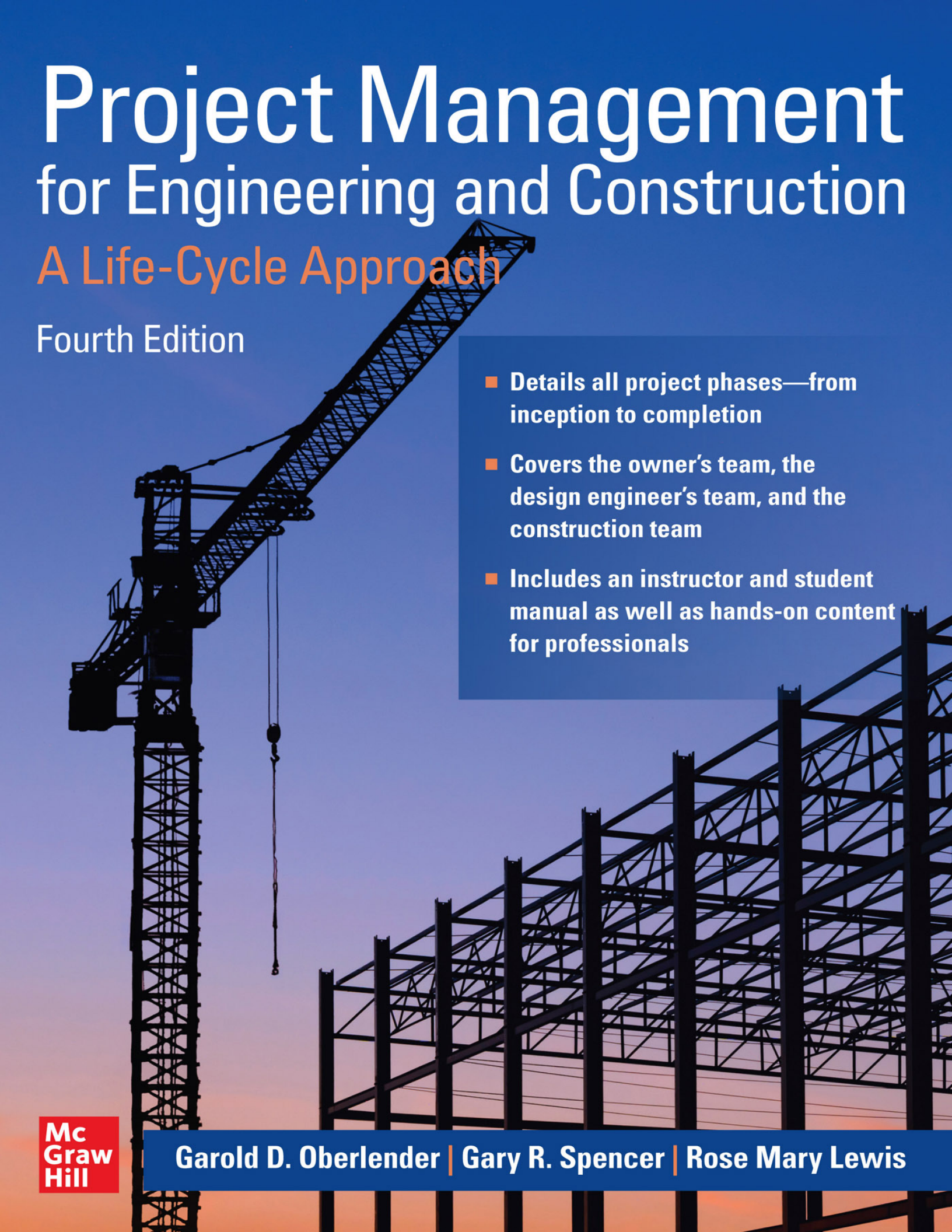
Project Management for Engineering and Construction

A Life-Cycle Approach

Fourth Edition



- Details all project phases—from inception to completion
- Covers the owner's team, the design engineer's team, and the construction team
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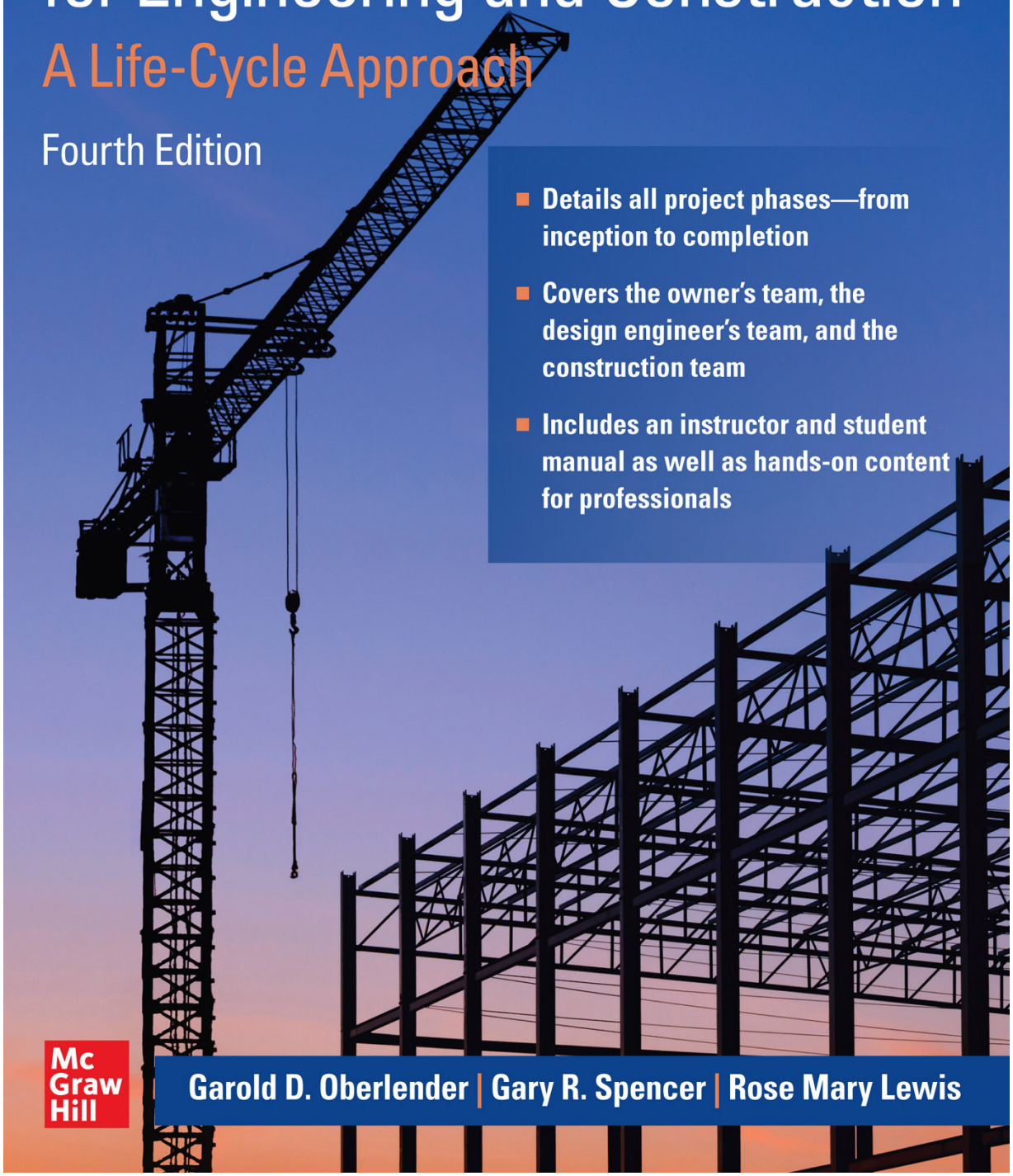
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Ms. Lewis holds B.S. and M.S. degrees in civil engineering. She completed Harvard Business School's General Management Program. Ms. Lewis is a registered professional engineer in Oklahoma and a member of Chi Epsilon, Tau Beta Pi, and Phi Kappa Phi honorary societies. Ms. Lewis was also a certified Project Management Professional by PMI until her retirement.

Project Management for Engineering and Construction

A Life-Cycle Approach

Garold D. Oberlender
Gary R. Spencer
Rose Mary Lewis

Fourth Edition



New York Chicago San Francisco
Athens London Madrid
Mexico City Milan New Delhi
Singapore Sydney Toronto

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Preface

This book presents the principles and techniques of managing engineering and construction projects from the initial conceptual phase, through design and construction, to completion. It uses a project lifecycle to emphasize the importance of project management during the early stages of project development. The project initiation stages of the project lifecycle provide the best ability to influence the quality, cost, and schedule of a project. Most books discuss project management during construction, after the scope of work is fully defined, the budget is fixed, and the completion date is firm. It is then too late to make any significant adjustments to improve the quality, cost, or schedule of the project.

Although each project is unique, there is certain information that must be identified and organized at the beginning of a project before any work is started. Numerous tables and graphs are presented and discussed throughout this book to provide guidelines for management of the three basic components of a project: scope, budget, and schedule. Throughout this book, achieving project quality to meet the owner's satisfaction is emphasized as an integral part of project management.

This fourth edition also has been reorganized into the sequence of steps a project will experience in order to emphasize the project lifecycle. A new chapter has been added to this fourth edition that addresses project document control. The topic of project document control is often overlooked, yet it is a key contributor to the success of

managing a project because the project team need the information contained in project documents. This topic is covered from the perspective of the engineer who is employed with either the owner's organization or the design firm.

In preparing this fourth edition, the authors have updated example problems in all chapters and added new material and electronic content to many chapters. The chapters have been rearranged to follow the project lifecycle presented in this book.

The intended audience of this book is engineers in industry who aid the owner in the feasibility study, coordinate the design effort, and witness construction in the field. It is also intended for students of university programs in engineering, architecture, and construction because graduates of these programs usually are involved in project management as they advance in their careers.

This book is based on the authors' experience in working with hundreds of project managers in the engineering and construction industry and on personal experiences across many years and several industries. Much of the material in this book is based on experience and formal and informal discussions with these project managers, who are actively involved in the practice of project management. Although the authors have observed that no two project managers operate exactly the same, there are common elements that apply to all projects and all project managers. The authors present these common elements of effective project management that have been successfully applied in practice.

The authors would like to thank Dan Mitchell for his careful review, helpful comments, and advice in the development of the project lifecycle approach presented in this book. Special thanks and gratitude is given to Jana Oberlender for her review and comments of copy editing

and page proofs for this fourth edition. The authors would also like to thank the many project managers in industry who have shared their successes, and problems, and who have influenced the authors' thoughts in the development of this book.

For further information, please see the following website for online ancillaries: https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E.

Garold D. Oberlender
Gary Rock Spencer
Rose Mary Lewis

CHAPTER 1
Introduction

Purpose of This Book

The purpose of this book is to present the principles and techniques of project management beginning with the conceptual phase by the owner, through coordination of design and construction, to project completion. Emphasis is placed on managing the project in its early stage of development, during the owner's study and design. It is presented from this perspective because the ability to influence the overall quality, cost, and schedule of a project can best be achieved early in the life of a project. Most books and articles discuss project management during the construction phase, after design is completed. At this time, in the life of a project, the scope of work is fully defined, the budget is fixed, and the completion date is firm. It is then too late to make any significant adjustments to improve the quality, cost, or schedule of the project.

Experienced project managers agree that the procedures used for project management vary from company to company and even among individuals within a company. Although each manager develops his or her own style of management and each project is unique, there are basic principles that apply to all projects and project managers. This book presents these principles and illustrates the basic steps, and sequencing of steps, to develop a work plan to

manage a project through each phase from conceptual development to completion.

Project management requires teamwork among the three principal contracting parties: the owner, designer, and contractor. The coordination of the design and construction of a project requires planning and organizing a team of people who are dedicated to a common goal of completing the project for the owner. Even a small project involves a large number of people who work for different organizations. The key to a successful project is the selection and coordination of people who have the ability to detect and solve problems and to complete the right project on time and within budget.

Throughout this book, the importance of management skills is emphasized to enable the user to develop his or her own style of project management. The focus is to apply project management at the beginning of the project when it is first formulated. Too often, the formal organization to manage a project is not developed until the beginning of the construction phase. This book presents the information that must be assembled and managed during the development and engineering design phase to bring a project to successful completion for use by the owner.

The intended audience of this book is new and experienced project professionals as well as students enrolled in university programs in engineering and construction. It is also intended for design professionals who aid the owner in the feasibility study, coordinate the design effort, and witness construction in the field. This book is also for personnel in the owner’s organization who are involved in the design and construction process.

Arrangement of This Book

A discussion of project management is difficult because there are many ways a project can be handled. The design and/or construction of a project can be performed by one or more parties. Regardless of the method that is used to handle a project, the lifecycle of a project generally flows through the following phases and describes project management in its simplest form:

Phase 1—Determining *project feasibility* to satisfy business objectives
Phase 2—*Conceptualization* of project alternatives to accomplish phase 1 objectives
Phase 3—Developing *detailed project scope* for the selected alternative
Phase 4—Performing *detailed engineering designs* based on the project scope
Phase 5—*Construction* through start-up and hand over to owner and close out

Beginning in the earliest phases, project management practices include many activities:

- Collaborating with owner's project sponsor to clearly understand the business and facility objectives, and potential alternatives to consider
- Team selection and development
- Establishing document control requirements
- Developing the Project Charter, Project Execution Plan, and Design Basis Memorandum including project scope, budget, and completion date
- Preparing and documenting early project cost estimates for economic evaluation
- Conducting risk assessments as the project progresses toward approval and funding

- Project scheduling and tracking including detailed design work and project construction, comparing plan to actual (scope, cost, time) to ensure successful project completion
- Project close out—consisting of final completion to ensure owner satisfaction, final testing, inspection, documentation, and confirming issue resolution and handing over the project to the owner.

In practice, there is considerable overlap between the activities, because any one activity may affect one or more other activities. For example, budget preparation overlaps project definition and scope development. Similarly, project scheduling relates project scope and budget to project tracking and control.

The topic of project management is further complicated because the responsibility for these activities usually involves many parties. Thus, the above steps must all be integrated together to successfully manage a project. Subsequent chapters of this book describe each of these activities.

Chapter 1, Introduction, defines general principles related to project management. These basic principles must be fully understood because they apply to all the remaining chapters. Many of the problems associated with project management are caused by failure to apply the basic management principles that are presented in Chapter 1.

Chapter 2, Project Definition, presents material that is generally performed by the owner during the Feasibility, Conceptualization, and Detailed Scope phases. However, the owner may contract the services of a design organization to assist with the any or all aspects of these early phases. The project manager should be involved during feasibility and conceptualization phases to establish the objectives and scope. This requires input from

experienced technical people that represent every aspect of the proposed project.

Chapter 3, Detailed Scope—Work Plan Development, applies to the project manager who is responsible for management of the of the entire project for the owner or for the project manager responsible for the design effort. Generally, he or she is employed by the professional design organization, which may be an agency of the owner or under contract by the owner to perform design services. The material presented in this chapter is important because it establishes the work plan that is the framework for guiding the entire project effort. The information in this chapter relates to all the project management steps and chapters of this book.

Chapter 4, Team Selection and Development, presents the human aspects of project management. The project team is a group of diverse individuals, each with a special expertise, that performs the work necessary to complete the project. Team members may be remote or colocated. As leader of the project team, the project manager acts as a hub to answer questions, coordinate the work and to make sure the team understands what is expected of them and the desired outcome of the project.

Chapter 5, Project Document Control, comprises an essential and often undervalued function for engineering projects. Document control must begin in the earliest phases and encompass all aspects ranging from electronic communication, myriad of reports, drawings, and all construction documents. This function requires dedicated staff and a disciplined project team to be effective. Well-executed document control saves enumerable hours of wasted staff time spent searching for the correct documents or drawing versions. It can be considered risk mitigation for communication issues or noncompliance with regulations, permits, or contracts.

Chapter 6, Early Estimates, presents the techniques and processes of preparing estimates in the early phases of a project. As a project proceeds through the prefunding lifecycle phases, the early estimate will reflect the additional information gained from developing the project. Preparation of early estimates is a prerequisite to project budgeting. For engineering and construction projects, the early cost estimate is used by the owner in making economic decisions to approve the project. The early cost estimate is a key project parameter for cost control during the design process.

Chapter 7, Project Budgeting, applies to all parties in a project: the owner, designer, and contractor. The budget must be linked to the quantity, quality, risk profile, and schedule of the work to be accomplished. These parameters are established in the funding authorization for the project. A change in scope or schedule almost always affects the budget, so the project manager must continually be alert to changes in a project and to relate any changes to the budget.

Chapter 8, Risk Management, involves taking a pessimistic view of the project to identify events that can adversely affect the project. Quantifying the impact of those events and the probability of occurrence provides for contingency budgeting for cost and schedule. As the project progresses through the development phases, subsequent updates to the risk assessment help owners make informed funding decisions.

Chapter 9, Design Proposals, presents the process of preparing proposals from the design organization to the owner. After the owner has defined the goals, objectives, intended use, and desired outcome of the project, a request for proposals is solicited from the design organization. The design organization must convert the owner’s expectations of the project into an engineering scope of work, budget,

and schedule. Once awarded, the design organization must manage the design process to meet the stated objectives.

Chapter 10, Project Planning and Scheduling, provides the detailed base against which all activities are measured. The schedule integrates the work to be accomplished by those who will perform it, within the budget and time frame set by the owner. Project scheduling cannot be accomplished without a well-defined work plan, as described in Chapter 3, and it forms the basis for project tracking, as described in Chapter 13.

Chapter 11, Design Coordination, applies to the project manager of the design organization. The quality, cost, and schedule of a project is highly dependent on the effectiveness of the design effort. The result of the design process is to produce plans and specifications in a timely manner that meet the intended use of the project by the owner. The product of design must be within the owner's approved budget and schedule and must be constructable by the construction contractor.

Chapter 12, Construction Phase, is important because most of the cost of a project is expended in the construction phase, and the quality of the final project is highly dependent on the quality of work that is performed by the construction contractors. Most of the books written on project management have been directed toward a project in the construction phase. This book emphasizes project management from the initial conception of the project by the owner, through coordination of design and development of the construction documents, with reduced emphasis on the construction phase, and fully details project close out.

Chapter 13, Monitoring and Reporting, cannot be effectively accomplished without a well-defined work plan, as described in Chapter 3, and a detailed schedule, as described in Chapter 10. This chapter is important because there is always a tendency for scope growth, cost overrun,

or schedule delays. A control system must simultaneously monitor the three basic components of a project: the work accomplished, the capital spent, and the time expended. These three components must be collectively monitored, not as individual components, because a change in any one component usually will affect the other two components.

Chapter 14, Project Close Out, discusses the steps required to complete a project and turn it over to the owner. This is an important phase of a project because the owner will have expended most of the budget for the project, but will not receive any benefits from the expenditures until it is completed and ready for use. Also, it is sometimes difficult to close a project because there are always many small items that must be finished.

Chapter 15, Personal Management Skills, addresses the human or “soft” aspects of project management. Although the primary emphasis of this book is on the techniques of project management, the project manager must possess a broad range of nontechnical skills to lead, motivate, and form a cohesive project team. Project managers must overcome the challenges of remote team members, provide clear and accurate communication, and make decisions with uncertainty, among others.

Definition of a Project

A project is a time-bound endeavor that is undertaken to produce the results that are expected from the requesting party. For this book, a project may be design only, construction only, or a combination of design and construction. A project consists of three components: scope, budget, and schedule. When a project is first assigned to a project manager, it is important that all three of these components be clearly defined. Throughout this book, the term *Scope* represents the work to be accomplished, that is,

the quantity and quality of work. *Budget* refers to costs, measured in dollars and/or labor-hours of work. *Schedule* refers to the planning, logical sequencing, and timing of the work to be performed. The quality of a project must meet the owner's business and facility objectives and is an integral part of project management.

Figure 1-1 is shown as an equilateral triangle which is the most stable geometric shape. Scope is shown at the top of the triangle to highlight its importance as the first task in developing a project budget and project schedule. Scope, budget, and schedule are essential predecessors to building a good project work plan to be used during the project's execution.

