place. Logic processors and associated development software, network architecture, common 24V voltage, and common safety designs were among the first elements specified. The architecture was also among the first deliverables of the Controls, Robotics, and Welding (CRW) group that was newly organized under a single point of management and staffed with people from various car and truck divisions as well as technical center personnel.

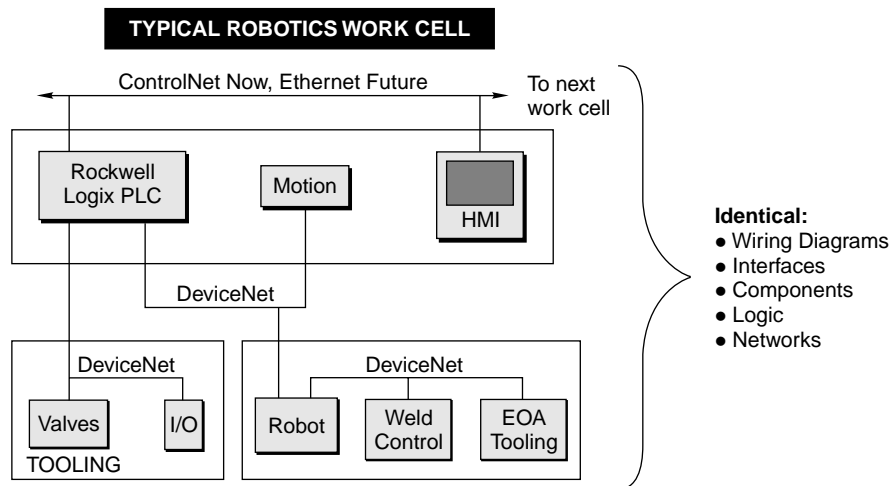
The first order of business for CRW was to decide on a common PLC strategy. After extensive analysis of GMs automation and production needs and the commercial capability of controls suppliers, CRW chose to communize on the Rockwell Automation-centric architecture of Logic processors, RS Logics development software, and Ethernet/ControlNet/DeviceNet network tiering. To the casual observer this may have been an obvious choice, but in fact each of these decisions were made in an environment that could easily have thwarted the team's efforts.

The common controls architecture was among the first deliverables from the new GM NA-wide controls, robotics, and welding organization

CRWs Common Controls Architecture is designed to leverage control industry standards and technology to achieve GM priorities. For example, while General Motors was and remains Rockwell

Automation's largest single customer, at the time the decision was made the Logic control processor and its associated RS Logic development environment were new and unproven relative to the longstanding PLC-5 and SLC-500 lines. Given that bids were issued on a program-by-program basis, some existing programs did not even use Rockwell Automation processors. The decision to adopt a proprietary PLC processor also came in the heyday of market interest in PC-based control, with GM NA's sister unit GM Powertrain serving as the movement's poster child due to their adoption of the PC-based FloPro control software. The limitations of PC-based control and the open control software (OCS) supplier's inability to deal with variability in the open PC-based environment eventually led CRW to forego the widespread adoption of PC-based control for PLCs. The next generations of PLCs were designed to incorporate many of the desirable attributes of a PC such as software flexibility and networking capabilities, while retaining the robustness and reliability of a traditional PLC. The CRW Common Architecture team still recognized the need to leverage readily available market standards and technology.

GM is well acquainted with the high cost associated with proprietary control systems. The drawbacks of these systems, including the inability of proprietary networks to talk to one another, limited flexibility, and negative cost competitiveness have precipitated the move toward common architecture and components within GM NA.



**Fig.13.7** Typical Robotics work cell

Reliance on industry standards was nowhere more apparent than in the network architecture decision-making process that took place in 1997 and 1998. While relatively straightforward given GM NA's relationship with Rockwell Automation, the decision on a device level network was nonetheless confounded by the success of Powertrain and GM Europe with the Profibus DP network. Ability to combine the purchasing power of GM NA, Powertrain, and GM Europe was an attractive value proposition but one that was ultimately not pursued due to the limitations of both GM and the automation supplier. Regardless, GM NA was able to achieve savings ranging from 30 to 60 per cent when it competitively bid components for its open device network relative to its prior proprietary I/O link. At the control level network level the situation was markedly different.

Rockwell Automations (at that time) new ControlNet architecture, the complement to its new line of Logic processors, was a proprietary offering. Wishing to minimize the proprietary component of its new architecture, GM convinced Rockwell Automation to place Control Net technology in the hands of an industry group, Control Net International. This allowed GM NA to potentially source Control Net-based products from multiple vendors.