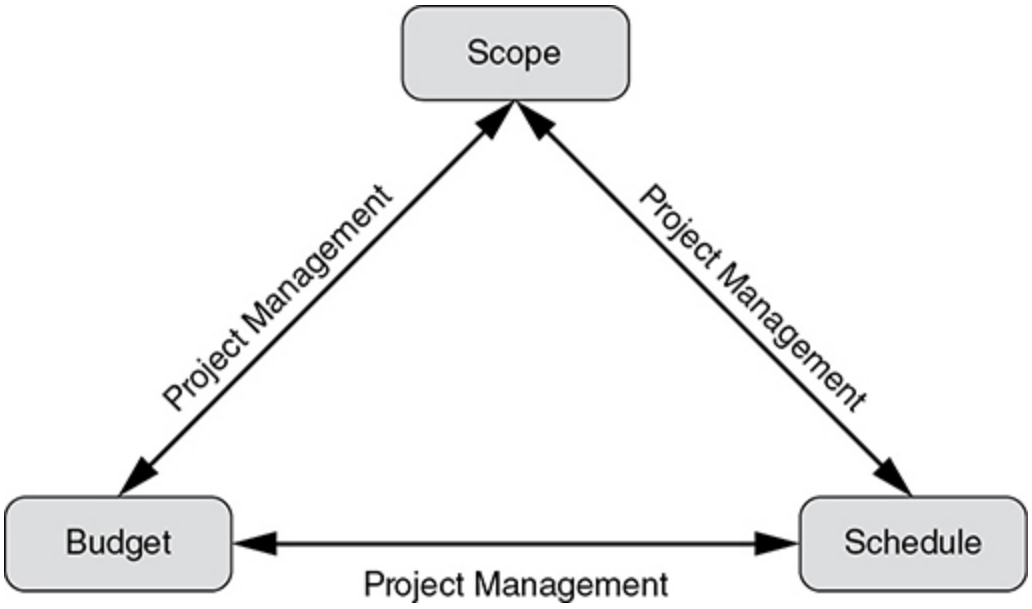


FIGURE 1-1 Principal components of a project.

All three components of the project are of equal importance in the successful completion of a project. Scope is the first component that must be developed because an accurate scope must be known before an accurate budget and schedule can be known. Just because scope should be defined first does not indicate it is more important than the

budget and schedule. To illustrate, when a project with a well-defined scope is completed, but the final cost is extremely high (budget problem) and/or the completion date is extremely late (schedule problem), it is not a successful project. Any adjustment in the scope of work requires a corresponding adjustment in the budget and schedule. This principle applies between any and all of the three components of a project. This simple concept of a balance between scope, budget, and schedule is sometimes not fully recognized during early project development as well as during design and construction. Using project management processes and principles creates a dynamic binding force to keep balance between the three essential components.

Project management (people) is the binding force for the entire system. It is people that make things happen, not things. It is the project team that develops the components (scope, budget, schedule) of a project. Project management (people) is the key component to achieve a successful project.

The source of many problems associated with a project is failure to properly define the project scope. Too often the focus is just on budget or schedule. Not only should the scope, budget, and schedule be well defined, but each must be linked together since one affects the other, both individually and collectively. The project manager must engage key stakeholders to clearly define the project objectives. They should utilize a disciplined phased approach to develop the project and select and involve the project team to deliver the project successfully.

Scope defines the work to be accomplished by the project. It should be the first task in the development of a project, prior to the development of either the budget or the schedule. Scope definition is an iterative process; it takes time to develop. Only the owner can describe the purpose

and reasoning behind the project. The owner's objectives act as inputs to developing the project's scope. Experienced project managers agree that the budget and schedule are derived from the scope. Too often, top management specifies a project budget or schedule and then asks the project team to define a scope to match the budget. This is the reverse order of defining a project and is not a good project management practice. It is the duty of a project manager to ensure that the project scope, budget, and schedule are linked together. Scope definition requires involvement by the project owner.

Budgeting is important because it establishes the amount of money the owner will spend to obtain the project and the amount of money that the design and construction organizations will be compensated for performing the work. Each party is concerned about project cost overrun because it adversely affects profitability and creates adverse relationships between the parties.

Scheduling consists of two different activities. Planning is the first and most important and consists of identifying and organizing the work, detailing how the work will be performed and developing a logical sequence to accomplish to the work. Planning includes identifying methods, contracting schemes, procurement strategies, and execution approaches. Scheduling brings together project definition, people, cost, resources, and timing. The schedule is the final product of scope definition, budgeting, and planning and forms the base against which all activities are measured. Project tracking and control cannot be accomplished without a good plan and schedule.

Quality is an element that is integrated into and between all parts of a project: scope, budget, and schedule. It should not be construed as merely creating drawings with a minimum number of errors, furnishing equipment and materials that meet specifications, or building a project to

fulfill the requirements of a contract. Certainly, these factors are a part of quality, but it involves much more. Quality is meeting the needs and business (or agency) and facility objectives, and satisfaction of the ultimate end user of the project, the owner. The project team, led by the project manager, should provide the owner with no more and no less than the stated agreed to project objectives.

Quality is the responsibility of all participants in a project, including all levels of management and workers in each of the principal parties. An attitude of collaboratively achieving quality must be instilled in everyone and perpetuate throughout the work environment. The attitude should not be “what can we do to pass quality control or final inspection?” Instead, it should be “what can we do to effectively execute our work and what is the best way we can deliver a project that meets the needs and objectives of the owner?”

Lifecycle of a Project

The ongoing challenge of managing a project is defining the proper combination of scope, cost, and time to meet the owner’s requirements and keeping those components in balance. Following a project lifecycle aids in selecting the right project and develops it sufficiently to allocate the required human and financial resources. Following a lifecycle launches a quality process that runs the entire duration of the project. Lifecycle processes act as risk mitigation by helping to scope the right project to satisfy the project sponsor’s intended use of the project (business or agency objectives) when the project is completed.

For engineering and construction, the project sponsor may be a business in the private sector or an agency of a government. The private sector typically involves companies that provide a product or service for a profit.

Examples of private-sector projects include commercial buildings, processing plants, oil and gas pipelines, manufacturing plants, and other similar facilities. The public sector typically involves a governmental agency that provides services to benefit the general public. Examples of public-sector projects include public buildings, roads, highways, bridges, water systems, and similar facilities. Table 1-1 compares the private sector to public sector. Although there are differences in the sectors, the lifecycle of public-sector projects is similar to the lifecycle for projects in the private sector. The following section presents an example lifecycle for the private sector.

	Private	Public
Purpose	Financial	Service, societal
Funding source	Debt and equity markets, internal funds	Taxes, tax-free bonds, low interest loans
Project durations	Shorter	Longer due to government and non-government organization (NGO) involvement and funding requirements
Labor	Can be nonunion	Davis Bacon Act, union labor, use of minority or local work forces may be required
Contractor selection	Sole source, competitive bidding, preapproved contractors	Miller Act or lowest prequalified bidder
Multipurpose	Some	Most
Project life	Shorter term	Longer term
Project benefits	Financial	Service, social, economic, aesthetic, etc.
Conflicts	Moderate to high	Common and high
Politics	Little to moderate	High
Measure of efficiency	Net Present Value (NPV), Internal Rate of Return (IRR), Return On Investment (ROI)	Exceedingly difficult to evaluate

TABLE 1-1 Private versus Public Projects

Private-Sector Project Lifecycle

Several lifecycle versions exist. Often, asset-intensive owner companies will follow a lifecycle specific to their industry or company practices. Lifecycles can have varying numbers of phases with the most common being four or five phases. This book will use a five-phase lifecycle as shown in Figure 1-2.

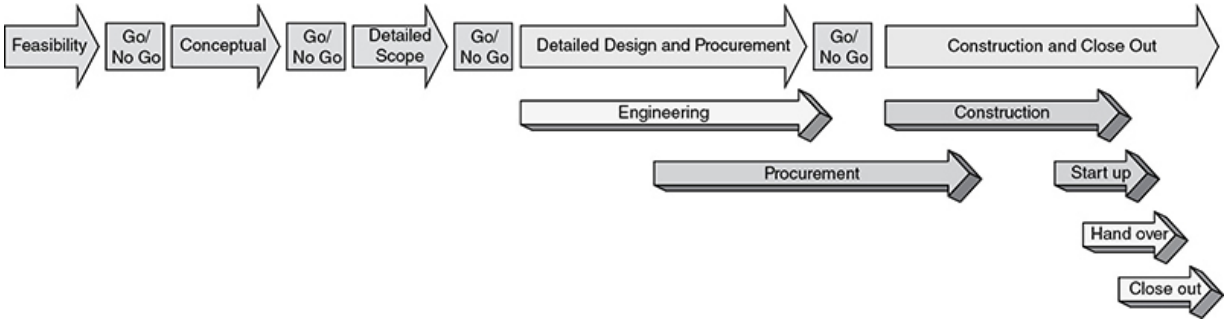


FIGURE 1-2 Example of private-sector project lifecycle.

As a project progresses from one phase to another, it passes through a stage gate. This gating process can be formal or informal, also known as hard or soft gates, respectively. For each phase, the stage gate is intended to act as a go/no go point in the project's development. This allows the project sponsor and key decision makers an opportunity to confirm that the project continues to satisfy the business objectives and economic requirements. The project sponsor and key stakeholders have the opportunity to cancel a project that fails to meet the business objectives or fails other gate criteria. The gate between Detailed Scope and Detailed Design and Construction is a critical decision point. If a project receives a "go" decision here, capital funds are authorized, and a full project team effort can begin. The project is considered sanctioned. In practice, as the project nears a stage gate, work in the following phase will be underway. For example, if the owner has contracted with a design firm to perform alternative identification and

analysis during conceptualization, the design firm may also be working on developing the detailed scope for the most promising two alternatives. As the project nears the sanctioning decision gate, the design firm may have already performed some detailed design to substantiate the budget and schedule provided to the owner for authorization. If the project is canceled at the sanction gate, the work can be archived until the owner decides to pursue the project at a later date.

The first three phases constitute what is often referred to as front end planning, front end engineering and design (FEED), or front end loading (FEL). This book emphasizes effort in these phases since concerted effort here can have the greatest impact on successful project outcomes. Basically, front end planning is selecting the right project to perform, scoping the right assets for a good design basis, setting the stage for successful execution, and documenting the scope of work into an organized basis for design. Effort in the early phases establishes the triangle of scope, budget, and schedule. Regardless of the number of phases in a lifecycle, the purpose of the front end phases, those prior to funds authorization, is to adequately define the objective, scope, and execution approach for the project to warrant authorization of funds.

The feasibility phase identifies the business objective necessitating the project. It is important to establish the business objective in order to properly define project scope. The feasibility phase identifies the market forces, the economic requirement (revenue generated, operating expenses, capital investment costs), strategic value for the company, and other considerations. Properly understanding why a project is needed aids in identifying alternatives. The conceptualization phase identifies several alternatives to meet the stated objective. Each alternative will be evaluated to determine if that combination of scope, cost,

and time satisfy the required elements of the objective. Evaluation techniques could include cost/benefit ratio, payback period, time to complete (time to first revenue), risk profile, or others. Once a preferred alternative is selected, the project can progress to the detailed scope phase. The scope, cost estimate, schedule, and risks are defined to a detailed level in preparation for sanctioning and funds authorization approval.

Ensuring Quality in a Project

Ensuring quality is the responsibility of all parties in a project—the owner, designer, and contractor. It is the owner's duty to define and communicate the desired level of quality in a project. The designer is responsible for producing contract documents that ensures the owner's level of quality will be achieved during construction. The contractor is typically responsible for providing the materials, equipment, and labor skills to ensure the work will be performed in accordance with the design drawings and specifications. In some asset-intensive industries, the owner will provide key materials and equipment.

Early in the project, before contracts are signed and commencing design, the owner's organization needs to hold a meeting to discuss, and agree on, the end product and the level of quality the project is to provide. Although upper management in the owner's organization is responsible for final approval of the level of quality, it is the end user of the project in the owner's organization that should be involved in defining the level of quality. The end user is the party that will use and maintain the project after it is completed. Members of the owners' staff that should be involved in defining quality should include financing, engineering, operations, and maintenance personnel. This group must separate "what the owner needs" from "what the owner

wants," while ensuring the completed project can be used as intended by the owner. If the owner does not have staff that is able to identify the desired quality, it may be necessary to involve the design team or outside consultants to assist the owner in defining the level of quality that can be achieved within the constraints of budget and schedule. It is important to maintain continuous communications with the owner throughout the project, so the owner understands the total effect that quality can have on the cost and schedule of a project.

The design organization plays a major role in quality. The owner's level of quality must be communicated to the design team, so the proper level of quality is translated into the design drawings and specifications. The project manager of the design team must ensure the level of quality is clearly defined in the designer's project proposal, which requires the designer to explain "design quality" in terms the owner can understand. The designer must develop a complete, and as error free as possible, set of contract documents that ensure the level of quality that is expected from the owner. Regularly scheduled meetings should be held to ensure the design team is on track regarding the expected level of quality, because it is often too easy for project participants to get distracted by costs and schedule, and forget that quality is a "must" in a project. There needs to be a thorough review of plans and specifications by experienced field construction personnel, before release to the contractor, to ensure constructability of the design. The design team should remain involved in the project during construction, to ensure the plans and specifications are being turned into a quality project during construction.

To ensure quality, the contractor must have a quality control system that is workable and understood by all parties. To work effectively, any quality control system requires a buy-in by all parties involved in a project. Quality

control should concentrate on those parts of a project where quality is important, and not get consumed in expending large amounts of effort inspecting work that has only a small impact on the performance of a project when it is completed and in use by the owner. Contractors, subcontractors, and suppliers should be carefully selected that have a record of quality work, rather than selecting contractors that quote the lowest cost. A work environment should be established that promotes quality and pride in workmanship among all parties in the project. There must be sincere interest in the importance of quality, and quality should be expected in all aspects of the project. Management needs to instill an attitude of achieving quality work by everyone in the project by recognizing and rewarding good quality work. Regularly held meetings need to be scheduled to address quality, just like meetings that are held to review budgets, schedules, and safety. Quality should be unique, tied to each specific project, rather than a standardization.

Responsibilities of Parties

Each of the three principal parties in a project has a role to fulfill in the various phases of design development and construction. A team approach between the owner, designer, and contractor must be created with a cooperative relationship to complete the project in the most efficient manner. Too often an adverse relationship develops that does not serve the best interest of anyone.

The owner is responsible for setting the operational criteria for the completed project. Examples are usage of a building, barrels per day of crude oil to be refined, millions of cubic feet per hour of gas to be transported in a pipeline, and so on. Any special equipment, material, or company standards that are to apply to the project must also be

defined. Owners need to assign a project manager that is responsible for delivering the project to meet the business objectives. The owner's project manager is in charge of the project including all other project managers (e.g., from the design firm or from the construction contractor). The owner's project manager needs to identify the owner's level of involvement in the project, for example, the review process, required reports, and the levels of approval. The owner through their project manager is also responsible for setting parameters on total cost, payment of costs, major milestones, and the project completion date.

Many problems can be created when owners fail to fulfill their responsibility of clearly defining the operational criteria of a project. If the operational criteria are not clearly defined, it will have to be defined as the project progresses through design and/or into construction, which causes confusion for all parties. The owner may end up paying for things in a project that are not needed, because participants in the project do not clearly understand the operational criteria of the project. The owner runs the risk of receiving a project that is within approved budget and on schedule, but may not be useable as intended. The designer may overdesign the project, trying to second-guess what the owner wants, which may cause the project to be more expensive than necessary. Or the designer may underdesign the project, not realizing what the owner expects in the project, which can lead to expensive additions during construction. Changes of the owner's operational criteria during design cause rework for the designer, which will increase the cost of the design effort and may adversely affect the budget and schedule of the project.

The probability of rework during construction is greatly increased when the owner has not adequately defined the operational criteria of the project. Timely responses to contractors' formally submitted questions may be impaired

because the owner is not sure of what they want in the project. The number of change orders is likely to increase, which may result in cost overruns, schedule delays, and claims against the owner by the contractor. The productivity and morale of construction workers may be impaired because of continuous changes by the owner to adjust the project during construction, so it will meet the operational needs of the owner.

The designer is responsible for producing design alternatives, computations, drawings, and specifications that meet the needs of the owner. In addition, there may be other duties that are delegated to the designer by the owner, for example, on-site or periodic inspection, review of shop drawings, and in some instances, the acquisition of land and/or permits. It is the duty of the designer to produce a project design that meets all federal, state, and local codes; standards; and environmental and safety regulations. In addition, a budget for the design should be prepared, along with a design schedule that matches the owner's schedule. The design schedule should be directly coordinated to the construction schedule so the project can be completed by the construction contractor when the owner needs it.

Many problems may arise when a designer fails to give adequate attention to the impact of design alternatives on the cost or schedule during construction. Sometimes a design alternative is selected that may cause restrictions in the method of construction that a contractor may want to use during construction, which can adversely affect the contractor's operations. The selection of design alternatives also can impact the procurement of major equipment required in a project, which can influence the scheduling of construction work. Also, lack of attention to details in the design drawings may cause erection problems at the jobsite, which can lead to delays in work, increased costs,

and claims from the construction contractor. Inadequate attention to details during design can cause confusion during construction, including delays in work in the field and unnecessary rework.

Designers also need to make a special effort to eliminate poor wording in the written specifications that can cause misinterpretation of the requirements of the work to be performed, which can lead to poor quality work or costly change orders. Overly restrictive wording in the specifications may place restraints on the contractor's operations and/or sequencing of construction work, which can affect costs and schedules. Designs that are poorly assembled can impair productivity of crafts, morale of workers on the jobsite, and lead to legal claims against the designer and/or owner from the contractors. The quality of design documents has a significant impact on the quality of construction and the long-term maintenance and operations after the project is completed.

Generally, designers are not obligated under standard-form contracts to guarantee the construction cost of a project, although there have been some cases where the designer has been held legally responsible for the construction price. As part of their design responsibility, designers usually prepare an estimate of the probable construction cost for the design they have prepared. Major decisions by the owner to proceed with the project are made from the designer's cost estimate.

The cost and operational characteristics of a project are influenced most, and are easier to change, during the design phase. Because of this, the designer plays a key role during the early phase of a project by working with the owner to keep the project on track so the owner/contractor relationship will be in the best possible form.

The construction contractor is responsible for the performance of all work in accordance with the contract

documents that have been prepared by the designer. This includes furnishing all labor, equipment, material, and know-how necessary to build the project. The construction phase is important because most of the project budget is expended during construction. Also, the operation and maintenance of the completed project is highly dependent on the quality of work that is performed during construction. The contractor must prepare an accurate estimate of the project, develop a realistic construction schedule, and establish an effective project control system for cost, schedule, and quality.

Serious problems can arise when contractors fail to perform their work in accordance with the contract documents. If the contractor does not perform work as specified in the contract, the owner has the option to call the performance bond, which brings a new contractor to the job to complete the project. The quality of the project may be impaired when another construction contractor must be brought to the jobsite to properly redo the defaulting contractor's work. When the owner calls the performance bond on a defaulting contractor, the ability of the defaulting contractor to acquire future contracts is greatly impaired. The contractor may be disqualified from bidding future work of the owner, and the designer may discourage other owners from allowing the contractor to bid on the designer's work. Also, the bonding capacity of the defaulting contractor may be reduced, or completely eliminated, by the bonding company. Adverse publicity may damage the reputation of the construction contractor, which can adversely affect the success of the contractor in securing future work.

Who Does the Project Manager Work for?

The project manager works for the project, although he or she may be employed by the owner, designer, or contractor. Therefore, for any project there are at least three project managers. Since the project belongs to the owner, the owner's project manager will always be the lead project manager and in charge of the overall project. Although these three individuals work for a different organization, they must develop methods to ensure good working relationships. At the beginning of a project, all project managers should meet together to define and agree on the authority and responsibility of each party. They need to agree on procedures for review and approval of documents and the distribution of documents between the parties of each organization. There needs to be regularly scheduled joint project manager's meetings, with a set agenda to share information and coordinate the work in an organized manner. Sharing information in a timely manner is necessary for a successful project. Each project manager needs to make a special effort to work together as a team to help each other. They need to show trust, respect, and confidence in the work of others with an attitude of finding solutions instead of finding blame.

The Construction Industry Institute (CII) has sponsored research and published numerous papers on a variety of topics related to project management. *Organizing for Project Success,* a CII publication, provides a good description of the interface between project managers for the owner, designer, and contractor. The following paragraphs are a summary of the project management teams that are discussed in the publication.

After commitment has been made by an owner to invest in a project, an Investment Management Team is formed within the owner's organization to provide overall project control. The major functions, such as marketing, engineering, finance, and manufacturing, are usually

represented. A Project Executive usually leads the team and reports to the head of the business unit which made the decision to proceed with the project. A member of this team is the Owner's Project Manager.

The Owner's Project Manager leads a Project Management Team which consists of each Design Project Manager and Construction Project Manager that is assigned a contract from the owner. Their mission is to accomplish the work, including coordinating the engineering, procurement, and construction phases. The Owner's Project Manager leads this team, which is one of the most important management functions of the project. The Owner's Project Manager is responsible for the accomplishment of all work, even though he or she has limited resources under his or her direct control because the work has been contracted to various organizations.

Reporting to each design project manager and construction project manager are the Work Managers who fulfill the requirements of their contracts. Each Design and Contractor Project Manager reports to the Owner's Project Manager for contractual matters and to his or her parent organization for business matters.

Work Managers are design leaders and supervisors who lead the teams actually accomplishing the work. They are directly responsible for the part of the contract assigned to them by their Project Manager. They must also communicate and coordinate their efforts with Work Managers from other organizations. Usually, this communication does not flow vertically through a chain of command, but instead flows horizontally between people actually involved in the work. It is their responsibility to also work with their Project Manager and keep them informed. This is further discussed in Chapters 4 and 12.

Purpose of Project Management

For the purpose of this book, project management may be defined as:

> The art and science of coordinating people, equipment, materials, money, and schedules to complete a specified project on time and within approved cost.

Much of the work of a project manager is organizing and working with people to identify problems and determine solutions to problems. In addition to being organized and a problem solver, a manager must also work well with people. It is people who have the ability to create ideas, identify and solve problems, communicate, and get the work done. Because of this, people are the most important resource of the project manager. Thus, the project manager must develop a good working relationship with people in order to benefit from the best of their abilities.

It is the duty of a project manager to organize a project team of people and coordinate their efforts in a common direction to bring a project to successful completion. Throughout the project management process there are five questions that must be addressed:

1. Who will do the work?
2. What work will be performed?
3. When will the work be done?
4. How much will the work cost?
5. What can go wrong?

The work required often involves people outside of the project manager’s organization. Although these individuals do not report directly to the project manager, it is necessary that effective working relationships be developed.

A manager must be a motivated achiever with a “can do” attitude. Throughout a project there are numerous obstacles that must be overcome. The manager must have perspective with the ability to forecast methods of achieving results. The drive to achieve results must always be present. This attitude must also be instilled in everyone involved in the project.

Good communication skills are a must for a manager. The management of a project requires coordination of people and information. Coordination is achieved through effective communication. Most problems associated with project management can be traced to poor communications. Too often the “other person” receives information that is incorrect, inadequate, or too late. In some instances, the information is simply never received. It is the responsibility of the project manager to be a good communicator and to ensure that people involved in a project communicate with each other.

Types of Management

Management may be divided into at least two different types: functional management (sometimes called discipline management) and project management. Functional management involves the coordination of repeated work of a similar nature by the same people. Examples are management of a department of design engineering, surveying, estimating, or purchasing. Project management involves the coordination of one-time work by a team of people who often have never previously worked together. Examples are management of the design and/or construction of a substation, shopping center, refinery unit, or water treatment plant. Although the basic principles of management apply to both of these types of management, there are distinct differences between the two.

Most individuals begin their career in the functional environment of management. Upon graduation from college, a person generally accepts a position in a functional group closely related to his or her formal education. Typical examples are design engineers, estimators, schedulers, or surveyors. The work environment focuses on how and who will perform the work, with an emphasis on providing technical expertise for a single function. Career goals are directed toward becoming a specialist in a particular technical area.

Project management requires a multifunctional focus to coordinate the overall needs of a project with reliance on others to provide the technical expertise. The project manager must be able to delegate authority and responsibility to others and still retain focus on the linking process between functions. Project managers cannot become overly involved in detailed tasks or take over the discipline they are educated in, but should focus on the project objectives.

A fundamental principle of project management is to organize the project around the work to be accomplished. The work environment focuses on what must be performed, when it must be accomplished, and how much it will cost. Career development for project managers must be directed toward the goal of becoming a generalist with a broad administrative viewpoint.

The successful completion of a project depends on the ability of a project manager to coordinate the work of a team of specialists who have the technical ability to perform the work. Table 1-2 illustrates the relationship between project management and functional management.

Project Management Concerns	Functional Management Concerns
What must be done	How it will be done
When it must be done	Who will do it
How much it will cost	How well it will be done
Coordinating overall needs	Coordinating specific needs
Multi-discipline focus	Single-discipline focus
Reliance on others	Providing technical expertise
Project quality	Technical quality
Administrative viewpoint	Technical viewpoint
A generalist's approach	A specialist's approach

TABLE 1-2 Distinguishing between Project Management and Functional Management

Functions of Management

Management is often summarized into five basic functions: planning, organizing, staffing, directing, and controlling. Although these basic management functions have been developed and used by managers of businesses, they apply equally to the management of a project.

Planning is the formulation of a course of action to guide a project to completion. It starts at the beginning of a project, with the scope of work, and continues throughout the life of a project. The establishment of milestones and consideration of possible constraints are major parts of planning. Successful project planning is best accomplished by the participation of all parties involved in a project. There must be an explicit operational plan to guide the entire project throughout its life.

Organizing is the arrangement of resources in a systematic manner to fit the project plan. A project must be organized around the work to be performed. There must be a breakdown of the work to be performed into manageable units, which can be defined and measured. The work

breakdown structure of a project is a multi-level system that consists of tasks, subtasks, and work packages.

Staffing is the selection of individuals who have the expertise to produce the work. The persons that are assigned to the project team influence every part of a project. Most managers will readily agree that people are the most important resource on a project. People provide the knowledge to design, coordinate, and construct the project. The numerous problems that arise throughout the life of a project are solved by people.

Directing is the guidance of the work required to complete a project. The people on the project staff that provide diverse technical expertise must be developed into an effective team. Although each person provides work in his or her area of expertise, the work that is provided by each must be collectively directed in a common effort and in a common direction.

Controlling is the establishment of a system to measure, report, and forecast deviations in the project scope, budget, and schedule. The purpose of project control is to determine and predict deviations in a project, so corrective actions can be taken. Project control requires the continual reporting of information in a timely manner, so management can respond during the project rather than afterward. Control is often the most difficult function of project management.

Key Concepts of Project Management

Although each project is unique, there are key concepts that a project manager can use to coordinate and guide a project to completion. A list of the key concepts is provided in Table 1-3.

1. Ensure that one person, and only one person, is responsible for the project scope, budget, and

schedule

2. Don’t begin work without a signed contract, regardless of the pressure to start
3. Confirm that there is an approved scope, budget, and schedule for the project
4. Lock in the project scope at the beginning and ensure there is no scope growth without approval
5. Make certain that scope is understood by all parties, including the owner
6. Determine who developed the budget and schedule, and when they were prepared
7. Verify that the budget and schedule are linked to the scope
8. Organize the project around the work to be performed, rather than trying to keep people busy
9. Ensure there is an explicit operational work plan to guide the entire project
10. Establish a work breakdown structure that divides the project into definable, measurable, and assignable units of work
11. Establish a project organizational chart that shows authority and responsibilities for all team members
12. Build the project staff into an effective team that works together as a unit
13. Emphasize that quality is a must, because if it doesn’t work, it is worthless, regardless of cost or how fast it is completed
14. Budget all tasks; any work worth doing should have compensation
15. Develop a project schedule that provides logical sequencing of the work required to complete the job
16. Establish a control system that will anticipate and report deviations on a timely basis, so corrective actions can be taken

17. Get problems out in the open with all persons involved so they can be resolved
18. Document all work, because what may seem irrelevant at one point in time may later be very significant
19. Prepare a formal agreement with appropriate parties whenever there is a change in the project
20. Keep the client informed; they pay for everything and will use the project upon completion

TABLE 1-3 Key Concepts of Project Management

Each of the key concepts shown in Table 1-3 is discussed in detail in subsequent chapters of this book. It is the responsibility of the project manager to address each of these concepts from the beginning of a project and through each phase until completion.

Role of the Project Manager

The role of a project manager is to lead the project team to ensure a quality project within time, budget, and scope constraints. A project is a single, nonrepetitive enterprise, and because each project is unique, its outcome can never be predicted with absolute confidence. A project manager must achieve the end results despite all the risks and problems that are encountered. Success depends on carrying out the required tasks in a logical sequence, utilizing the available resources to the best advantage. The project manager must perform the five basic functions of management: planning, organizing, staffing, directing, and controlling.

Project planning is the heart of good project management. It is important for the project manager to realize that he or she is responsible for project planning, and

it must be started early in the project (before starting any work). Planning is a continuous process throughout the life of the project, and to be effective, it must be done with input from the people involved in the project. The techniques and tools of planning are well established. Table 1-4 provides guidelines for planning.

1. Develop plans focused on the work to be performed
2. Establish project objectives and performance requirements early, so everyone involved knows what is required
3. Involve all functional managers and key staff members in the process of planning and estimating
4. Establish clear and well-defined milestones in the project, so all concerned will know what is to be accomplished, and when it is to be completed
5. Build contingencies into the plan to provide a reserve in the schedule for unforeseen future problems
6. Avoid reprogramming or replanning the project unless absolutely necessary
7. Prepare formal agreements with appropriate parties whenever there is a change in the project and establish methods to control changes
8. Communicate the project plan to clearly define individual responsibilities, schedules, and budgets
9. Remember that the best-prepared plans are worthless unless they are implemented

TABLE 1-4 Project Manager's Role in Planning

A project organizational chart should be developed by the project manager for each project. The chart should clearly show the appropriate communication channels between the people working on the project. Project team members must know the authority of every other team member in order to

reduce miscommunications and rework. Organized work leads to accomplishments and a sense of pride in the work accomplished. Unorganized work leads to rework. Rework leads to errors, low productivity, and frustrated team members. Table 1-5 provides guidelines for organizing.

1. Organize the project around the work to be accomplished
2. Develop a work breakdown structure that divides the project into definable and measurable units of work
3. Establish a project organization chart for each project to show who does what
4. Clearly define the authority and responsibility for all project team members

TABLE 1-5 Project Manager's Role in Organizing

Project staffing is important because people make things happen. Most individuals will readily agree that people are the most important resource on a project. They create ideas, solve problems, produce designs, operate equipment, and install materials to produce the final product. Because each project is unique, the project manager must understand the work to be accomplished by each function. The project manager should then work with his or her supervisor and appropriate functional managers to identify the persons who are best qualified to work on the project. Table 1-6 provides guidelines for project staffing.

1. Clearly define the work to be performed, and work with appropriate department managers in selecting team members
2. Provide an effective orientation (project goals and objectives) for team members at the beginning of the project

3. Explain clearly to team members what is expected of them and how their work fits into the total project
4. Solicit each team member's input to clearly define and agree on scope, budget, and schedule

TABLE 1-6 Project Manager's Role in Staffing

The project manager must direct the overall project and serve as an effective leader in coordinating all aspects of the project. This requires a close working relationship between the project manager and the project staff to build an effective working team. Because most project team members are assigned (loaned) to the project from their function (home) departments, the project manager must foster the development of staff loyalty to the project while they maintain loyalty to their home departments. The project manager must be a good communicator and have the ability to work with people at all levels of authority. The project manager must be able to delegate authority and responsibility to others and concentrate on the linking process between functions. He or she cannot become overly involved in detailed tasks, but should be the leader of the team to meet project objectives. Table 1-7 provides guidelines for directing the project.

1. Serve as an effective leader in coordinating all important aspects of the project
2. Show interest and enthusiasm in the project with a "can do" attitude
3. Be available to the project staff, get problems out in the open, and work out problems in a cooperative manner
4. Analyze and investigate problems early, so solutions can be found at the earliest possible date

5. Obtain the resources needed by the project team to accomplish their work to complete the project
6. Recognize the importance of team members, compliment them for good work, guide them in correcting mistakes, and build an effective team

TABLE 1-7 Project Manager's Role in Directing

Project control is a high priority of management and involves a cooperative effort of the entire project team. It is important for the project manager to establish a control system that will anticipate and report deviations on a timely basis, so corrective action can be initiated before more serious problems actually occur. Many team members resist being controlled; therefore, the term *monitoring a project* may also be used as a description for anticipating and reporting deviations in the project. An effective project control system must address all parts of the project: quality, work accomplished, budget, schedule, and scope changes. Table 1-8 provides guidelines for project control.

1. Maintain a record of planned and actual work accomplished to measure project performance
2. Maintain a current milestone chart that displays planned and achieved milestones
3. Maintain a monthly project cost chart that displays planned expenditures and actual expenditures
4. Keep records of meetings, telephone conversations, and agreements
5. Keep everyone informed, ensuring that no one gets any "surprises," and have solutions or proposed solutions to problems

TABLE 1-8 Project Manager's Role in Controlling

Professional and Technical Organizations

Due to the increased cost and complexity of projects, the interest in developing and applying good project management principles has gained considerable attention by owners, designers, and contractors. Numerous organizations have made significant contributions related to project management by conducting research, sponsoring workshops and seminars, and publishing technical papers. The following paragraphs describe some of these organizations.

The American Society of Civil Engineers (ASCE), founded in 1852, is the oldest national engineering society in the United States. Membership comprises over 100,000 civil engineers working in government, education, research, construction, and private consulting. The construction division of ASCE has many councils and technical committees that have published technical papers related to project management in its *Journal of Construction Engineering and Management.*

The National Society of Professional Engineers (NSPE), founded in 1936, is the national engineering society of registered professional engineers from all disciplines of engineering. NSPE membership comprises over 50,000 engineers who are organized in five practice divisions: construction, education, government, industry, and private practice. The construction practice division has numerous committees that have contributed to contract documents and legislation related to engineers in the construction industry.

The Project Management Institute (PMI), founded in 1969, consists of members from all disciplines and is dedicated to advancing the state-of-the-art in the profession of project management. PMI has a certification program for project

management professionals and publishes a *Project Management Book of Knowledge* (PMBOK).

The Association for Advancement of Cost Engineering International (AACE International), founded in 1956, is an organization of worldwide members. It serves total cost management professionals in disciplines such as cost engineering, cost estimating, planning and scheduling, decision and risk management, project management, project control, cost/schedule control, earned value management, claims, and more. Since 1976, AACE International has administered a certification program for individuals as Certified Cost Consultant, Certified Cost Engineer, Certified Estimating Professional, Earned Value Professional, Planning and Scheduling Professional, and others.

The Construction Management Association of America (CMAA), founded in 1981, is an organization of corporate companies, public agencies, and individual members who promote the growth and development of construction management (CM) as a professional service. CMAA publishes documents related to CM, including the *Standard CM Services and Practice.*

The Construction Industry Institute CII, founded in 1983, is a national research organization consisting of an equal number of owner and contractor member companies, and research universities from across the United States. CII is organized into committees, councils, and research teams consisting of owners, contractors, and academic members who work together to conduct research and produce publications on a variety of topics related to project management.

The following list of organizations is provided to the reader as sources for information related to project management:

American Institute of Architects

American Society of Civil Engineers
American Society of Military Engineers
Association for Advancement of Cost Engineering International
Construction Industry Institute
Construction Management Association of America
Design Build Institute of America
National Society of Professional Engineers
Project Management Institute
Society of American Value Engineers

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CHAPTER 2
Project Definition

Project Success Depends on Project Definition

As described in Chapter 1, design and construction projects progress through phases from initial inception through final completion. Figure 2-1 shows five phases that are common in the lifecycle of most engineering and construction projects. The early phases involve project definition of what is required to meet the intended use of the project, whereas later phases involve the project execution of design and construction. The emphasis of this book is on the early first three phases of project definition because problems during project execution are often a result of inadequate project definition.

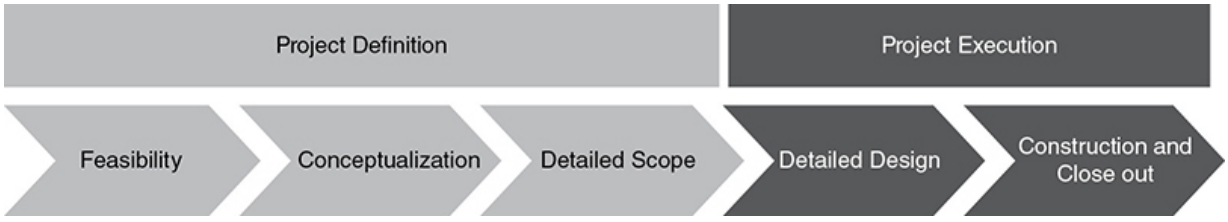


FIGURE 2-1 Project definition and project execution.

It should be noted small size or noncomplex projects should follow a lifecycle but may not require the same level of attention and rigor that a mega-size or complex project requires. It should also be mentioned that for the life of a

project in the private sector there are business and asset strategic planning steps that precede feasibility, and there are operations and maintenance, modification, and termination phases that follow construction.

Project lifecycles can vary in the number of phases, phase names, and approval required to progress from phase to phase. The lifecycle presented here has five phases. The emphasis of this book is on project definition that consists of three phases: Feasibility; Conceptualization and Alternative Analysis; and Detailed Scope. The last two phases are considered project execution. Figure 2-1 highlights the phases of a project lifecycle that are the focus of this book.

Project definition sets the stage for project execution consisting of design work and construction. The project definition phases involve discovery to identify and analyze project requirements and constraints. Although the initial focus is on the owner's requirements and constraints, it must be recognized that the owner's requirements and constraints carry over to both the designer and contractor.

The goal for project definition is to conceive, shape, and plan the right project to deliver good business or agency outcomes as shown in Figure 2-2. To accomplish this requires key stakeholder involvement and the use of project management best practices. The project manager (PM) must use a disciplined phased approach with an active engaged team to achieve clearly stated objectives.

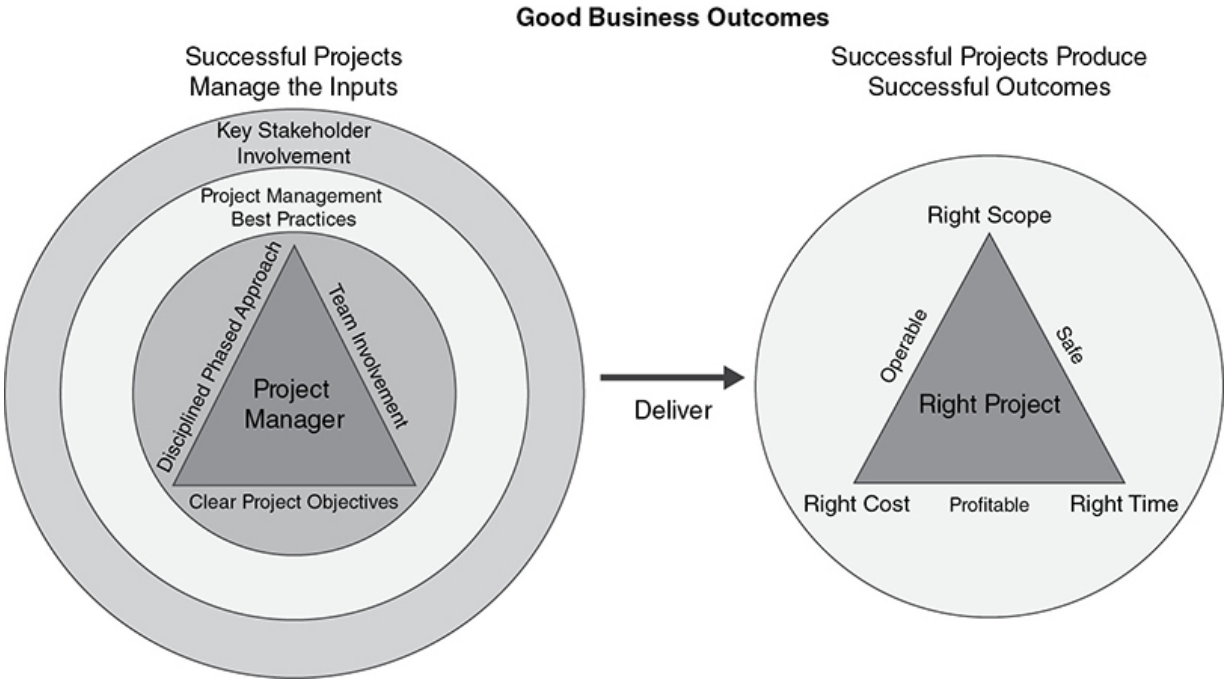
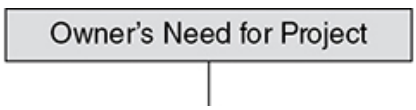


FIGURE 2-2 Goal of project definition is good business outcomes.

Project Workflow

Following a project lifecycle does not mean that the project will progress in a step-by-step manner. A project is in a continual state of change as it progresses from its start, as a need by the owner, through project definition and, finally, project execution. Figure 2-3 shows the workflow process during the life of a project. As the project moves through the workflow, additional parties become involved, and more information is obtained to better identify scope, budget, and schedule. Many times, a project recycles through early phases in order to gain management approval to proceed to the subsequent phase. During each phase, it is the responsibility of the project manager, if assigned, to keep all work within the approved scope, budget, and schedule.