### 13.2.8 GM NA.s Common Control System Architecture

Given a plan that encompasses such basic infrastructure elements as controls and network architecture, it is important to note that CRW originally positioned these elements of the Common Controls Architecture as to be items for programs beginning in the early 2000.s. Plants were not expected to retrofit existing controls on current programs, and a migration plan was offered with a common set of detailed design standards and specifications. Also, to ensure performance across all applications, all new technologies and architectural components are continually subject to testing in areas such as conformance, performance, and interoperability. Commonization of the most basic components is yielding tremendous savings.

### 13.2.9 Components Contribute to the Bottom Line Common

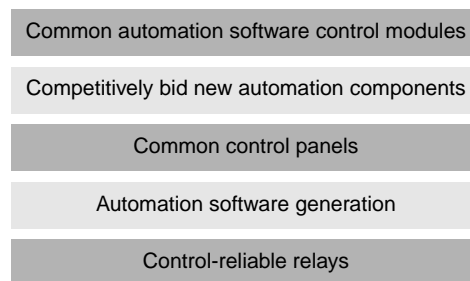
Probably the best-known aspect of GM.s move to common is the competitive bidding of component requirements. In roughly the same time frame that GM.s Common Architecture Team was initiating the Common Controls Architecture, GM NA was beginning to formulate a Common Automation Components Plan. This was no small task considering that the notion of common had to be taken to a very low level such as common voltages, enclosures, connectors, and all manner of field components. The resulting effort involved months of meetings and evaluations concerning a wide range of issues such as NEMA versus IEC components and common connectors. The Common Component Initiative outlined some very specific goals:

- Competitively bid electrical components across multiple GM NA vehicle programs, therefore leveraging GM NA.s total volume.
- Utilize smaller niche component manufacturers only for specific items when this approach is clearly the best choice (cost, safety, compatibility, etc.).
- Achieve the lowest possible automation component cost and efficient parts control management through competitive bidding of supplier bundled automation packages.
- Consolidate the number of suppliers: GM has actually reduced the number of suppliers from 400 to 92, and worked with distributors to consolidate sourcing of numerous components to one common distributor.
- The primary objective in this company-wide initiative was to address the high cost of automation in production line changeovers and new plant implementations.

GM NA wanted to achieve significant cost savings in the implementation of new production automation systems and the upgrade of legacy automation systems. The ultimate goal was to lower the actual production cost of each vehicle produced. Today, the fruits of this effort have netted anywhere from 30 to 60 per cent cost savings for electrical components for automation systems. Cost savings such as these, plus improved operations, have made GM Detroit's low-cost producer.

### 13.2.10 Implementation and Validation Team

The common components team formed at CRW consisted of an implementation team and a validation team. The goal here was to evaluate alternative automation components for functionality and conformity within the scope of CRW's common production architecture, as well as to secure these components for the best price. This approach adheres to GMs overall goal of obtaining the best possible hardware at the most favorable performance/cost ratio. At the same time, there is a concerted effort to maintain standard control software across all production systems in order to preserve their total software investment and consolidate hardware wherever possible. Even with the immediate cost benefits obtained by the Common Components Plan, the CRW Controls Team points out that this strategy was a hard sell across GM NA. The established culture of the procurement process for automation equipment within GM often resisted moving away from established purchasing policies to one of purchasing components based purely on cost and function. There is a real and obvious concern about system compatibility and local support capabilities when introducing alternative components. Additionally, there is a certain comfort level when dealing with a single source automation provider that can assure that all of their equipment will always be compatible. In the end, compatibility and interoperability were rendered non-issues owing to the comprehensive and diligent work by the CRW Common Components Validation and Implementation Team who insured that all potential components would function interchangeably. GM NA will be applying the common philosophy across all areas of their controls architecture. In this current phase they are developing common automation software modules that can be applied to new automation lines. When a product program hits a legacy plant a detailed analysis is performed to determine whether to bring in new equipment using common or Competitive bidding of common components, including



**Fig. 13.8** Key elements of GM.s common controls architecture: 2002–2003

Device Net-based I/O devices, has resulted in cost savings of 30 per cent or more legacy standards. Typically, if the percentage is 25 per cent new equipment, that new equipment will be brought in with the common standards. The idea is to greatly reduce or even eliminate redundant control engineering designs and use common, interchangeable software modules designed with interfaces based on the selection of common component hardware. This approach should drive down control engineering costs significantly. Along with common control software modules CRW is developing automatic software generation tools that should significantly improve control system implementation times. GM has classified automation components into general categories that identify major sub-groups based on function and automation infrastructure. This enables them to focus on identifying and selecting the suppliers that fit into specific component categories.