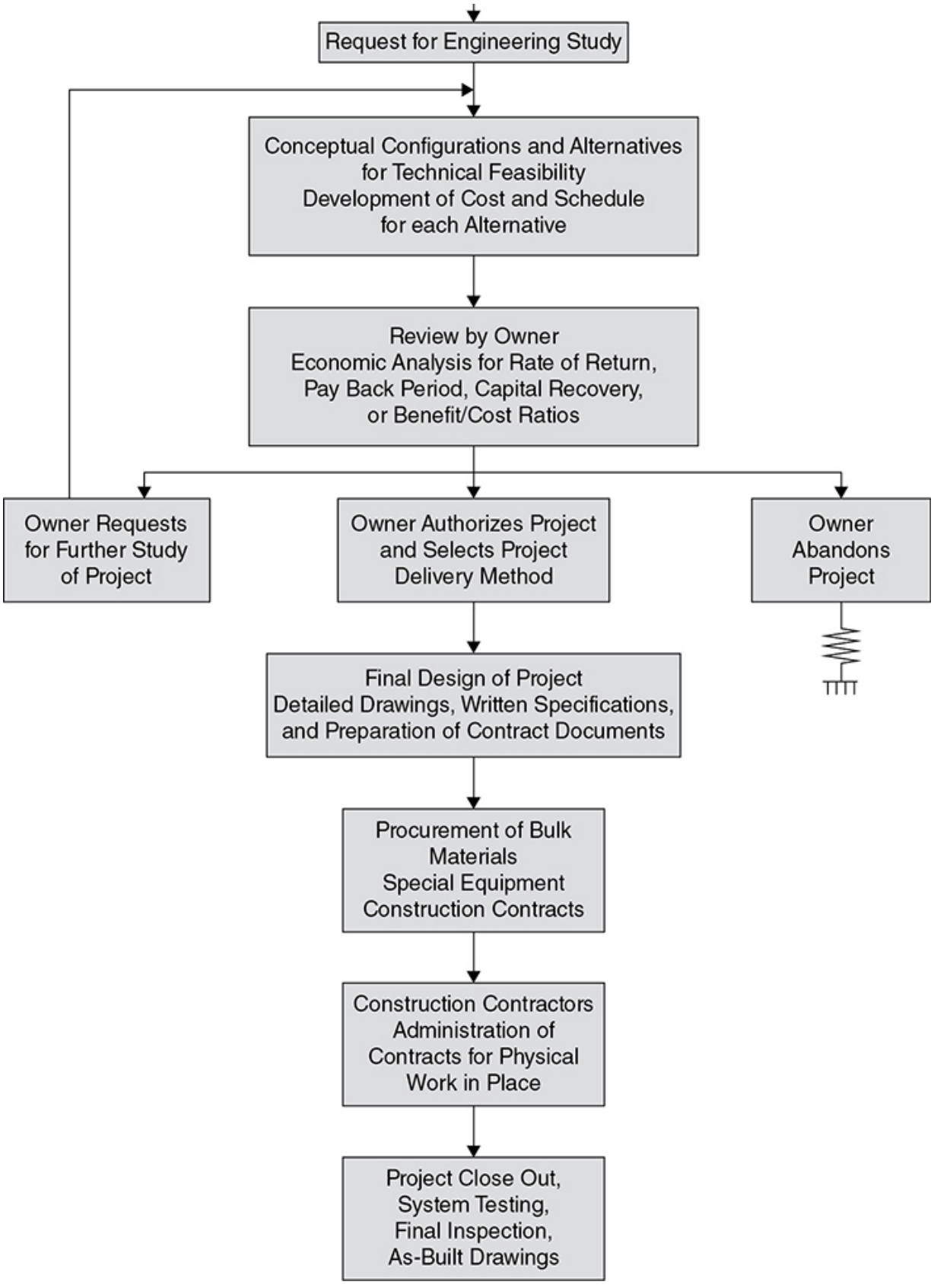

Request for Engineering Study
Conceptual Configurations and Alternatives for Technical Feasibility Development of Cost and Schedule for each Alternative
Review by Owner Economic Analysis for Rate of Return, Pay Back Period, Capital Recovery, or Benefit/Cost Ratios
Owner Requests for Further Study of Project
Owner Authorizes Project and Selects Project Delivery Method
Owner Abandons Project
Final Design of Project Detailed Drawings, Written Specifications, and Preparation of Contract Documents
Procurement of Bulk Materials Special Equipment Construction Contracts
Construction Contractors Administration of Contracts for Physical Work in Place
Project Close Out, System Testing, Final Inspection, As-Built Drawings

FIGURE 2-3 Project workflow process.

In the early phases of feasibility or alternative analysis, there may not be sufficient information to define the scope accurately enough to know the work to be performed. A characteristic of most project managers is “I can do it.” This characteristic often leads to assignment of work to the project manager before the work is completely defined or officially approved. The project manager should avoid the pitfall of accepting project material with scant or incoherent information from a business or owner that has little or no intent on being involved in developing the project. Lack of owner participation in project development is the cause for later project rework and hardship for the project manager’s team. The business or the owner must take and execute the responsibility to push the project forward through development.

This applies to the project manager in either the owner, designer, or contractor organization. The people who work with the project manager include clients, subordinates, project team members, upper management, and colleagues who are themselves project managers. A project manager cannot efficiently utilize his or her time or effectively manage when special requests are made for work that is not well defined. If these conditions exist, the project manager should call a time-out or a pause in the project development work and meet with the key stakeholders to obtain clear direction and clear priorities. For a design firm providing services in these phases, the work should be performed on a time and material basis for actual work accomplished, until an adequate scope, budget, and schedule can be determined. Another option is to define a scope, with a matching budget and schedule. When there is a deviation from the defined scope, the project manager can advise the owner of the readjusted budget and schedule caused by the

change in scope and obtain the owner’s approval before proceeding with the work.

During the development of conceptual configurations and alternatives, the quality and total cost of the project must be considered. This can only be achieved through extensive input from the owner who will ultimately use the project, since the cost to operate and maintain the facility after completion is a major consideration for project design. Sometimes the budget is a controlling factor, which causes the owner’s contemplated scope to be reduced, or expanded. If this condition exists, care must be exercised to ensure the project meets the minimum needs of the owner, and there is a clear understanding of the level of quality that is expected by the owner. It is the duty of the project manager to ensure that project development meets the owner’s expectations.

The owner’s authorization to proceed with final design places pressure on the designer to complete the contract documents at the earliest possible date. However, the quality and completeness of the bid documents have a great influence on the cost of the project. Adequate time should be allocated to the designer to produce a design for the project that is constructable and will perform for the owner at optimal maintenance and operating costs.

For large projects the procurement of bulk material and special equipment has a large impact on the construction schedule. The project manager must ensure that long lead-time purchase items are identified, sourced, communicated, and early funding approved and procured to align with construction needs. Procurement prior to project authorization (sanction) must be coordinated and approved with the owner’s key stakeholders on the project team. When this issue occurs, an approved risk management plan should be in place to manage the capital risk should the project fail to be sanctioned.

The type of contract chosen and contractors selected to bid the project influence cost, schedule, and quality. The project manager plays an important role in the process of qualifying contractors, the evaluation of bids, and recommendations of the award of construction contracts.

Owner’s Needs and Project Objectives

An owner must know his or her needs and objectives before any productive project work can be started. If the owner cannot provide a clear project objective, a reason why the project is needed, the project requirements cannot be detailed. Without a clear objective and detailed requirements, no one knows what to do. Defining owner’s needs is the first step in a broad range of preauthorization activities that ultimately lead to detailed scope definition. A project manager cannot form the project team to execute the project without a clear project objective and requirements.

The process of identifying owner’s needs and objectives requires the involvement of a wide range of people within the owner’s organization. This includes top managers and investors, financial personnel, and, in particular, the people who will use and/or operate the project after it is constructed. The process of identifying owner’s needs and objectives usually involves numerous activities and discussions. It is important that “what is needed” be separated from “what is wanted.” Without constraints of cost and schedule, focus easily shifts from what is needed to what is wanted. This makes a project unaffordable and nonfeasible. Because there are always constraints of cost and schedule, the owner must develop a project definition based on need. This process involves an optimization of quantity, quality, cost, and schedule.

Members of the owner’s organization must realize that it is their responsibility to resolve all issues related to project objectives and needs before assigning the project to the project manager. It is not the duty of the project manager or the project team to define the owner’s needs. Vague owner needs lead to project changes, scope growth, cost overruns, rework, and misunderstandings among team members. The best way to determine needs, and information related to needs, is to talk to the people who will use the facility after it is constructed.

Prior to launching any project effort, it is imperative for the project manager to clearly understand the owner’s business objectives. Understanding the overall value and benefits of an opportunity connects the project manager and project team to the importance of pursuing the effort. In addition to understanding why the project is being pursued, the project manager should collaborate with key stakeholders to understand the envisioned proposed physical asset and its proposed capabilities. Without understanding what the business owner is trying to accomplish, proper and accurate project development is difficult to perform.

The project manager should understand that early in the project lifecycle, specifically feasibility and conceptualization, the activities driving the business case are often being developed by the project sponsor. The activities that drive the business case may include market research, competitive analysis, timing, regional activities, product changes, volume analysis, supply chain, and other business development risk factors. In the early project phases (Phase 1—Feasibility and Phase 2—Conceptualization), the business drivers can quickly evolve and change the efforts and alternatives being analyzed by the project manager. Business case outputs drive the opportunity and objectives. These outputs can change

quickly and result in a project scope modification or even cause the cancellation of a project. In order to optimize progress through the project definition, the PM should keep a timely feedback loop with the project sponsor, who is managing the business case.

Because of the fluid nature of a project early in the project lifecycle, the project sponsor should collaborate with the project manager to write a project charter that defines the project opportunity and the project sponsor's objectives. The charter should include goals for incrementally advancing the project through each project lifecycle phase. The project charter should include, by phase, the proposed scope of work activities, resource capabilities and resources needed on the team, risks or constraints that need to be managed, the work products that need to be created, the expected cost and schedule, and communication and progress reporting. The project charter document should be reviewed and agreed to by the sponsor, project manager, and key stakeholders. The project charter is an important component in planning the project and is used through project definition phases to the point where the decision to fully fund and authorize completion of the project is made.

Key Stakeholder—Project Manager Collaboration Example

The following paragraphs present a hypothetical example of the development of an owner's needs. An owner may define a company goal of centralization of its operations to streamline operating efficiency. To achieve this goal, company management may set the objective of consolidating the service facility of each of its five operating districts into a single location. Thus, there is a need to design and build a service facility that will serve the five operating districts. Key people, from each district, must meet and agree on what is needed in a facility that satisfies

the intended usage by each operating district. Negotiations between the people should focus on what is best, overall, for the company in order to achieve efficiency of operations, which is the company's goal. Compromise is often necessary to separate "what is needed" from "what is wanted." The end result should be a facility that meets the needs of all five districts and can be operated more efficiently than five separate service facilities. For example, agreement may be reached that the owner needs a facility consisting of three buildings: an employee's office building, a warehouse, and a maintenance shop. Additionally, an outside heavy equipment and bulk materials storage area may be needed. These minimum requirements of the facility then initiate the process of project definition and scope.

A part of the owner's needs and objectives study is an assessment of the total project budget because management generally will not approve starting the design of a project unless the probable total cost is known. The project budget at this stage of development is based on parametric costs, such as cost per square foot of building or cost per acre of site development. If the anticipated project cost exceeds the amount that management is willing to approve, then it is necessary to reduce the scope of work. For example, the employee's office building and maintenance shop may be retained in the project and the warehouse eliminated. This decision would be made if the warehouse is the lowest priority of the three buildings. Consideration would be given to adding the warehouse at a future date when funds are available, after completion of the site work, the employee's office building, and the maintenance shop. The project management of this type of project is further discussed in Chapters 3, 10, 13, and the Appendix.

Table 2-1 shows the interactive role of the owner and project manager in the process to ensure a well-defined

understanding between the two parties.

Project objectives
The owner has the primary responsibility for setting project objectives
Project objectives define the needs of the owner that must be met by the project
A detailed definition of project objectives is a prerequisite to defining project scope
There needs to be a separation between "what is needed" and "what is wanted"
People involved should include operations people, financial, and upper management
The owner needs to assign a project manager for the entire project
Project scope
The project manager has the primary responsibility of defining the scope of the project
The project scope identifies work items, "deliverables," required to achieve the project, documented in a project execution plan
The owner's project manager collaborates with the designer's project manager and all other functional project managers to develop the project execution plan
Each work item in the scope should be budgeted and scheduled before starting work
Need separation between "what should be done" and "what should not be done"
People involved should include designers, lead designers, and upper management
Interactive roles of owner and project manager
A joint meeting of the owner and project manager is necessary to clarify objectives and scope
The owner should relate objectives in terms that can be understood by the project manager
The project manager should relate scope in terms that can be understood by the owner
Both the owner and project manager should agree that the objectives and scope are compatible
The preliminary project budget and schedule can be developed after scope is defined

TABLE 2-1 Owner's Project Objectives and Designer's Project Scope

Phase 1—Project Feasibility

Projects arise from a need whether it be a business need in the private sector or a public need in the public sector. An owner, be it a large multinational company or a small local business, needs to undertake a project to achieve part of its business strategy. The company decides to pursue an opportunity, hence it initiates a project. What are those objectives? Are they new products, expanding capacity,

entering a new market, anticipating a business threat, or replacing an existing facility that is outdated or at the end of its useful life? The need for a facility may be recognized by an operating division of the company, a corporate planning group, a top executive, a board of directors, or an outside consulting firm. Generally, one or more persons within the owner's organization are assigned to perform a need assessment to study the merits of pursuing the project. The business objective for the project must be clearly defined; it forms the basis for the project decision.

For public sector projects, the same questions apply. What is the agency's mission? What projects need to be done to fulfill that mission? What are the alternatives and how do they compare to each other?

From the stated business or agency objective, the project scope definition begins. A project objective statement clearly states what the project will accomplish and is tied to the stated objective. Defining scope begins with major components and considerations such as design criteria, dismantling and demolition needs, utility requirements, and general site characteristics. Environmental considerations and environmental permitting at the federal, state, and even county level have become significant aspects of project development both in cost and time. For major transportation projects, the environmental permitting process requires several years and impacts the design of the project. Public involvement, support or opposition, and impacts should also be included in project considerations.

Economics, return-on-investment, or benefit/cost ratios can be best associated with a reason a project is undertaken. Other factors to consider also include technical capability, operability, resource availability, environmental requirements, regulatory changes, new laws, market risks, financial limitations, and schedule. The question to be answered (the *outcome* of feasibility phase) is "What

alternatives might be studied that could meet the business or agency opportunity and objectives?" If any one or more of these factors undermine the opportunity, the project may be jeopardized. Initiating the project feasibility phase, including preliminary study development, ensures that an owner selects the best project (the right project), scopes and organizes the necessary components for a good design basis (the right assets, at the right cost, and right schedule) and paves the way for successful project execution (the right way). The early phases of a project (project definition) have the greatest impact on project success.

The thoroughness and completeness of the owner's study has a significant impact on total project cost. An inadequately defined project definition leads to changes during design and/or construction. An incomplete scope leads to costly change orders and, frequently, claims and disputes which lead to major cost overruns, delays, and other problems. Experienced managers agree the time to achieve savings and reduce changes is in the early life of the project, not at the start of construction. This concept is illustrated in Figure 2-4.

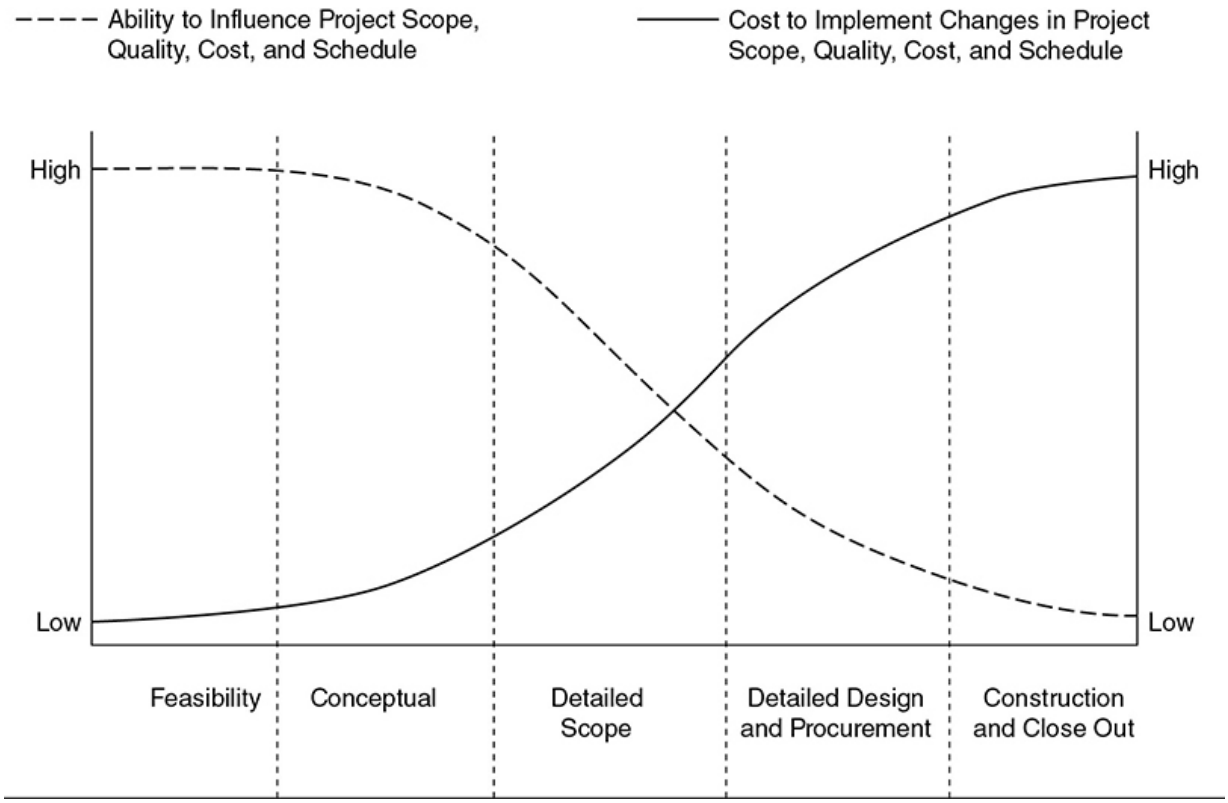


FIGURE 2-4 Importance of clear project definition in the early phases.

Owner's Study

For private sector projects, establishing the business objective is fundamentally important because it provides a focus for scope definition, guides the design process, and influences the motivation of the project team. The process of setting objectives involves an optimization of quality, cost, and schedule. The owner's objectives must be clearly communicated and understood by all parties and serve as a benchmark for the numerous decisions that are made throughout the duration of the project. Typically, the owner commissions a study, the owner's study, to evaluate the feasibility of the desired project effort and its alignment with business strategy.

The magnitude of the owner's study varies widely, depending on the complexity of a project and the

importance of the project to the owner. It is an important study because the goals, objectives, concepts, ideas, budgets, and schedule that are developed will greatly influence the design and construction phases.

A part of the owner's study is defining the requirements of the proposed project. However, some owners do not have the experience or expertise to conduct a study to effectively define, in engineering and construction terms, the operational needs of their company. The owner may be highly successful in running a manufacturing operation, but not be familiar with defining scope, budget, and schedule for engineering and construction projects. Therefore, the project manager of the design team may need to assist the owner with the important owner's study to define the requirements of a proposed project. Table 2-2 presents methods to assist the owner in defining project requirements.

Meet with the owner's staff, in particular the operations and maintenance people who will use the project when it is completed
Spend adequate time with the operations and maintenance people, to become acquainted with the work they do, how they do it, and what they are trying to accomplish
Conduct a series of meetings to separate "what they need" from "what they want," and relate those needs to the requirements that must be designed and built into the proposed project
Develop preliminary scope, budget, and schedule requirements of the project and translate those requirements into terms that can be understood and agreed upon by the owner's operating group and management
Obtain feedback from the owner's staff to verify that they understand the project requirements that must be accomplished in order to satisfy the needs of the owner's operating group
Document the results of the meetings, discussions, alternatives, and the decisions made and ensure that the results are distributed to the design group

TABLE 2-2 Methods of Assisting the Owner in Defining Project Requirements

The Project Charter

The owner's study must conclude with a well-defined set of project objectives and needs, the minimum requirements of quality and performance, an approved maximum budget, and a required project completion date. Failure to provide any of the above items starts a project in the wrong direction and leads to future problems. Sometimes an owner will contract parts of the study to an outside consulting firm. If an outside firm is utilized, the owner must still be involved to be certain that his or her needs are represented.

The thoroughness and completeness of the owner's study has a significant impact on total project cost. An inadequately defined project scope leads to changes during design and/or construction. An incomplete scope leads to costly change orders and, frequently, claims and disputes, which lead to major cost overruns, delays, and other problems. Experienced managers agree that the time to achieve savings and reduce changes is in the early life of the project, not at the start of construction.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the project charter template.

Once the project sponsor, project manager, and key stakeholders reach an agreement on the project objectives as documented in the project charter, the project can be approved to continue into the next phase, that is, conceptualization and alternative analysis. Approval to proceed should include agreement on the scope of work for the phase, the estimated cost to complete the work for the phase, and a schedule of activities to complete the phase.

Project Strategy

Once an owner decides that a project is feasible, the project manager and project sponsor need to discuss an overall project strategy. This strategy will help guide evaluation of

alternatives in the second phase. Project strategy forms the framework for developing the project and is the basis for developing the project execution plan during the detailed scope phase. The project strategy will be subdivided into specific details of the project execution plan during the detailed scope phase. Considerations for operational strategies such as redundancy in equipment, contracting strategies, procurement strategies, acquiring staff, and other items need to be considered at a high level before going into details. For example, an owner with internal engineering and construction resources has determined that a large expansion project is feasible given the current market conditions. The owner does not have experience with projects as large as the expansion project under consideration. The project manager and project sponsor need to consider a strategy of outsourcing the entire project to a firm with large project experience. Such a strategy sets parameters for the conceptualization and detailed scope phases. The owner will need to enter into a contract with a firm to develop a project to consider for fund authorization.

Contract strategy is key and identifies the overall organizational structure and the allocation of risk among the contracting parties. In the early stages of project development, the owner must decide the work that can be performed by internal staff and the work that must be contracted to outside organizations. The owner may have a large engineering staff that can handle the entire project: design, procurement, and construction. In other cases, the owner may only have a limited staff for projects, which requires the assignment of contracts to outside organizations that have the capability to perform the necessary work.

Although a large organization may have the internal capability, it may not be able to schedule the work when it is needed due to prior commitments. The owner’s

organization must make a realistic assessment of the work that can be accomplished internally and an outside firm's capability to perform the work, and then evaluate the cost and schedule trade-offs of purchasing outside services.

The type of contract chosen defines the allocation of responsibilities and risks for each party and influences the project schedule. The Construction Management Association of America (CMAA) published an "Owner's Guide to Project Delivery Methods," which provides a concise explanation of the available project delivery methods. This guide can be used to help an owner develop a project contract strategy during project development. If a fast-track schedule is important in order to obtain an early return on the project investment, then a cost-plus-fee contracting strategy may be desirable. Government projects of an emergency nature are sometimes handled in this manner. If there is ample time to complete the entire design, a traditional design/bid/build approach with a lump sum contract may be desirable. The owner must evaluate all possibilities, identify the advantages and disadvantages, and consider what best meets his or her needs, objectives, budget constraints, and schedule requirements. Chapter 12, Construction Phase, describes key decisions for project delivery. These decisions should be evaluated as part of the contracting strategy.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on "An Owner's Guide to Project Delivery Methods."

Phase 2—Conceptualization and Alternative Analysis

Based on the documented project objective and preliminary scope, alternatives are conceptualized. Each alternative is described with a scope overview, preliminary cost estimate,

and high-level schedule. Risks for each alternative are identified. Key personnel or skills needed for the project are captured. The conceptualization phase evaluates and eliminates the various alternatives until the one alternative that satisfies the business objective can be selected. At this point, the nodes of the triangle, budget, schedule, quality, encompass a project scope. Conceptualization continues to establish those activities (the basic unit of workflow) that contain the deliverables (activity outputs) that form the basis of design for the project.

For example, site factor activities might include developing information that improve project definition on scope, cost, and schedule via preliminary studies or research, such as performing geotechnical and hydrological characteristics studies, environmental assessments, access road routing, plot plans with topography, utilities, and restrictions. Engineering definition activities might include identifying and sourcing major pieces of equipment, conceptual or preliminary process flow diagrams, building program statements, and space identification, all which build out the developing basis of design and project scope. Design parameters specific to the project round out the basis of design.

All these variables influence decisions regarding how the design and construction, or project delivery of the project, will be executed. Each activity and deliverable should be assigned to a responsible resource to develop and integrate into the project work plan. Based on all this work, the preferred alternative is selected by the owner’s key stakeholders, or the project is cancelled. If an acceptable alternative is selected, it should have a project scope statement, cost estimate, schedule, and risk assessment. This package (business objective, project objective, preferred alternative with scope, estimate, schedule, and

risk register) is input for the detailed scope phase (phase 3) that leads to project authorization.

Engaging the project manager during the feasibility or conceptualization phase initiates the project manager's role as the leader of the project. The project manager can ensure that critical aspects such as site access, permitting, public outreach, infrastructure for construction, and key skills are included in the scope of each alternative being considered. The project manager can be the catalyst to move the project package through the detailed scope phase and on to the funding authorization decision.

Identifying and assigning the project manager during the conceptualization phase is a critical step for the project. The timing of the project manager's assignment can be leveraged into an opportunity for the project if it occurs when the best two or three alternatives solidify. The project manager's assignment can fester into a significant risk if it occurs after project authorization.

Phase 3—Detailed Scope Definition

The purpose of detailed scope definition is to provide sufficient information to identify the work to be performed, to allow the design to proceed without significant changes that may adversely affect the project budget and schedule. Detailed scope identifies those activities and work products that are required to meet the needs of the owner. Detailed design requires a detailed scope that adequately defines deliverables, that is, what will be furnished and placed in the project manager's hand. Examples of deliverables are design drawings, specifications, assistance during bidding, construction inspection, record drawings, and reimbursable expenses. All this information must be known before starting detailed design because it affects the project budget and schedule. To accomplish this, the project

manager from the design organization, and other functional leaders, must be involved early in the project. They will require input from experienced technical people to represent every aspect of the proposed project. Developing the detailed scope for the selected alternative must include the project manager and key team members. The outcome of this phase is project authorization, recycling the project for additional validation, or cancellation. If the project receives authorization to proceed into project execution, cost and resource requirements increase dramatically.

During detailed scoping, the basis of design is completed. Depending on the type of project, the remaining details for site information, piping and processes, equipment, structures, site access, land requirements, and design parameters for civil, mechanical, electrical or structural designs, and safety are identified and documented. For example, a project may need three buildings consisting of an employee's office building, a warehouse, and a maintenance shop. In addition, the project may need a crushed aggregate area for storage of heavy equipment and bulk materials. Each of the above items should be defined in further detail, such as number of employees in each building, type and amount of storage needed in the warehouse, type of maintenance required, and size and weight of equipment. This type of information is needed by the project manager and team to define the work required to meet the owner's needs and objectives.

An owner that describes a project as three buildings and an outside storage area is not giving enough information to start the design phase. To assist the owner in this effort, a comprehensive checklist of items should be prepared. Table 2-3 is an abbreviated checklist for detailed scope definition of a petrochemical project. The table is provided for illustrative purposes only and does not include all the items that should be considered. A similar checklist should be

prepared for other types of projects. Experienced design and construction personnel can provide valuable input to assist an owner in the development of a checklist for project scope.

1. General
1.1 Size of plant capacity
1.2 Process units to be included
1.3 Type of plant feedstock
1.4 Products to be made, initial and future
1.5 Should plant be designed for minimum investment
1.6 Horizontal vs stacked arrangement of equipment
1.7 Layout and provisions for future expansion
1.8 Any special relationships (e.g., involvements of other companies)
2. Site information
2.1 Access to transportation: air, waterway, highway, railway
2.2 Access to utilities: water, sewer, electrical, fire protection
2.3 Climate conditions: moisture, temperature, wind
2.4 Soil conditions: surface, subsurface, bearing capacity
2.5 Terrain: special precautions for adjacent property
2.6 Acquisition of land: purchase, lease, expansion potential
2.7 Space available for construction
3. Buildings
3.1 Number, types, and size of each
3.2 Occupancy: number of people, offices, laboratories
3.3 Intended usage: offices, conferences, storage, equipment
3.4 Special heating and cooling requirements
3.5 Quality of finish work and furnishings
3.6 Landscaping requirements
3.7 Parking requirements
4. Regulatory requirements
4.1 Permits: construction, operation, environmental, municipal
4.2 Regulations and codes: local, state, federal
4.3 Safety: detection systems, fires, emergency power
4.4 Environmental: air, liquids, solids, wetlands
4.5 Preservation restrictions

TABLE 2-3 Abbreviated Checklist for Project Scope Definition of a Petrochemical Project

A realistic budget and schedule cannot be determined for a project without a well-defined scope of work. Thus, the project scope should be developed first, then a project budget and schedule developed that matches the scope. It is the responsibility of all project managers to keep all work within the approved scope, and all costs and schedule within approved limits.

There are times when an owner may become excited about the merits of a project and anxious to begin work as soon as possible. This usually occurs when a new product is developed, or a government official decides a facility should be built at a particular time or location. The project manager must thoroughly review the project scope and be certain that it is sufficiently well defined before starting work on the project. If this is not done, the project team is forced into defining scope while work is being performed, which leads to frustration and adverse relationships. The simple solution to this problem is to lock in the scope at the beginning of the project, before starting design work, to make *certain all parties know the full extent of the required work.*

After completing the project scope definition, the project manager should assemble the team to discuss if or how all functional groups might interact to optimize a schedule. An erratic unplanned start to the project is not realistic or prudent. Often there are bouts of starts and pauses while waiting on others to provide critical information. The project team often discovers that many of their activities and deliverables are dependent on other functional team members completing or providing, in piecemeal, their scope item(s) first. These circumstances can drive cost up and prolong schedule thus impacting the overall expected project budget and project schedule. Each functional leader needs to assess how others can impact their cost, schedule, and resources. For example, civil design cannot begin until a site location is selected and purchased. Only then can the

site geotechnical deliverables begin, followed by foundation engineering. In some cases, resources may need to be added or removed (if practical) to accomplish the work. Integrated project workflow planning detailed in the project execution plan (PEP) is essential for each functional leader to optimize its cost and schedule to produce the scoped activities and deliverables.

The PEP is a comprehensive document that is a major deliverable for the project team and is required for project approval and authorization of funds. The PEP defines how the project will be undertaken to achieve success. As noted, development of the PEP is a complete team effort and includes numerous necessary components ranging from the key stakeholder's project objectives, the project description and project goals to detailed plans for every aspect of the project. All of these plans and information help the project team and key stakeholders to have a successful project outcome. Chapter 3 discusses the PEP in greater detail and provides an example outline.

Project Execution Considerations during Project Definition

Since the detailed design and construction of the project, project execution makes up the majority of the project time and cost; the detailed scope phase should produce the contracting and procurement strategies for project execution as previously discussed. During project execution plan development, the owner must select how detailed design and construction will be completed. Many choices exist for project delivery methods, each with advantages and disadvantages. The method selected affects financing; selection of team members; and the project cost, risk profile, quality, and schedule. Although the method selected is important, selecting good quality people is more

important. A successful project is achieved by people working together with clear responsibilities.

Design and construction firms may be engaged during project definition to assist in detailed scope development. Their services may comprise key contracts in the project execution plan. Regardless of when design firms or construction firms are engaged, integration of the owner's requirements and constraints from the detailed scope provides a description of the project and helps identify a plan for the time and cost of delivering the project.

A brief discussion of contractual arrangements follows, so the project manager can start to formulate contracting strategies for detailed design and construction. If the project manager works for the owner, the detailed scope phase may possibly be done through a contract with a design firm. Chapter 12 also discusses project delivery methods.

Contractual Arrangements

Project management requires teamwork among the three principal contracting parties of owner, designer, and contractor. The form of contract will have a significant effect on the relationships between the three principal parties. It will also affect the risk profile of the project and impact resource planning. The contractual arrangement must be selected with care; therefore, detailed scope phase should evaluate and select that arrangement to best accomplish the project objectives.

Members of the owner's team must provide the project's needs, the level of quality expected, a permissible budget, and the required schedule. They must also provide the objective and overall direction of the project. The designer's team must develop a set of contract documents that meets the owner's needs, budget, required level of quality, and schedule. In addition, the work specified in the contract documents must be constructable by the contractor. The

contractor’s team must efficiently manage the physical work required to build the project in accordance with the contract documents.

For competitive-bid projects, contractors bid the project after the contract documents are completed. After accepting the bid, the contractor must develop shop drawings to build the project. Shop drawings are prepared by the contractor and submitted to the designer for approval. The shop drawings show the detailed fabrication and installation that will be used during construction. Thus, the contractor is also involved in design. The production of shop drawings impacts the quality of fabrication of manufactured items that will be installed at the jobsite. Site construction involves labor, material, and construction equipment to physically build the project.

For noncompetitive-bid projects, the owner negotiates a contract with a firm to provide engineering and/or construction services. Typically, the cost of the project is negotiated on some type of cost-reimbursable basis. The agreement also specifies how the engineering design will be integrated with the construction process.

There are numerous combinations of contract arrangements for handling a project. Figure 2-5 illustrates the fundamental arrangements in their simplest form. Each of these arrangements is briefly described in the following paragraphs.

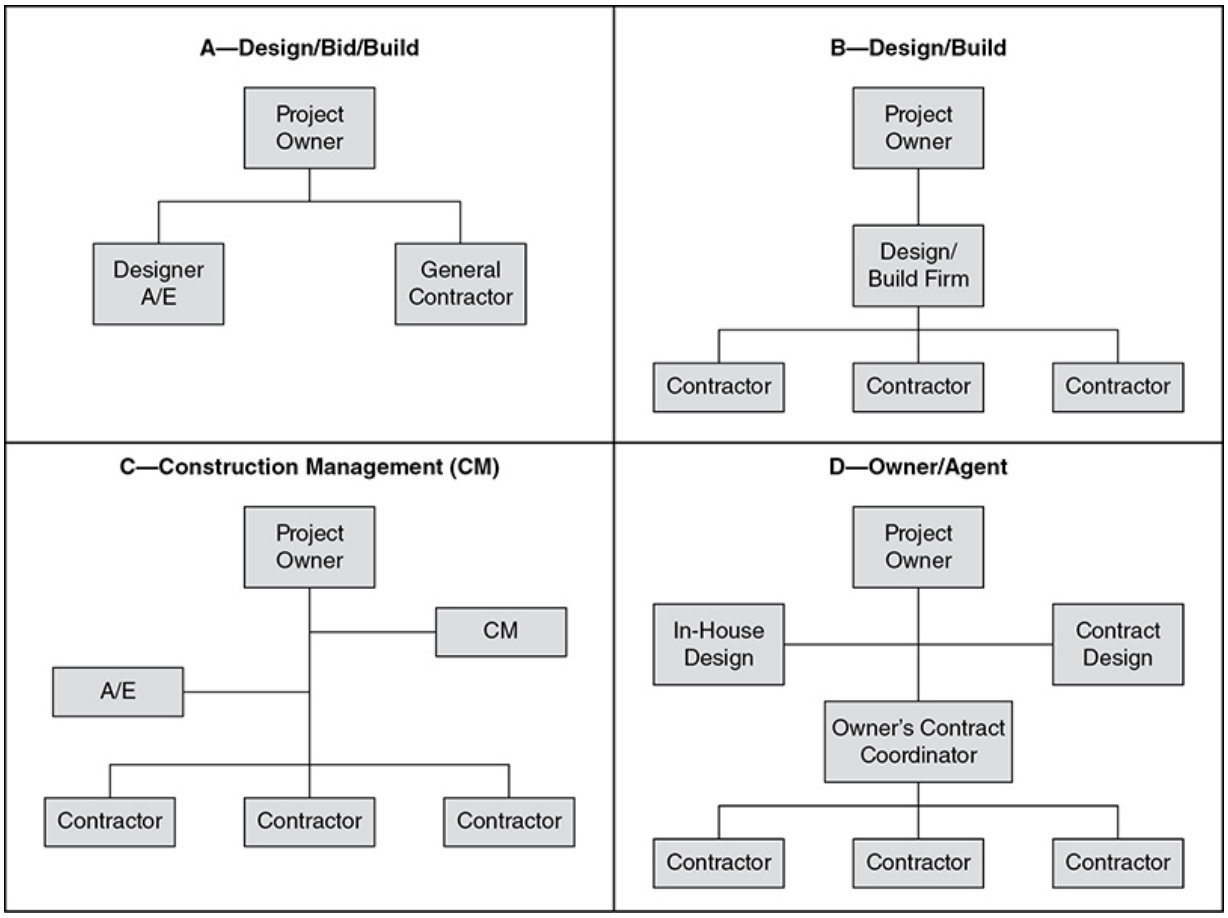


FIGURE 2-5 Contracting arrangements.

A design/bid/build contract is commonly used for projects that have no unusual features and a well-defined scope. It is a three-party arrangement involving the owner, designer, and contractor. This method involves three steps: a complete design is prepared, followed by solicitation of competitive bids from contractors, and the award of a contract to a construction contractor to build the project. Two separate contracts are awarded, one to the designer and one to the contractor. Since a complete design is prepared before construction, the owner knows the project's configuration and approximate cost before commencing construction. Considerable time can be required because each step must be completed before starting the next step. Also changes during construction can be expensive because

the award of the construction contract is usually based on a lump-sum, fixed-price bid before construction, rather than during construction.

Table 2-4 gives several advantages and disadvantages of using the design/bid/build method of contracting construction work.

Advantages	Disadvantages
Cost of project is known before owner commits to signing construction contract	Changes by owner after the contract is signed can be costly and cause delays
Responsibilities and risks of parties are defined in contract documents	Major changes, outside of the original contract bid documents may be difficult and costly
Owner has a high level of involvement and control during design development	Combined time required to design, bid, and build the project can be extensive
Selected for projects when cost is primary and schedule is secondary	Owner has little control of the project during construction

TABLE 2-4 Advantages and Disadvantages of Design/Bid/Build Contracts

A design/build contract is often used to shorten the time required to complete a project or to provide flexibility for the owner to make changes in the project during construction. It is a two-party arrangement between the owner and the design/build firm. Since the contract with the design/build firm is awarded before starting any design or construction, a cost-reimbursable arrangement is normally used instead of a lump-sum, fixed-cost arrangement. This method requires extensive involvement of the owner for decisions that are made during the selection of design alternatives and the monitoring of costs and schedules during construction.

Table 2-5 gives several advantages and disadvantages of using the design/build method of contracting construction work.

Advantages	Disadvantages
Less time to complete the project because construction can overlap design	Difficult in evaluating design/build contractor with respect to total cost of project
Reduced adversarial relationship between design and construction personnel	Total cost of project is not known at the beginning of project because design is not complete
Provides flexibility to the owner to make changes during design and construction	Handling of inspection is an issue that must be addressed because the designer is the builder
Having one contracting firm reduces the owner's management responsibility	Considerable time may be required of owner to make major decisions and monitor costs

TABLE 2-5 Advantages and Disadvantages of Design/Build Contracts

A construction management (CM) contract can be assigned to a CM firm to coordinate the project for the owner. The CM contract is a four-party arrangement involving the owner, designer, CM firm, and contractor. During the past 30 years there has been considerable debate regarding the CM process and the amount of responsibility assigned to the CM firm by the owner. This has resulted in the construction management at risk (CMAR or GM/GC). The basic CM concept is that the owner assigns a contract to a firm that is knowledgeable and capable of coordinating all aspects of the project (development, design, and construction) to meet the intended use of the project by the owner. During development and design, the CMAR consults the owner regarding project decisions. During the construction phase the CMAR acts as a general contractor (GC). The CM method of contracting is discussed further in Chapter 12.

Another project delivery method is integrated project delivery (IPD). This method attempts to share the risk, responsibility, and liability for project delivery equitably among the owner, designer, and builder.

An owner/agent arrangement is sometimes used for handling a project. Some owners perform part of the design with in-house personnel and contract the balance of design

to one or more outside design consultants. Construction contracts may be assigned to one contractor or to multiple contractors. Although uncommon, an owner may perform all design and construction activities with in-house personnel. When a project is handled in this manner, it is sometimes referred to as a force account method.

While summary level explanations and comparisons are provided here, the Construction Management Association of America (CMAAnet.org) provides in-depth analysis and guidance for project delivery methods. The Design Build Institute of America (DBIA.org) also provides details for the design build approach.