Category	Components
Large Electrical Packages	All electrical components and I/O
Controls	PLCs, HMI, SoftLogic
Network Infrastructure	Cabling, routers, bridges, hubs, etc.
Factory Networks	Device and Control Network infrastructure

**Fig. 13.9** Common component categories lower component costs, streamline procurement, and contribute to stable designs

### 13.2.11 Common Networks

In 1997, GM NA announced its Open Network Decision that specified Ethernet, ControlNet, and DeviceNet as the core networks within its Common Controls Architecture. Standardization on the DeviceNet network in particular allowed the company to open up bidding on its I/O level devices, which resulted in savings exceeding 30 per cent relative to prior programs. Along with lower component, material, and training costs, adoption of common components has streamlined procurement, shortened lead times, and contributed to establishment of stable designs. CRW plans to establish Ethernet/IP communications at the control bus level. This deployment complies with the Common Controls Architecture migration strategy to utilize Ethernet to ultimately provide plant-wide device connectivity. However, DeviceNet and eventually Device Net Safety Bus will be used for the foreseeable future.

### 13.2.12 Common Control Panels

CRW is moving toward incorporation of common control panels throughout their production lines. Their goal was to create a modular standard for an identical control panel that would come in four standard sizes. The immediate benefits were lower design costs due to a standard panel design, simplified logistics in obtaining panels for planned implementations or on short notice, and the ability to bid out large quantity build contracts leading to significant cost reduction per panel. Electrical control systems could be standardized as well as 80 percent common and identical designs for wiring design templates.

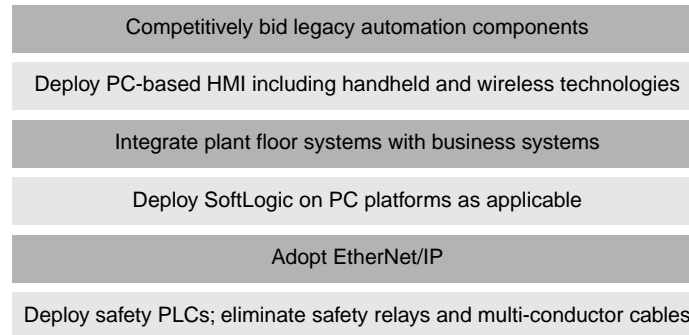
### 13.2.13 Common HMI

CRW is taking an evolutionary approach to common HMI, with the first steps being a migration from Rockwell Automation's Panel View to Panel View Plus. One of the benefits introduced here is a thin-screen form factor.

By 2004 the evolutionary approach gives way to a more revolutionary direction with the planned use of Visual Basic generated Active X re-useable HMI components, along with RSMobile View handheld CE devices. Wireless devices will come into play, but not in direct connection to controls

where safety issues are critical. As GM migrates to applications of PC based HMI, this will translate into a common generic HMI workstation that will be able to host multiple production applications.

This will provide a common HMI look and feel for across all production lines and a uniform control information presentation interface for any function whether it's welding, painting, or general assembly. Additionally, the migration to an Ethernet based networking infrastructure will flatten out a factory architecture that was very hierarchical from the device bus level upward to control and business systems.



**Fig.13.10** Key elements of the deployment phase of GM's common controls architecture: 2004–2005

The reasons for GM's deployment of PC-based HMI are straightforward and compelling. Today, these applications are cost competitive with proprietary HMIs. Combined with Ethernet communications, a single HMI application can take the place of several HMIs in several forms, including a PLC interface, weld controller data entry, robot teach pendant, or servo teach pendant. Finally, they are practical to deploy using diskless technology or as a thin-client intranet browser. Production lines across all of GM NA plants will have a common look and feel that all plant floor personnel within any functional area (welding, painting, general assembly, etc.) can relate to. Additionally, this will present an opportunity to apply wireless and remote access technologies on the plant floor to further expand the integration capabilities of the common HMI platform. There was an evolving need across their Metal Fab, Body Shop, Painting, and General Assembly areas for an integrated solution that would include PC-based HMI and controls on a single platform that would lead to consolidation of hardware. It was found that significant cost-savings could be realized with this integrated platform approach over using a standalone platform for Soft Logic only. This was ultimately one of the qualifying cost justifications for the move to PC-based HMI.