There are two general types of owners: single-builder owners and multiple-builder owners. Single-builder owners are organizations that do not have a need for projects on a repetitive basis, normally have a limited project staff, and contract all design and construction activities to outside organizations. They usually handle projects with a design/bid/build or CM contract.

Multiple-builder owners are generally large organizations that have a continual need for projects and generally have a staff assigned to project work. They typically will handle small-sized, short-duration projects by design/bid/build. For a project in which they desire extensive involvement, a design/build, CM, or owner/agent contract arrangement is often used.

An owner can select a variety of ways to handle a project. The contract arrangement that is selected depends on the experience of the owner with the particular project, the resources available to the owner, the amount of project control the owner wishes to retain, the amount of involvement desired by the owner, the amount of risk that is shared between the owner and contractor, and the importance of cost and schedule.

Private versus Public Projects

Projects may also be classified as private sector or public sector projects. The owner of a private sector project is typically a business that provides goods and services for a profit. Examples include commercial retail stores, manufacturing facilities, industrial process plants, and entertainment facilities. Since the owner is a private business, the business administrators have the flexibility to choose any engineering and construction services that suit their specific needs. For example, they can competitively bid the project or select a sole source firm to provide engineering and construction services. They are not restricted to accepting the lowest bid for the work and can choose any form of payment for services. Some companies that require construction projects on a continual basis develop a list of preapproved contractors. When a new construction project is ready to start, the company can solicit bids from the list of preapproved construction contractors.

The owner of public sector projects is typically a government agency, such as city, county, state, or federal. Examples include local school boards, state highway departments, or the federal department of energy or defense. In the past, public sector projects typically used the competitive-bid method based on the lowest bid price for securing engineering and construction services. However, the range of procurement (contractor) methods available to public agencies has grown.

For both sectors, as projects have encountered increasing environmental requirements and public involvement, new contractual arrangements allow contactors to significantly derisk their involvement and deliver a cost-effective project to the owner.

Project Classifications

Projects can generally be classified into three sectors: buildings, infrastructure, and process. Examples of building-sector projects include commercial buildings, schools, office buildings, and hospitals. For building-sector projects, where the architect is the prime designer, the design follows three stages: schematic design, design development, and contract documents. The schematic design produces the basic appearance of the project, building elevations, layout of floors, room arrangements within the building, and overall features of the project. At the conclusion of schematic design, the owner can review the design configuration and the estimated cost before giving approval to proceed into design development. Design development defines the functional use and systems in the project in order to produce the contract documents, the plans, and specifications for constructing the project.

Infrastructure-sector projects include transportation systems, such as city streets, county roads, state and federal highways, airports, or navigational waterways. The infrastructure sector also includes utility projects, such as water and sewer line systems, gas distribution lines, electrical transmission and distribution, telephone, and cable lines. For these types of projects the owner may be a private company or an agency of the government. The prime designer is the engineer, who generally prepares a complete design before construction contracts are created.

Process-sector projects include chemical, oil refining, pharmaceutical, pulp and paper, and electrical generating plants. Engineers are the prime designers of process-sector projects. The stages of design include preliminary engineering, detailed engineering, and development of the contract documents. For example, preliminary engineering may involve designing the process flow sheets and mechanical flow sheets for a chemical processing plant. The

preliminary engineering produces the major processes and major equipment required in the project. Detailed engineering involves the actual sizing of pipes that will connect to the equipment and control systems to operate the facility, such as piping and instrumentation drawings. The contract documents are the final drawings and specifications for constructing the project.

Depending on the project delivery method, procurement may start during the design phase. For example, as soon as the specification is completed for a major piece of equipment, a purchase order may be issued to procure the equipment if it is a long lead-time item that must be ordered in advance of construction to ensure that it can be installed without delaying the project. Procurement is not restricted only to equipment. Procurement may also apply to long lead-time acquisition of bulk material or procurement of construction or specialty contractors.

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CHAPTER 3
Detailed Scope—Work Plan Development

Planning versus Scheduling

The discussion of developing the project work plan or project execution plan (PEP) in this chapter is focused on early project planning prior to detailed design. Planning during these early phases of the project involves a focused and specific breakdown of the project in the early stages of development, prior to detailed design. Emphasis on early project planning is presented in this chapter because the ability to influence the overall quality, cost, and schedule of a project toward successful outcomes can best be achieved by rigorous planning during project development phases of the project lifecycle.

Often planning and scheduling are used together or synonymously. However, planning is a prerequisite to scheduling. Project planning is the process of identifying all the activities necessary to successfully complete the established scope of the project. Project scheduling is the process of determining the timing of when the planned activities should be done. In simple terms, work has to be identified and planned before it can be scheduled.

AACE International defines planning as determining the project's objectives with identification of the activities to be performed, methods and resources used for accomplishing

the tasks, assignment of responsibility and accountability, and building an integrated plan to complete the project as required. A simpler definition for planning is determining the individual tasks that must be performed to carry out the project and establishing a sequential relationship between them. Planning is concerned with how the work will be done not when the work will be done.

The effort expended in planning is an investment toward the success or failure of the project. Planning presents the opportunity to create a firm foundation on which to build the project. Once the plan is formed, documented, approved, and the project is fully funded, the project manager (PM) must ensure that the team is held accountable for performing as planned.

Project Manager’s Initial Review

When a project manager is assigned to a project whether from the owner’s organization or hired as a third party, their first duty is to gather all the background material that has been prepared by the sponsoring organization. If the project manager is assigned during project definition, he or she should focus on proper development and documentation of the project scope statement, design basis, estimate, schedule, risk assessment, and project work plan. Such documentation includes the owner’s study and any applicable contracts including the contract (if the PM is a third party) that has been signed by the project manager’s organization. These documents must be thoroughly reviewed to be certain they are sufficiently developed for the project phase. If the project has been approved and has received funds authorization, documents must include a well-defined scope that is detailed in the project scope statement, an approved detailed budget, a detailed schedule that shows activities and major milestones for the

project, in particular, the required completion date and a project execution plan.

The purpose of this initial review process is to become familiar with the owner's objectives, the overall project needs, and to identify any additional information that may be needed to begin the process of developing a work plan to manage the project. To organize the review process it is best to divide the questions into the three categories that define a project: scope, budget, and schedule. To guide this initial review, the project manager should continually ask questions like those shown in Table 3-1.

Scope 1. What is missing? 2. Does it seem reasonable? 3. What is the best way to do this? 4. What additional information is needed? 5. What technical expertise is needed? 6. How is the best way to handle construction? 7. What is the owner's expected level of quality? 8. What codes and regulations are applicable?
Budget 1. Does the budget seem reasonable? 2. How was the budget determined? 3. Who prepared the budget? 4. When was the budget prepared? 5. Should any portion of the budget be rechecked? 6. Has the budget been adjusted for time and location?
Schedule 1. Does the schedule seem reasonable? 2. How was the schedule determined? 3. When was the schedule prepared? 4. Who prepared the schedule? 5. How firm is the completion date? 6. Are there penalties or bonuses?

TABLE 3-1 Guidelines for Project Manager's Initial Project Review

Owner's Orientation

After the project manager has performed the initial project review and become familiar with the project, the owner's authorized representative should be identified, and a meeting scheduled to set up the necessary coordination

arrangements with the owner. The owner's representative serves two roles in a project: as a participant in providing information and clarifying project requirements, and as a reviewer and approver of all team decisions. The owner must be considered an integral part of the project team, beginning at the start of the project and continuing through all phases until completion.

The project manager should assess the owner's experience with the type of project being proposed. The project manager should determine what parts of the project, if any, the owner will perform. Often an owner believes they possess the capability to perform key parts of a large project because they have experience with similar smaller projects. Experience in building a 10-mi intrastate pipeline is not the same as experience building a 1000-mi interstate pipeline. The project manager is in a difficult position. They are responsible for managing the project to a successful completion and may be required to advise that the owner does not possess the capability to perform any of the project's scope. The project manager is acting in the best interest of the project which is also the best interest of the owner. Objective diplomacy becomes a key leadership skill for the project manager.

During this initial meeting, the owner's authorized representative should set priorities for the project. There are four elements of concern for a project: quality, scope, time, and cost. It is understood that quality is an element that must be satisfied. The owner should set the level of quality that is expected in the project. There must be a mutual understanding of quality between the project manager and the owner's representative. Scope is the fixed quantity of work to be performed. It may be expanded or reduced by the owner as the project proceeds, generally depending on the cost. The priority of time or cost is set by the owner. Frequently, time is initially set as a priority over cost.

However, cost may take precedence over time if the market for the product changes or other conditions arise. Just as frequently, the owner sets cost as the priority over schedule. As the project progresses and changes occur in the market, new competition may enter the arena or other circumstances may arise to cause the owner to shift priority to schedule over cost. If a priority is not set, the project manager must attempt to optimize time and cost.

The level of involvement required by the owner's representative must be determined at the beginning of the project. If he or she wants to sign everything, then the project manager must include time in the project schedule and cost into the budget for the owner's representative involvement. The project manager and the owner's representative must determine and agree upon decision-making authority. If the owner's representative cannot make decisions on behalf of the project, the project manager will need to add time for decisions into the schedule. This creates a risk event that decisions will be late or changed as the project progresses. Regardless, two-way communication is an absolute requirement. The project manager should also inform the owner's representative of how he or she plans to create a project team that will be coordinated to represent each part of the project.

This initial meeting also gives both the owner's representative and the project manager the opportunity to meet each other. At this meeting it may be desirable to visit with other key stakeholders in the owner's organization that may be concerned with the project. Issues to discuss might include clarification of goals and requirements, desired level of quality, any uniqueness about the project, financing, regulatory agencies, public outreach, and approval processes.

In some instances, this meeting may be the project manager's first introduction to the owner's representative.

Because many owners expect an all-knowing project manager, some precautions need to be taken. Since the project team has not yet been formed, all discussions should focus on the work to be performed rather than on work that has been completed. Ideally, the project manager should have assisted in the proposal preparation that was approved by the owner to proceed with the project. This gives the project manager a better understanding of the history behind the project and previous contact with the owner's representative.

Considerations for Detailed Scope

Advances in Engineering and Construction

Developing the detailed scope for a selected alternative requires consideration of all aspects of the project from legal issues and regulatory permits to start-up of the new facility. Being aware of and understanding advances in the engineering and construction process can help the project team form an optimal plan for project execution.

The construction industry continues to develop and take advantage of available technology to enhance the integration of activities in the design, fabrication, construction, and operation of constructed facilities. Computer-Aided Drafting (CAD) and Geographical Information Systems (GIS) technology provide powerful platforms for versatile modeling systems that can be used throughout the design, engineering, and construction phases to improve project delivery. These and other technologies are employed to improve construction jobsite safety and operator safety in the completed facility.

Three-dimensional (3D) models are used as the basis for Building Information Modeling (BIM). BIM was first discussed as early as 1962. [BIM 101: What Is Building Information

Modeling, Erin Green, engineering.com]. BIM strives to make all information necessary for the construction of a facility available to the project team including on-site construction personnel. Access to this information whether using specific software or other technology improves coordination of activities within an integrated process, rather than automating individual activities within the existing fragmented design/construction process. The design intent may not be fully realized in the field using traditional information flow to the field through the use of drawings and other hardcopy documents. Traditional paper-based construction documents do not permit field personnel to interact with the 3D model to extract information that meets their needs or to access updated drawings and specifications. Communication that uses 3D modeling coupled with improved representation of design intent and other supplemental information can help alleviate many typical construction problems associated with material availability, work packaging, construction sequencing, and field changes.

Additional dimensions of BIM (4D, 5D, 6D) integrate additional data into the 3D model. 4D BIM incorporates a time element to the data. Time data can include construction duration for the element, lead time, and dependencies on other elements. At its simplest level, time data provides a view of how the project will be constructed. 5D BIM adds a cost dimension to the data set. Costs can include the capital cost of construction, procurement cost of materials, and maintenance or replacement costs. 6D BIM can also be called integrated BIM (iBIM) and merges operations and maintenance information into the facility. The objective of adding this data is to help make better operational decisions for the facility thereby improving the facility’s impact on business revenues. When these data dimensions are used during project development, decisions

can be made that improve the total cost of ownership of the facility, not just the capital cost of construction.

Some practitioners have the opinion that “if it stands still, it’s a candidate for BIM.” The level of effort required to develop, integrate, and capture the multiple levels or dimensions of data for BIM needs to be evaluated against the long-term and near-term advantages and disadvantages. The project manager must focus on doing what is right for the project within the parameters established by the project objective statement. The project is about building a facility not improving a business process.

Drones are another technological advance. Their use to collect project information for project conceptualization through construction and operations is just beginning. For example, collected aerial data can be integrated to the BIM to monitor construction progress and to check for interference.

No amount of technology will overcome a lack of discipline in following project processes. For example, an updated specification must be properly documented and communicated to all stakeholders regardless of communication method. Chapter 5, Project Document Control, will further discuss managing key documents for proper use during project definition, detailed engineering, and construction.

Selection of Design Firms and Construction Contractors

The detailed design and the construction of the project constitute the majority of the project cost and schedule. Time spent planning the procurement of these services is essential to successful project execution.

Selection of the designer and constructor varies depending on many factors including the type, size, and complexity of the project; the owner’s knowledge in

handling engineering and construction projects, and how soon the owner wants the project to be completed. The method of selection depends on the owner's project execution strategy and the contract arrangement chosen by the owner.

When the owner plans to complete all the design before selecting a construction contractor, then a procedure must be initiated for selecting the designer. Typically, an owner selects a designer that he or she has used before and with which he or she has had a satisfactory experience. For private-sector projects, owners can simply choose their preferred designer, or they may desire to obtain proposals from several design organizations that they have used in the past. A request for proposal (RFP) is issued to the prospective designers who then each prepare a design proposal as discussed in Chapter 9. After the design organizations have submitted their proposals, the owner can review and evaluate the proposals and decide for award of the design contract. For public-sector projects, selection of the designer depends on the policies and restrictions of the agency. Generally, designers are selected from a list of prequalified firms. Chapter 9 presents methods of compensation for professional design services.

If the owner has no prior experience in working with designers, a procedure must be established to select the designer. After the owner has studied the proposed project and its need for design services, a list of prospective design organizations is identified. Often the list is compiled based on recommendations of other owners or those acquainted with design firms who are known to have the expertise required to design the project. Generally, the list consists of at least three design firms that appear to be best qualified for the particular project. Each design firm is sent a letter that briefly describes the proposed project and inquires about the firm's interest in the project. Upon receipt of

confirmation that the design firm is interested in the project, the owner then conducts a separate interview of each design firm. At the interview the owner reviews the qualifications and records of the firm to assess its capability to complete the work within the allotted time and to review specific key personnel that would be assigned to the project. It is important for the owner to meet the specific people who will be performing the design work to ensure compatibility of personalities. The owner should also contact references provided by each firm to discuss the firm's performance, key personnel, quality of design, ability to meet schedule, and other considerations.

Typically, after all interviews are conducted, the owner lists the design firms in the order of their desirability, considering their location, reputation, size, experience, financial stability, available personnel, quality of references, workload, and other factors related to the proposed project. Based on the evaluation, one or more additional interviews of the top design firms may be conducted before a decision is made on the final selection. An inexperienced owner can elect to follow the RFP process described above after the owner has determined which firms are eligible for the work.

If the design is 100% complete, the owner may issue requests for bids (RFBs) to construction contractors. For most private-sector projects, the contract documents generally state that selection of the construction contractor will be based on the lowest and best bid. Typically, for public-sector projects the contract documents state the selection of the construction contractor will be based on the lowest qualified bidder. However, the lowest bid is generally the criteria for selection of a construction contractor when the design is 100% complete.

Sometimes the owner may desire to start construction before design is completed. For example, the construction contractor may be chosen after 70% design completion, or

the construction contractor may be selected at the same time the designer is selected in order to take advantage of the contractor's knowledge of building the project. When the owner desires to start construction before design is complete, selection of the construction contractor cannot be made on price alone because the design documents are not completed. When the construction contractor is selected before design is completed, a procedure is established to review and evaluate prospective construction contractors similar to the procedures presented in preceding paragraphs for selection of the designer. A more detailed discussion of project delivery methods for construction is presented in Chapter 12.

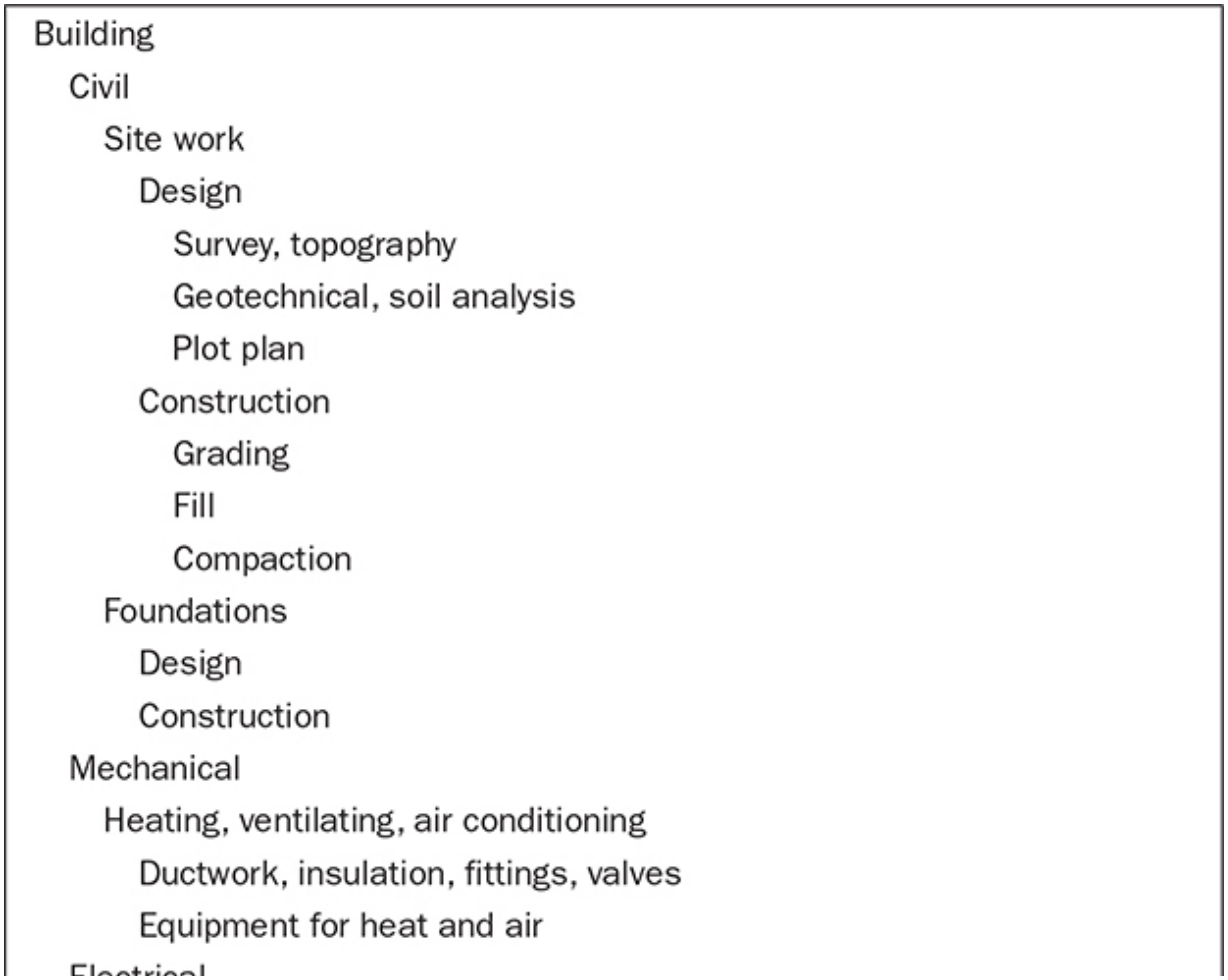
Plan for Value Improving Practices

As the project manager develops the project execution plan, they should plan to evaluate the use of value improving practices for the project. A value improving practice (VIP) when employed on a project should produce measurably improved project outcomes such as operability, reliability, cost, safety, or other performance characteristics. Some VIPs (like constructability reviews) can serve to improve the project schedule; this supports a greater return on investment since revenue streams could possibly begin sooner. The objective of utilizing VIPs is to improve the project investment, in other words, to improve the lifecycle return on investment for the asset being constructed. Because of this comprehensive aspect of VIPs, the owner must apply them consistently and systematically from project to project.

Considering the various VIPs for the project requires intention, resources, and time. Planning for VIP utilization during project development ensures that adequate time and resources are allocated to the effort. VIPs are discussed further in Chapter 9, Design Proposals.