### 13.2.14 A Common Goal: Connecting the Plant Floor with Business System

Plant floor automation systems need to connect to upper tier business systems so that production lines are in sync with supply chain execution, scheduling, and other production management systems. GM NA recognizes that control systems have not only matured in terms of applied technology and a broader scope of supplier offerings, but have truly evolved to a reliable, robust, and capable automation applications that meet the requirements of today's collaborative manufacturing environment. Additionally, CRW recognized the need to provide an improved interface between

plant floor control systems and business systems. There existed a requirement to establish a reliable interface with existing PLC-based control systems. Creating the link between business systems and PLCs has become a major objective for CRW as the benefits of this exchange of information became evident. The concept of sharing control system data, particularly information required for remote diagnostics, allows remote monitoring and provides a range of interaction with Supply Chain Management, Plant Asset Management, and Production Management systems.

### 13.2.15 Common Controls Architecture Enables Collaborative Manufacturing

As manufacturers move into the era of the Internet-enabled production operations, the collateral benefits of open systems automation supercede the issue of the PC platform used solely for control systems. Highly distributed factory production systems along with the collaborative manufacturing requirements levied by the need to connect and disseminate information, from the most granular device level to enterprise supply chains, necessitate not just PC-based HMI, but information systems-based architectures across the factory floor. Today, the Internet enables the sharing of real time information both internal and external to the boundaries of a company. The concept of sharing control system data, particularly information required for remote diagnostics, allows remote monitoring and supplies a range of interaction with Supply Chain Management (SCM), Plant Asset Management Systems, and Production Management (PM) systems. With the convergence of IT and factory operations, the boundaries between disparate systems are disappearing and collaborative manufacturing becomes critical across the product lifecycle. Web services, powered by XML, Java technology, and .NET frameworks, and coupled with open systems architecture will enable the visualization, diagnosis, and graphical debugging of the automation process via any Internet browser, regardless of the operating system. Web servers can be embedded in PLCs, motion controllers, drives, CNCs, sensors, and all classifications of field devices. These Web-based factory architectures will collect, store, and move controller and device data through Web servers and across existing Ethernet TCP/IP back planes to supervisory and enterprise tiers to drive applications like machine condition monitoring and Enterprise Asset Management (EAM) that will help preserve investments in factory equipment. Windows-based PC platforms have been a significant component in the overall automation solution. The hardware reliability of today's PC platform is equal to PLCs, and GM will apply PC-based control where it makes sense both from a controls and business case perspective. Typically, this will occur where proprietary process equipment is delivered with PC-based control, using Soft Logic to interface production equipment with conveyors and other automated systems. Moreover, next generation PLCs are now capable of robust processing, and able to perform multi-operational functions such as network communications, common operating systems and programming language, all on a common back plane. It has become clear that data sharing must be at the core of factory control systems. In today's collaborative manufacturing environment, real-time data acquisition from intelligent devices on the factory floor will need to connect to the upper tier PM, SCM, and PLM systems. Automated factory systems will consist of hybrid combinations of PLCs and PC-based control that best fit the automation requirements of the production process. GM will continue to use the PLC throughout their factories, but will complement their use with PC-based HMI and PC-based control for those applications that demand more resource intensive processing.

### 13.2.16 Acronym Reference

AI	Artificial Intelligence
ANSI	American National Standards Institute
API	Application Program Interface
APS	Advanced Planning and Scheduling
B2B	Business-to-Business
BPR	Business Process Reengineering
CAGR	Compound Annual Growth Rate
CAN	Controller Area Network
CMM	Collaborative Manufacturing Management
CNC	Computer Numeric Control
CPM	Collaborative Production Management
CRM	Customer Relationship Management
CRW	Controls, Robotics, and Welding Group within GM NA
EAI	Enterprise Application Integration
EAM	Enterprise Asset Management
ERP	Enterprise Resource Planning
GMNA	General Motors North American
HMI	Human Machine Interface
IT	Information Technology
LAN	Local Area Network
MCBF	Mean Cycles Before Failure
MRP	Materials Resource Planning
MTTR	Mean Time to Repair
OCS	Open Control System
OEM	Original Equipment Manufacturer
PLC	Programmable Logic Controller
PM	Production Management
ROA	Return on Assets
ROI	Return on Investment
SCM	Supply Chain Management
TMS	Transportation Management System
WMS	Warehouse Management System