Work Breakdown Structure

The Work Breakdown Structure (WBS) is an essential tool to identify and quantify all of the work to be done by the project. The WBS is the critical step in planning and defining a project scope. The WBS is a detailed process used to break down and identify a project's scope elements into identifiable, quantifiable, and measurable work components, activities, and deliverables. AACE International defines Work Breakdown Structure as a systematic approach creating a framework for organizing and ordering activities making up a project. It is typically a top-down hierarchy with each lower level providing more detail and smaller components of the overall work. Table 3-2 provides a simple example of a WBS for a building project.



Electrical
Rough-in electrical
Wires, cables, boxes
Circuit breakers
Finish electrical
Light fixtures
Switches
Plumbing
Water distribution
Piping, fittings, valves
Water piping, insulation, fittings, valves
Fixtures, sinks, tubs, showers
Sanitary sewer
Mains, manholes
Laterals
Structural
Steel
Concrete
Finishes
Exterior
Façade, roofing
Interior
Flooring, walls, ceilings
Landscaping

TABLE 3-2 Simple Example WBS for a Building Project

For any size project, large or small, it is necessary to develop a well-defined WBS that divides the project into identifiable parts that can be managed. The concept of the WBS is simple; in order to manage a whole project, one must manage and control each of its parts. The WBS is the cornerstone of the project execution plan. It defines all of the work to be performed, identifies the needed expertise,

assists in selection of the project team, and establishes a base for project scheduling and control. Chapters 10 and 13 show how the WBS is used in project scheduling and tracking.

A WBS is a detailed outline of all of the work required to complete the project. It can be a graphical display similar to an organizational chart or it can be in outline form. It displays the division of work of the project in a multilevel system. Figure 3-1 is a simple illustrative example of a WBS for a project that has three major facilities: site work utilities, and buildings. Each major facility is subdivided into smaller components. For example, the major facility of buildings is subdivided into three buildings: office, maintenance, and warehouse. The project is further broken down so the components at each level are subsets of the next higher level. The number of levels in a WBS will vary depending on the size and complexity of the project. The smallest unit in the WBS is a work package. A work package must be defined in sufficient detail so the work can be measured, budgeted, scheduled, and controlled at that level. Development of work packages is discussed later in this chapter. The WBS must describe 100% of the project. Omitting scope from the WBS omits work, yielding a project that fails to meet the triad requirements of scope, cost, and time.

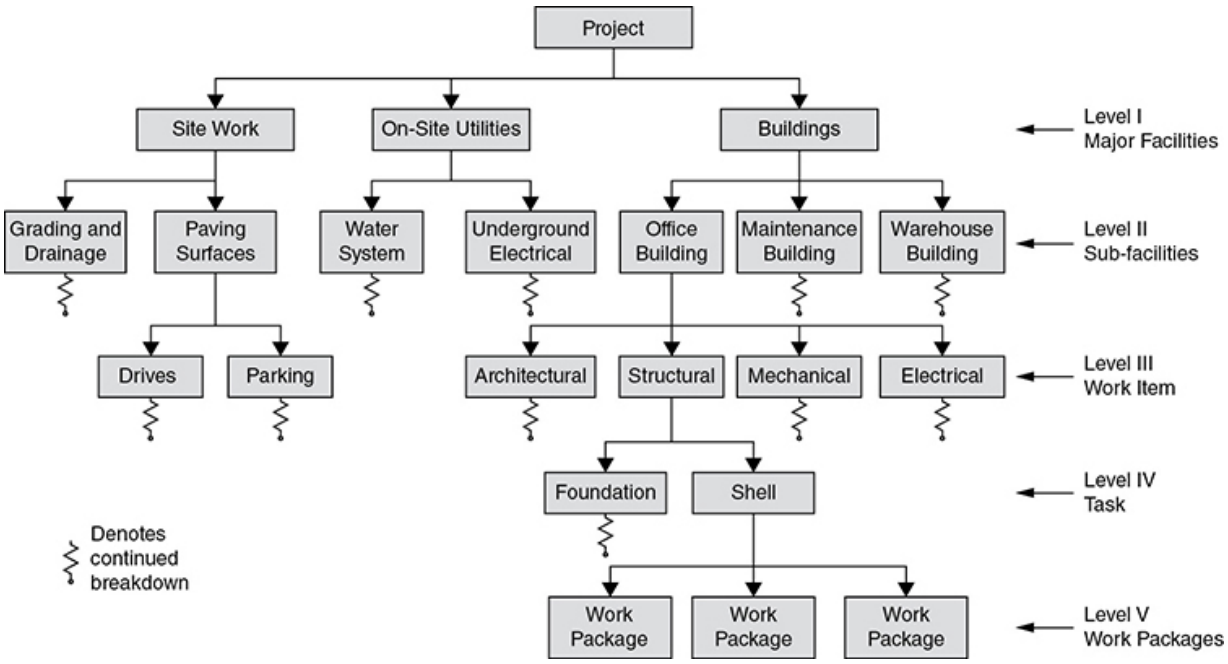


FIGURE 3-1 Illustrative work breakdown structure (WBS).

Building the WBS is a key requirement for project planning. Techniques for defining the WBS include using a WBS from a similar project and adapting it for the project at hand, starting with a blank page, or buying a template. An effective technique that carries the added benefit of team building is to conduct a team planning session. As a follow-up to the project kick-off meeting, each team member prepares in advance of the planning meeting the statement and outline of work for their function. At the meeting each function discusses their work, information needs from other functions, and information obligations to dependent functions. A facilitator guides the team through these discussions and captures additional components of scope identified for each function. The team has a better mutual understanding of the scope of the project, the interdependencies between functions, and how each member's part contributes to the project as a whole.

The development of the WBS is a continuing process that starts when the project is first assigned to the project

manager and continues until all work packages have been defined. The project manager starts the process of developing the WBS by identifying major areas of the project. As members of the project team define the work to be performed in more detail, the WBS is adjusted accordingly. Thus, the WBS is used from the start to the finish of the project for planning and controlling. It is an effective means of defining the whole project, by parts, and providing effective communication channels for exchange of information that is necessary for management of the project.

The WBS is the foundation of a project management system. Code numbers can be used to relate the WBS to the Organizational Breakdown Structure (OBS) for management of people. Code numbers can also be used to relate the WBS to the Cost Breakdown Structure (CBS) for management of costs. Similarly, code numbers can relate the WBS to the Critical Path Method (CPM) schedule to manage time. Thus, the WBS provides a systematic approach, for identifying work, compiling the budget, and developing an integrated schedule. The WBS is developed jointly by the project team, the people that will actually perform the work. It is an effective tool for relating work activities to ensure that all work is included, that work is not duplicated, the format of work products, and that proper hand-offs between team members occur. Most importantly, it provides a basis for measurement of performance.

Formats for Work Breakdown Structures

A WBS can be developed in a graphic format or outline format. Figure 3-2 is an illustrative example of a graphic format WBS for a project and Figure 3-3 is a WBS in an outline format for the same project. The WBS in these

figures represent the Engineering, Procurement, and Construction (EPC) for a maintenance facility. The WBS for this EPC project has three major divisions: engineering, procurement, and construction. The engineering division is subdivided into contract design and in-house design. Procurement is subdivided into purchase of major equipment and securing contractor bids. Construction is subdivided into site work and two buildings. The project management of this type of project is further discussed in Chapters 10, 13, and Appendix A.

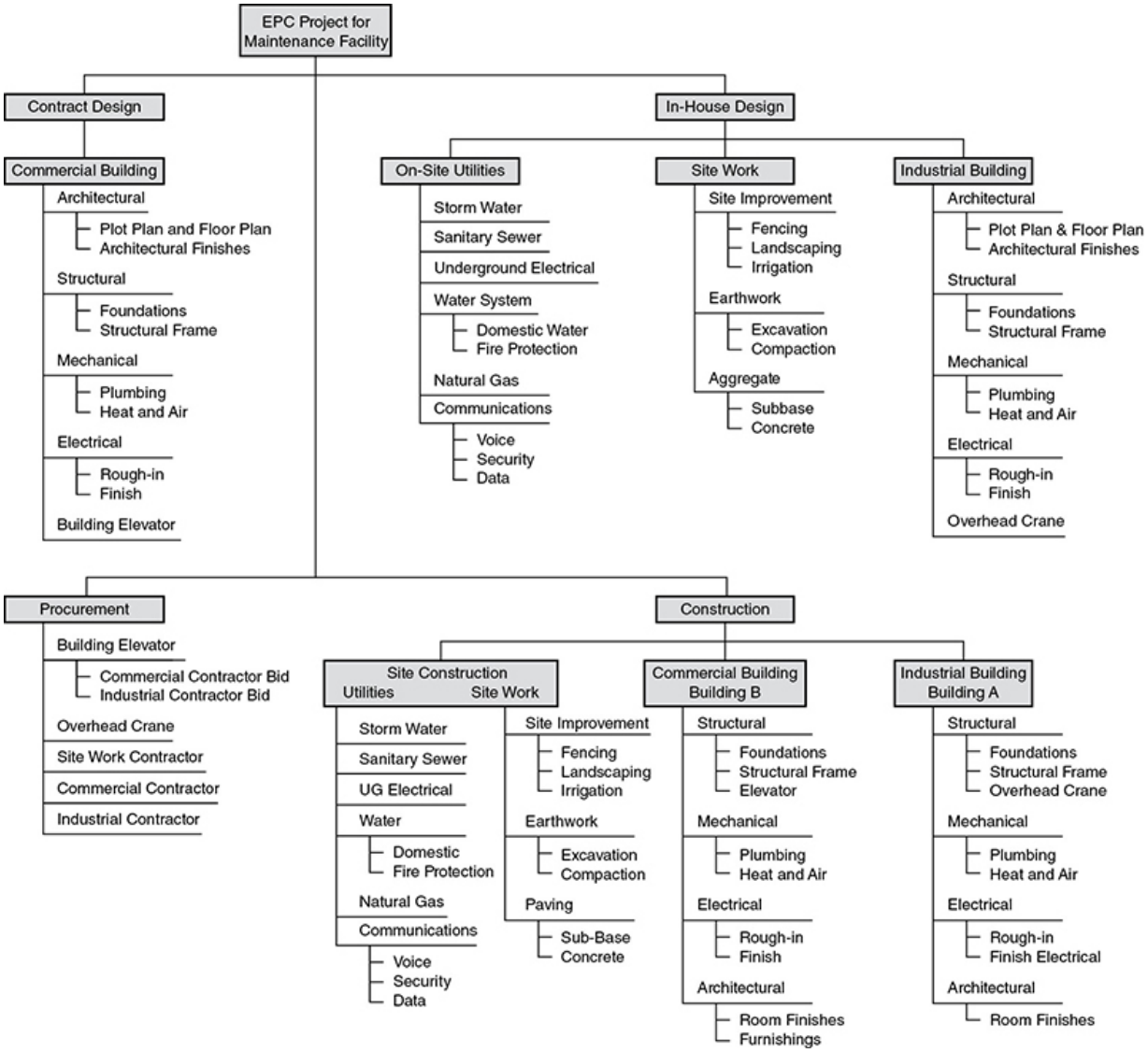


FIGURE 3-2 WBS in graphical format for engineering, procurement, and construction (EPC) of maintenance facility.

1.0 Engineering design

1.1. Contract design

1.1.1. A/E for Building B

1.1.1.1. Plot and floor plan

1.1.1.2. Architectural finishes

1.1.2. Structural

1.1.2.1. Foundations

1.1.2.2. Structural frame

1.1.3. Mechanical

1.1.3.1. Plumbing

1.1.3.2. Heat and air

1.1.4. Electrical

1.1.4.1. Rough-in

1.1.4.2. Finish

1.1.5. Building Elevator

1.2. Internal design

1.2.1. On-site utilities

1.2.1.1. Storm water

1.2.1.2. Sanitary sewer

1.2.1.3. Underground electrical

1.2.1.4. Water system

1.2.1.4.1. Domestic water

1.2.1.4.2. Fire protection

1.2.1.5. Natural gas

1.2.1.6. Communications

1.2.1.6.1. Voice

1.2.1.6.2. Security

1.2.1.6.3. Data

1.2.2. Site work

1.2.2.1. Site improvement

1.2.2.2. Fencing

1.2.2.3. Landscaping

1.2.2.4. Irrigation

1.2.2.5. Earthwork

1.2.2.5.1. Excavation

1.2.2.5.2. Compaction

1.2.2.6. Paving

1.2.2.6.1. Sub-base

1.2.2.6.2. Concrete

1.2.3. A/E Building A

1.2.3.1. Architectural

1.2.3.1.1. Plot and floor plan

1.2.3.1.2. Architectural finishes

1.2.3.2. Structural

1.2.3.2.1. Foundations

1.2.3.2.2. Structural frame

1.2.3.3. Mechanical

1.2.3.3.1. Plumbing

1.2.3.3.2. Heat and air

1.2.3.4. Electrical

1.2.3.4.1. Rough-in

1.2.3.4.2. Finish

1.2.3.5. Overhead crane

2.0 Procurement

2.1. Building elevator

2.2. Overhead crane

2.3. Site work contractor

2.4. Commercial contractor bid

2.5. Industrial contractor bid

3.0 Construction

3.1. Site construction

3.1.1. Utilities

3.1.1.1. Storm water

3.1.1.2. Sanitary sewer

3.1.1.3. Underground electrical

3.1.1.4. Water

3.1.1.4.1. Domestic

3.1.1.4.2. Fire protection

3.1.1.5. Natural gas

3.1.1.6. Communications

3.1.1.6.1. Voice

3.1.1.6.2. Security

3.1.1.6.3. Data

3.1.2. Site work

3.1.2.1. Site improvement

3.1.2.1.1. Fencing

3.1.2.1.2. Landscaping

3.1.2.1.3. Irrigation

3.1.2.2. Earthwork

3.1.2.2.1. Excavation

3.1.2.2.2. Compaction

3.1.2.3. Paving

3.1.2.3.1. Sub-base

3.1.2.3.2. Concrete

3.2. Commercial Building B

3.2.1. Structural

3.2.1.1. Foundations

3.2.1.2. Structural frame

3.2.1.3. Elevator

3.2.2. Mechanical

3.2.2.1. Plumbing

3.2.2.2. Heat and air

3.2.3. Electrical

3.2.3.1. Rough-in

3.2.3.2. Finish electrical

3.2.4. Architectural

3.2.4.1. Room finishes

3.2.4.2. Furnishings

3.3. Industrial Building A

3.3.1. Structural

3.3.1.1. Foundations

3.3.1.2. Structural frame

3.3.1.3. Overhead crane

3.3.2. Mechanical

3.3.2.1. Plumbing

3.3.2.2. Heat and air

3.3.3. Electrical

3.3.3.1. Rough-in

3.3.3.2. Finish electrical

3.3.4. Architectural

3.3.4.1. Room finishes

FIGURE 3-3 WBS for EPC of maintenance facility (outline format).

The graphic format of a WBS is easy to read and gives a good overall picture of the total project. However, most projects have many items in the WBS, which makes it difficult, or impossible, to display all items in the WBS on one page. For presentations to upper management or clients, it is usually desirable to display the WBS on a large-size drawing. Another option is to develop the graphic format of the WBS on three smaller-size drawings. For example, for an EPC project all of engineering is displayed on one page, procurement on the second page, and construction on the third page.

Most project teams develop the WBS in the outline format. It is easier to transmit the WBS in a paper size sheet than handling a large drawing. The outline format can be easily modified with little effort and becomes a working document to guide the work of the project team. The numbering system shown in Figure 3-3 provides a good system to show the divisions and subdivisions in the WBS. For some projects it may be desirable to develop the graphic format for upper management and the outline format for the project team.

Forming the Project Team

A key concept in project management is to organize the project around the work to be accomplished. After review of all backup material from the owner's study and all other information that is known about the project, the project manager should develop a preliminary WBS that identifies the major work that must be done. A detailed list of tasks should be prepared and grouped into phases that show the sequencing of tasks and the interdependences of work. This

structures the project to assist in selection of resources and the technical expertise that will be required of the project team. A time schedule should be attached to each task. All this preparatory work is required because the project manager cannot effectively form the project team until the work to be done is known. In essence, the project manager must develop a preliminary project work plan, which should be reviewed by his or her supervisor. This plan will be expanded into a final project work plan after the project team is formed.

After the preparatory work is complete, the project manager is responsible for organizing the project team to achieve project objectives. The project manager and appropriate functional managers are jointly responsible for selecting team members. This can sometimes be difficult because every project manager wants the best people on his or her team. Each project has a specific list of needs, but the overall utilization of all people in the company must be considered. It is not practical to shift key personnel from project to project; therefore, compromise in the assignment of people is required. The assignment of appropriate staff for a project must take into consideration the special technical expertise needed and personnel available on a company-wide basis. Chapter 4 discusses team selection and development.

The project team consists of members from the various functional departments (architectural, civil, structural, mechanical, electrical, environmental, etc.), project controls (estimating, planning and scheduling, quality control, etc.), and the owner's representative. The number of team members will vary with the size and complexity of the project. The project manager serves as the leader of the team. All team members represent their respective function's area of expertise and are responsible for early detection of potential problems that can have an adverse

effect on the project’s objectives, cost, or schedule. If a problem occurs, each team member is to notify the project manager and their immediate supervisor.

It is important that each team member clearly understands the project objectives and realizes his or her importance in contributing to the overall success of the project. A cooperative working relationship is necessary between all team members. Although the project manager is the normal contact person for all functional departments involved in the project, he or she may delegate contact responsibility to lead members of the team. Since the initiative and responsibility to meet project objectives, costs, and schedules rest with the project manager, he or she should be kept fully advised and informed.

The project manager must organize, coordinate, and monitor the progress of team members to ensure the work is completed in an orderly manner. He or she should also maintain frequent contact with the owner’s representative.

Kick-Off Meeting

After formation of the project team, the project manager calls the first team meeting, commonly called the kick-off meeting. It is one of the most important meetings in project management and is held prior to starting any work. The purpose of the kick-off meeting is to get the team members together to identify who is working on the project and to provide them with the same base of knowledge about the project so they will feel like they are a part of the team. It is important for the project manager to fully understand the project objectives, needs, budget, and schedule and to transmit this information to team members early in the project. In particular, the scope of work must be closely reviewed.

The kick-off meeting allows the team to set priorities, identify problem areas, clarify member responsibilities, and to provide general orientation so the team can act as a unit with a common set of goals. At the meeting the project manager should present project requirements and the initial work plan, discuss working procedures, and establish communication links and working relationships. Every effort should be made to eliminate any ambiguities or misunderstandings related to project objectives, scope, budget, and schedule. These elements of a project cannot be changed without approval of both the project manager and the owner's representative.

Additional preliminary work includes establishing the technology environment for the project. A public-facing project information website, an internal team environment, adequate data storage for the documents, photographs, and data that will be collected and stored through the life of the project must all be identified and secured quickly. Chapter 5 on project document control discusses in greater detail considerations for the project's electronic document environment.

Prior to the meeting, the project manager should prepare general project information data, including the project name (that will be used for all documents and correspondence), project location, job account number, and other information needed by the project team. Standards, CADD requirements, policies, procedures, and any other requirements should also be presented. It is important to provide this information to key people on the project, so they know the project is approved for work and feel that they are a part of the team. The project manager should visit with key team members prior to the meeting to identify and resolve any peculiar problems and clarify any uncertainties.

In general, the meeting is short in duration, but it is the first step in understanding what needs to be done, who is going to do it, when it is to be done, and what the costs will be. This is not a design meeting but an orientation meeting. The project manager must keep the meeting moving and not get overly involved in details. Minutes of the meeting must be recorded and distributed to team members. In particular, there should be documentation of the information that is distributed, the agreements among the team members, and the identification of team concerns or questions that require future action by the project manager or team members.

There are three important purposes of the kick-off meeting: to orient team members regarding project objectives and needs, to distribute the project manager's overall project plan, and to assign to each team member the responsibility of preparing work packages for the work required in his or her area of expertise. Work packages should be prepared and returned to the project manager within two weeks of the kick-off meeting. To facilitate orderly conduct of the meeting and to ensure that important items are covered, the project manager should use a check list for the kick-off meeting as illustrated in Table 3-3.