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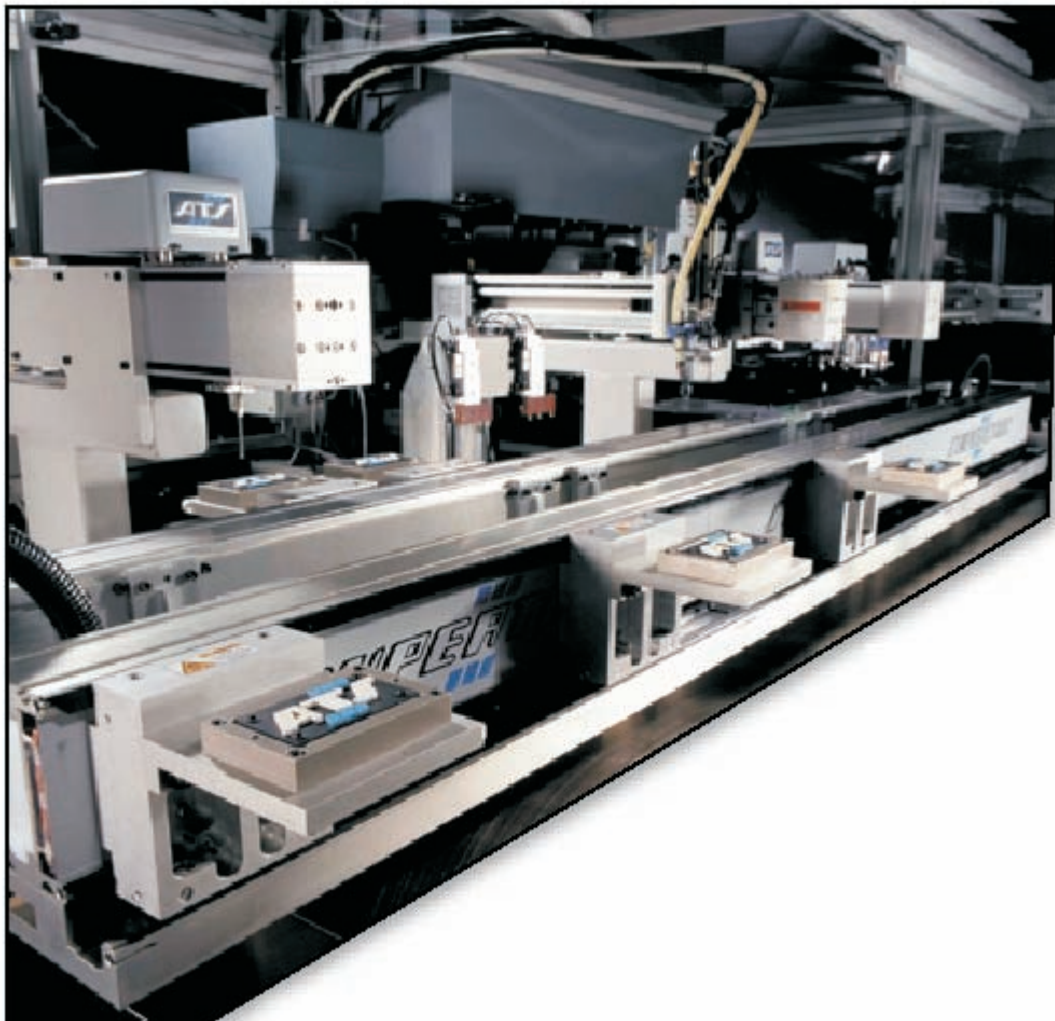
### 13.3 CASE III: THE ROVER LM-500 FMS

#### 13.3.1 Introduction

A flexible manufacturing system and host at rover cars Ltd. Birmingham, UK has been developed for the manufacture of 16-valve cylinder heads.

The object of the host development is

- to ensure optimum machine capacity utilization
- to achieve high product quality
- to enable a flexible response to changes in production and market requirements



**Fig. 13.11** Flexible manufacturing system

The FMS is used for mixed batch and series production; the FMS host controller co-ordinate 3 production areas.

1. The first production area is for machining piece parts
2. The second production area is for finishing including assembly of piece parts.
3. Third production area is for supplying raw materials, removal of finished parts and organization of a quarantine buffer.

Interconnection of these three production areas is provided by two fully automatic robot-clamping areas, which clamp piece parts, supplied to the FMS on transport containers, on to pallets, which then carry the work into the FMS under host control, the robots also unload the completed work from the pallets for removal of the work from the FMS. With in these three production areas the host computer supplies the processing station with necessary tooling and part-program information and also provides

The inductive transport system with transport orders to supply the machines with pieces parts. The host's material flow control modules organize material supply in accordance with the piece parts process plans. There can be adapted by the operators from one production order to another using the host, if it proves necessary to change a production orders process sequence.

Quality control is in the form of random part measurement organized by the host. The host blocks any m/c responsible for exceeding tolerance and identified to the operator the piece parts which have been in the quarantine store since the last random sample inspection. There the operator then inspects quarantined piece parts.

### **13.3.2 The FMS Layout Incorporate**

#### **13.3.2.1 Raw Material Supply Area**

It consists of autonomous transport system with trucks, input and output station for blanks and production parts, connection to a transfer line via robotic cell storage and quarantine station for 16 value cylinder head and can shaft areas in an intermediate buffer, for delivery of the dieses cylinder heads as they are removed from the supply transfer line a service station for the manual inspection of work pieces and the exchange of transport containers.

#### **13.3.2.2 Machining Area**

It consists of machining centers each with 80 magazine pockets, a pallet changes and a station for chip containers. Head—indexing (bore) machines each with a pallet changes, a wash station with a wash robot so that several pallets can be washed simultaneously, a coordinate measuring machine, a chip connection station, a tool-cutter setting m/c, service station for a manual inspection and scrap/refinishing work, a transport system with AGV'S.

#### **13.3.2.3 Assembly and Finishing Area**

The robot assembly cell for the assembly of value seats to value guides and heads to cover for sixteen value cylinder heads and a finishing cell, each cell consist of several special purpose machines and a robot. Total quality control is integrated in the cells.

#### 13.3.2.4 Robotic Clamping Cells

In robotic clamping cells the material supply, machining and assembly areas are linked with two fully automatic robotic clamping cells, each clamping cell consist of a conveyer for the transfer of max of nine pallets a number of stations for the raw material transport containers and a robot and several manual buffer store areas.

In order to minimize transfer times, all stations, except for the machining centers, are designed in such a way that a transport vehicle can deliver and pick a pallet up simultaneously.

#### 13.3.3 The FMS Host Control

The host organizer the production of a piece part mixes of ten different types. The piece parts are produced in an average batch size of 500 parts per batch.

The LM-500 host function are:

- Control of the processing machines
- DNC (direct numerical control)
- Release of a machines for processing
- Management of the tools in the machines magazines and of the piece parts on the pallets in the machines

#### 13.3.4 Control of the Automatic Clamping Area

- Control of the material supply/removal system
- Control of tool-setting activities
- Capacity planning
- Materials tracking
- Management of control data
- Transfer of NC Programs from a CAD computer to the host computer

### 13.4 CASE IV: THE HNH (HATTERSLEY MEWMAN HENDER) FMS

An FMS host computer has been developed for a machining system installed to manufacture high and low pressure bodies and caps for water, gas and oil valves.

Figure 13.12 shows the system layout

This FMS, installed at HNS Ltd., Ormskirk, UK, has been designed for the manufacture of 2750 different types of pieceparts. It has been developed for a high throughput rate for pieceparts with short machining cycle times.

The FMS consists of primary and secondary facilities. The primary facilities include 5 universal machining centers and 2 special processing centers. The secondary facilities consist of auxiliary facilities consist of auxiliary facilities such as tool setting and manual workstations.

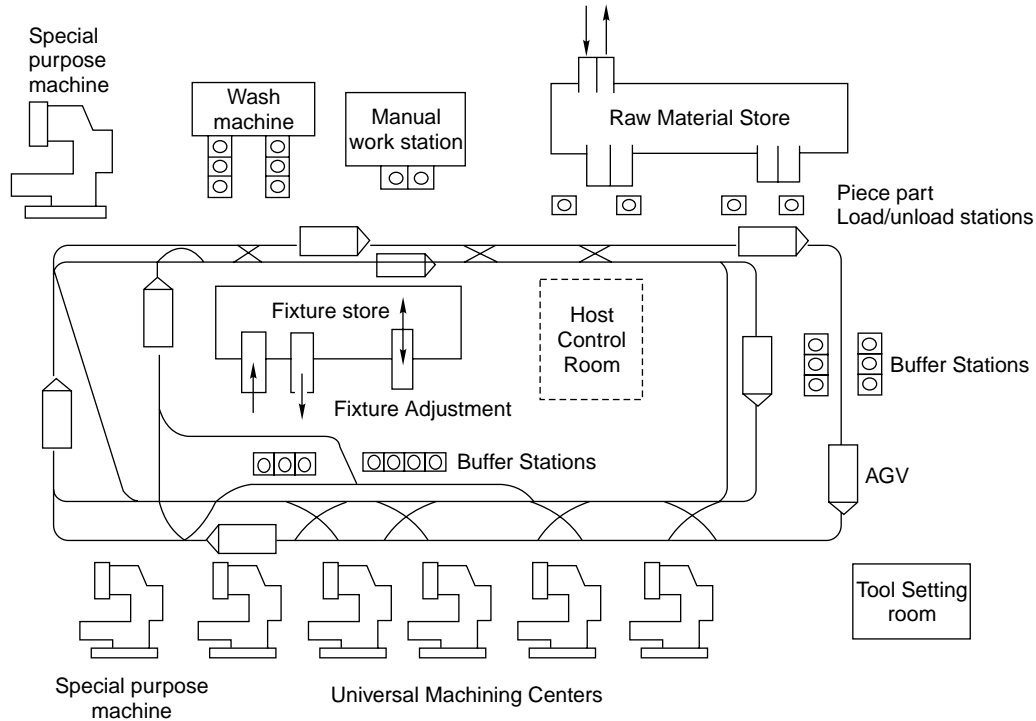


Fig. 13.12 The Hattersley Newman Hender FMS

### 13.4.1 The System Layout and Facilities

**(a) Machining centers:** Two 5 axis horizontal machining centers work under host control in the FMS. All the machines have a rotating pallet changer, each with two pallet buffer stations. These stations transfer pallets to and from the transport (eight automated guided vehicles) and also to and from the machining zone in the machine tools. The 5 universal machining centers have 2 magazines, each with 40 tool pockets per magazine. Thus each machine has a capacity for 80 single pocket tools. The 2 special purpose out facing machines (OFM) each have one magazine of 40 tools. The magazines are either loaded in an interactive mode by the operator in dialogue with the host computer or manually with the help of a data acquisition control terminal, which is linked with the machine's numerical controller.

**(b) Processing centers:** The system incorporates 2 types of processing centers—a wash machine and two manual workstations:

**Wash machine:** Two conveyor belts (one for input and one for output of pallets) can each convey three pallets. The wash booth can accommodate up to seven pallets. The pallets are washed in the booth and turned upside down to allow them to drip most of the water out of the piece parts before being rinsed and dried with blown air.

**Manual workstations (ring fitting area):** The system's two manual workstations enable operators with working instructions via two data acquisition control terminals. The operators fit the rings into

each valve body (which are supplied by the transport system to the workstation). When the job has been completed, the operator informs the host computer through a dialogue using the terminal. The host computer is responsible for organizing the removal of the piecepart from the workstation.

### 13.4.2 HNH Secondary Facilities

The FMS consists of auxiliary stations and facilities.

#### (a) Auxiliary stations:

- **Load/unload stations:** The FMS has four piecepart load/unload stations. The host works in an interactive mode with the operators. The host computer ensures that the operators are supplied with the information and instructions concerning which pieceparts are to be loaded and /unloaded. Loading and unloading is performed with the instructions being displayed on a further four data acquisition control terminals, one at each station. The host computer organizes the delivery and removal of empty and loaded pallets at the stations.
- **Fixture setting station:** To readjust the fixture on a pallet into a different setting to carry an alternative piecepart type, the host computer can communicate interactively with an operator, at the fixture store, through a seventh data acquisition control terminal. The purpose of this operation is to enable the fixture concerned to be used for another type product mix.
- **Administration of tools:** Tools are assembled manually. The dimensional offsets of the tools of the tools can be checked on a tool setting machine generates a bar code to identify the tool that has been set. This code is later during an interactive host and operator dialogue, at the machine tool magazine, for the loading and unloading of tools. Tools are exchanged at the machines manually. The host administrator's tool lives and the required tool exchanges.

#### (b) Auxiliary facilities:

- **Transport system:** The transport system consists of a controller (microprocessor) and eight AGVs guided by submerged inductive control wires. An AGV battery charging area is also included in the transport system. The host computer supplies transport orders to the transport system controller, which determines which AGVs are needed to carry out the order.
- **Buffer stores:** The FMS has 20 buffer stores to store the empty and loaded pallets while they are waiting to be taken to another transfer station (i.e., a load/unload station or a machine tool, etc.)
- **Maintenance area:** Empty and loaded pallets are taken into and out of the system at a special transfer station. This facility caters for pallets that may be damaged or need servicing or for scrapped pieceparts.
- **Raw material size:** Containers with raw material (pieceparts such as forged valve bodies) are stored in the stacker store which is located in front of the load and unload area. The store is served by two forklift stacker cranes. It supplies the piecepart containers to the load/unload operator via motor roller conveyors. The store can accommodate up to containers.
- **Fixture store:** A second stacker crane has space for approximately 120 fixtures for their storage when they are not used live on the FMS. At any one time the fixtures are assigned to a specific pallet. They can be reset by an operator when the stacker crane supplies the fixtures via a motorized roller conveyor to the manual workstation for the resetting of the fixture.

The fixtures are fetched from and delivered to the FMS by means of two further input and output motorized roller conveyors. These fixtures are collected by AGVs for transfer into the system.

### 13.4.3 Production Strategy

The host through the following parameters fulfills the strategy for the production:

- (i) Administration of 5000 NC part programs
- (ii) Up to 2750 different piece parts to be machined in the FMS. Each piece part needs one NC part program. As some of the work pieces need more than one operation that is more than one NC part program, the host has to manage the total number of 5000 part programs
- (iii) 26 different pieceparts can be manufactured simultaneously in a mix production strategy
- (iv) **Piece part pallets administration.** The FMS has 120 identical pallets, each of which can carry one fixture. A total of 64 different fixture designs are available which allow all the 2750 work pieces to be incorporated into the FMS
- (v) **Tool administration.** The FMS needs 600 tools. These are made up of 140 different tool types. The tool type mixes in the magazines are not changed but administered as tool sets. Sister tools are exchanged when a master tool becomes blunt.
- (vi) **Ring administration.** There are 50 different types of rings to be fitted into the relevant valve bodies in the ring fitting area. The rings are made of various types of metal.

Production a HNH is determined mainly by the following factors:

- 1–1000 parts per production order
- 12–17 production orders per active production mix
- Two ‘filler mixes’ per 1–10 production orders
- Up to 26 piece par pallets in the system at one time
- 2 to 3 shifts per day
- NC program runtimes of 2–40 min. (average 5 min.)
- Time spent by work piece in the FMS (throughput/workpiece) 10–140 min. (average 80 min.)
- Typical transport time 2 min.
- Up to eight pallet settings per piece part (average 2 settings)
- Up to seven operations per pallet setting (average 5)
- Up to 5 alternative allocations of interchangeable machine tools to one piece part operation (the 5 horizontal machining centers)

Three main routes are used which are determined by the different tool set mixes. The host computer also manages various other routes. The principal routings are:

- Load—horizontal machining center—wash—unload
- Load—horizontal machining center—horizontal facing machine—wash—unload
- Load—horizontal machining center—wash—ring fitting area—horizontal facing machine—wash—unload

The host control technology is provided by a Siemens FMS host computer. The host computer organizes the activities that are required for production. These are mentioned in Table 13.1.

**Table 13.1** The HNH FMS host functions

<p><i>Data base management system:</i></p> <p>Management of master and control data:</p> <ul style="list-style-type: none"><li>• Factory calendar</li><li>• Planning sheets</li><li>• Work piece pallets</li><li>• Tools</li><li>• NC programs</li><li>• Production orders</li></ul> <p><i>Capacity planning of machining centers:</i></p> <p>Tool requirements Pallet requirements Utilization/loading</p> <p><i>Preparation:</i></p> <p>Tool Pallets DNC</p> <p><i>Material flow:</i></p> <p>Control of production facilities Machining centers with DNC Transfer programs to the machines Material flow control Material tracking Order control Production facilities check End of work switching</p> <p>Production Data Acquisition (PDA):</p> <ul style="list-style-type: none"><li>• Order management</li></ul> <p>Machine Data Acquisition (MDA):</p> <ul style="list-style-type: none"><li>• Mode change</li><li>• Fault messages</li><li>• Organizational interruption</li></ul> <p><i>Monitoring:</i></p> <p>Data logging Message logging Lower manpower shift Visualization of the system Machine loading statistics Shift log</p>
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