1. Review the agenda and purpose of the meeting
2. Distribute the project title, account number, and general information needed by the project team
3. Introduce team members and identify their areas of expertise and responsibility
4. Review project goals, needs, requirements, and scope (including guidelines, limitations, problems)
5. Review the project feasibility estimate of the owner and the approved budget for the project team
6. Review the project preliminary schedule and milestones
7. Review the initial project work plan:
   - How to handle design
   - How to handle procurement
   - How to handle construction
8. Discuss assignments to team members:
   - Ask each member of the team → Who?
   - To review the scope of work required in their area → What?
   - To develop a preliminary schedule for their work → When?
   - To develop a preliminary estimate for their work → How much?
9. Ask each team member to prepare design work packages for their responsible work and report this information to the project manager within 2 weeks
10. Establish the next team meeting, write minutes of kick-off meeting, and distribute to each team member and management

TABLE 3-3 Kick-Off Meeting Checklist

Work Packages

The project manager is responsible for organizing a work plan for the project; however, he or she cannot finalize the project execution plan without extensive input from each team member. The kick-off meeting should serve as an effective orientation for team members to learn the project requirements and restrictions of budget and schedule. At that meeting the project manager assigns each team member to review the scope of work required of his or her respective expertise, to identify any problems, and to develop a budget and schedule required to meet the scope.

This can be accomplished by preparing a design work package that describes the work to be provided.

Each team member is responsible for the development of one or more work packages for the work he or she is to perform. A work package provides a detailed description of the work required to meet project needs and to match the project manager's initial work plan. The work packages should be assembled by each team member and supplied to the project manager within 2 weeks of the kick-off meeting.

A work package is divided into three categories: scope, budget, and schedule. Figure 3-4 illustrates the contents of a work package. The scope describes the required work and services to be provided. It should be described in sufficient detail so other team members, who are providing related work, can interface their work accordingly. This is important because a common problem in project management is coordinating related work. There is a risk of the same work being done by two persons, or work not being done at all, because two people are each thinking the other person is providing the work. Team members must communicate among themselves during the process of preparing the work packages for a project.

Work Package

Title _____

WBS Code _____

1. Scope

Required scope of work

Services to be provided

Services excluded from this work package but included in another work package

Services excluded from this work package but performed by

2. Budget

Personnel Assigned to Job	Work Hrs	$-Cost	CBS Code

Total Work Hrs _____

Total Personnel Cost _____

Other personnel costs

Travel Expenses _____

Training Expenses _____

Overhead loading _____

Total budget = Personnel + Other _____

3. Schedule

OBS Code	Work Task	Responsible Person	Start Date	End Date
		Work Package: Start & End Dates		

Additional Comments

Prepare by: _____ Date: _____

Approved by: _____ Date: _____

FIGURE 3-4 Team member's design work package.

A work package is the lowest level in the WBS and establishes the baseline for project scheduling, tracking, and cost control. Characteristics of work packages are as follows:

- Discreet and independent of other work packages
- Manageable by the assigned resource
- Measurable for progress
- Can be assigned time and cost
- Consist of a product (drawing, permit, calculation, report, etc.)

The work package is extremely important for project management because it relates the work to be performed to time, cost, and people. As shown in the budget section of Figure 3-4, a code account number relates the work to the Cost Breakdown Structure (CBS). Likewise, the schedule section has a code number that relates the work to the Organizational Breakdown Structure (OBS). The CBS is used for management of project costs and is further discussed in Chapter 13. The OBS code number identifies and links the work to the people. Many articles have been published that discuss the relationship of the work packages to the WBS, OBS, and CBS. An example of a prepared design work package is shown in Chapter 9, Figure 9-9.

The preparation of the budget portion of a work package requires a careful evaluation of all resources needed to produce the work. All work tasks and items must be budgeted, including personnel, reproduction expenses, travel, expendable supplies, and incidental costs.

Team members must consider their overall workload when they prepare the schedule portion of a work package. Since team members are generally assigned to one or more

projects, their other assigned duties and future commitments to other projects must be considered when preparing a work package for a new project. The failure of team members to carefully integrate the schedule of all projects for which they are assigned is a common source of late completion of projects. Too often team members overcommit their time without making allowances for potential interruptions and unforeseen delays in their work. All tasks should be identified and scheduled.

Follow-up Work

After the exchange of information at the kick-off meeting and a review of the required work by each team member, there may be a need to readjust the WBS of the initial project plan. A team member may have the capability to perform the work, but may determine that the magnitude of the work is in excess of what he or she can schedule because of prior commitment to other projects. Thus, a part or all of his or her portion of the project may require assignment to outside contract work. Another option would be a restaffing of the project based on the overall available resources of the project manager's organization. These situations should be resolved within 2 weeks of the kick-off meeting. As discussed earlier, this can be accomplished in an effective way through a planning meeting.

An accumulation of the budgets from all the team's work packages provides an estimated cost for the total project. If the estimated cost exceeds the approved budget, the project manager is made aware of this situation early in the project, within 2 weeks of the kick-off meeting. The team as a whole must then work together to determine alternative methods of handling the project to keep the estimated cost within the approved budget. If it cannot be resolved within the team, the project manager must work with his or her

supervisor to determine a workable solution. If a solution cannot be found, the owner must be advised so an agreeable solution can be determined for a scope of work that matches the approved budget. It is important to resolve issues of this nature at the beginning of the project, when choices of alternatives can be made, rather than later when it is too late.

After receipt of all work packages, the project manager must integrate the schedules of all team members to develop a schedule for the entire project. If the project schedule exceeds the required completion date, the team as a whole must work together to determine alternative methods of scheduling the work. If the discrepancy between the planned schedule and required schedule cannot be resolved within the team, the project manager must then resolve the issue with his or her supervisor. If the required schedule cannot be achieved, then the owner must be advised so that acceptable agreements can be reached.

Issues related to project scope, budget, and schedule must be resolved early. Effective communication and cooperation among team members is necessary. The results of the team assignments and definitions of work packages allow the project manager to finalize the WBS that forms the foundation of the PEP. After receipt of all information, the project manager can finalize the overall plan to manage the project.

Project Execution Plan

The project manager must develop a written execution or work plan for each project that defines the approach to project execution. The execution plan identifies all of the work that needs to be done, who is going to do it, when it is to be done, and what the costs will be. It describes the contracting plan, provides a detailed schedule and a project

control plan. The level of detail should be appropriate for the size of the project. It should be sufficient to allow all project participants to understand what is expected of them in each phase and time period of the project; it should be thorough and complete. Otherwise, there is no basis for control. It is important that a participatory approach be used and that team members understand project requirements, jointly resolve conflicts, and eliminate overlaps or gaps in related work. The team must agree on priorities, schedule, and budget.

The PEP is the opportunity to plan an efficient approach to completing activities. It allows for proper resource planning including finding the right team members for delivering the project scope. The execution plan provides an alignment between the project scope, work plan, and project budget.

A critical part of the execution plan is conducting a project risk assessment and identifying a risk management plan for the execution of the project. Risk assessment is a vital part of the work plan and is too often overlooked by project managers and team members. Risk assessment and analysis address the question “What can go wrong?” Before commencing work on any project, there needs to be a thorough evaluation of the risks associated with the project. Each risk needs to be identified and an evaluation made on the probability of occurrence of each risk. There also needs to be a plan to prevent risks and a strategy to mitigate a risk when it occurs. Chapter 8 is dedicated to risk assessment and analysis.

Upon receipt of all the team members’ work packages, the project manager can assemble the final project work plan. Table 3-4 provides the basic components of a work plan, which include general project information, the comprehensive task list, schedule, budget, and risk management plan. General project information contains all pertinent information, such as project title, number,

objectives, project organization chart, and contact list. The project organization chart shows all participants, including the owner’s representative. The detailed list of tasks, and grouping of tasks, is derived from the WBS and work packages. The sequencing and scheduling of tasks can be obtained by integrating the schedules of work packages provided by team members. Likewise, the budget can be obtained from a summary of the costs from all work packages. An additional description of PEP core components is found in document *04.03.e_PEP Core Components.pdf*. A detailed PEP outline is contained in the document *04.03.e_PEP Outline.docx*.

Project Plan of Work	
Project Plan Elements	
General Information	
Project title and number Project objectives and scope Project organizational chart Project contact list	Who …
Project Objective	
Objective general description Specific objectives Justification general description	
Project Scope	
General description Work breakdown structure Task groups Detailed task list Work packages Scope change log	Does what …
Project Costs	
Basis of estimate Budget summary Budget—labor-hours and cost of staff for each task Estimate Engineer's construction estimate Contractor's construction bid (schedule of values) Other expenses anticipated for each task Billing approach and anticipated revenue or expenditure by month	For how much …
Project Schedule	
Basis of schedule Major milestone summary Project schedule showing sequencing, interdependencies, and estimated duration of tasks Calendar showing start and finish dates for tasks Scheduling threats, project schedule risks and opportunities Engineer's construction schedule Contractor's construction schedule	When …
Risk Management Plan	
Risk matrix Risk assessment including list of risks, probability of occurrence, and expected impacts Impact of each risk on quality, cost, schedule Risk mitigation plan	What can go wrong …
Monitor & Control Plan	
Design progress measurement methods Construction progress measurement methods Procurement progress measurement methods Change (budget, schedule baselines) procedures	What is accomplished …

TABLE 3-4 Components of a Project Work Plan

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the PEP core components.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the PEP Outline.

Once the work plan is finalized, it serves as a document to coordinate all work and as a guide to manage the overall effort of the project. It becomes the basis for control of all work. Appendix A illustrates some components of a work plan for a project: Work Breakdown Structure, project organizational chart, sample work package, and project schedule. Note the transfer of information from one component to another to form the integrated work plan.

The first and most important step in organizing a project is developing a WBS. The WBS defines the work to be accomplished, but it does not define who is responsible for performing the work. A successful project depends on people to make things happen. However, merely selecting good people is not enough. A key function in project management is to organize the project around the work to be accomplished and then select the right people to perform the work within the approved budget and schedule.

When developing a WBS, the project manager and team should consider the results of the risk assessment. The mitigation plans for substantial risks may warrant an unconventional or different approach to organizing the work. For example, if a key risk is related to environmental permit restrictions or the possibility of the permit being rescinded, the work should probably be organized to complete areas covered by those permits before any other work. The approach may break with traditional organization and

execution; however, losing a permit may prevent the completion of the project or delay the project such that the economics for the project become unfavorable.

After the WBS is complete, the next step is to link the OBS from the company to the required work that is defined in the WBS. Figure 3-5 illustrates the linking of the WBS and OBS to identify the various disciplines that are responsible for each part of the WBS. The project manager, with the assistance of discipline managers, can then begin the process of selecting individuals from the various discipline departments who will form the project team.

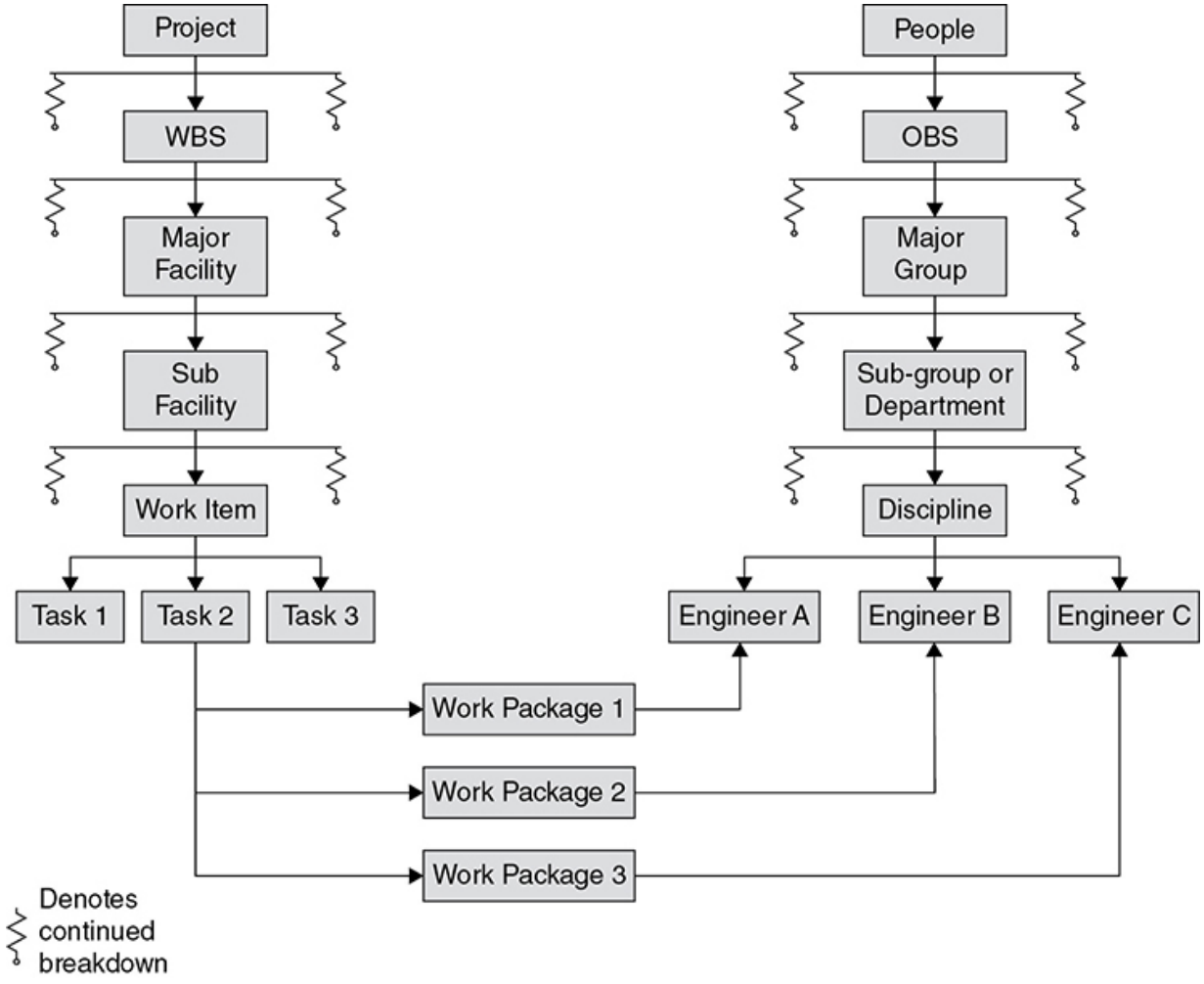


FIGURE 3-5 Linking the WBS and OBS.

The linking of the WBS and OBS establishes the project framework for management of the entire project. The WBS provides a breakdown of scope, “what must be done,” and the OBS identifies “who will be doing the work.”

After completion of the WBS and OBS framework, a Cost Breakdown Structure (CBS) can be established. The CBS is a breakdown of costs for all components in the WBS. The costs in the CBS can be obtained from the work packages in the WBS. The CBS is essential for managing costs during project execution by allowing the project manager to compare budgeted costs to actual costs. The CBS provides a common code of accounts used by all participants in the project because it relates costs directly to the work to be performed. Coding systems to develop the CBS are discussed in Chapters 10 and 13.

Also, after completion of the WBS and OBS a project time schedule can be developed to guide the timing of activities and interface-related work. The time and cost required to accomplish each activity can be obtained from the work packages in the WBS. The Critical Path Method (CPM) technique is the most common network scheduling system that is used in the engineering and construction industry. Techniques for project scheduling are discussed in Chapter 10.

The integration of the WBS, OBS, CBS, and CPM forms the core of the project work plan, and it establishes the base for project tracking and control during project execution. The project manager must ensure effective linking of the WBS, “what work will be done,” to the OBS, “who will do the work,” to the CBS, “how much it will cost,” and the CPM, “when the work will be done.”

Regardless of the size or complexity of the project the WBS, OBS, CBS, and CPM must be linked together to form an all-encompassing project plan so the project manager and his or her team can effectively and efficiently manage the

project. A complete project plan enables the project team to compare actual work to planned work, in order to evaluate the progress of a project and to develop trends to forecast at-completion costs and completion dates.

The development phases of the project execution plan are illustrated in Figure 3-6. Topics related to project definition are discussed in Chapters 2 and 7. Project framework and planning related to project definition are discussed in Chapters 2 and 7. Project framework and planning are presented in this chapter. Project scheduling and tracking are presented in Chapters 10 and 13, respectively.

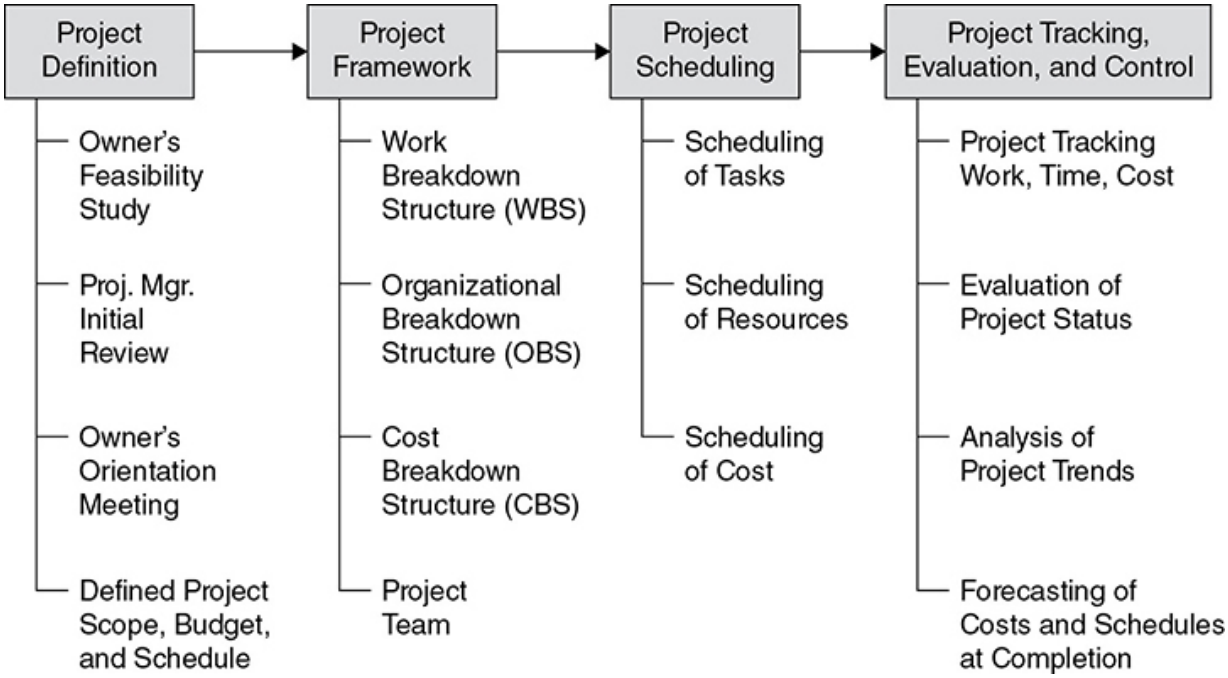


FIGURE 3-6 Phases of development of work plan.

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CHAPTER 4
Team Selection and Development

Importance of Team Selection

Team selection and development begins during the Feasibility phase with the identification of key skills necessary for the project. It also continues into Alternative Analysis and is documented in the project charter. During Detailed Scope, development of the project execution plan includes establishing a project organizational plan and includes selection of specific team members. These are the key people essential to doing the work necessary to fulfill the project's scope of work. Team selection, staffing levels, and their associated costs increase as the project progresses through the lifecycle.

The key work products of a quality organizational plan include how the resources available for the project will be used to make the project successful:

- A project organization chart showing all key members
- Each member's name, project role, task responsibility, reporting relationship (e.g., reports directly to project manager or reports to functional manager)
- Level of involvement (full time, 50% commitment, as needed)

- Required external resources (contracted resources) to be integrated into the project team to help develop defined deliverables for work to be performed
- A document clarifying roles and responsibilities and establishing clear ownership for specific tasks and decisions

Team Management

Effective teamwork is a key factor in the successful management of any project. Usually, the project manager is involved with three areas of responsibility: within the project team, between the team and the client, and between the team and other management of the project manager's organization. In each of these areas, numerous situations often arise that can cause disruptions, conflicts, delays, and misunderstandings that may affect the team's performance. It is the duty of a project manager to coordinate the team in a manner that minimizes the development of these situations, to be able to identify problems immediately, and to act quickly to resolve them in a satisfactory manner. Table 4-1 is a list of typical problems that can arise related to team management.

1. Differing outlooks, priorities, interests, and judgements of team members
2. Project objectives become unclear to the team members
3. Communication problems
4. Scope changes by the owner
5. Lack of coordination by team members
6. Lack of management support
7. Changes in team members
8. Misunderstanding requirements
9. Conflicting priorities

TABLE 4-1 Typical Problems in Team Management

A team is a group of individuals, each of whom is usually responsible for performing work on more than one project. As the number of projects for which a team member is involved increases, the risk of losing control of priorities also increases. The project execution plan (PEP) must include setting priorities at the start of the project. The project manager must ensure that project objectives are known and clearly understood by team members because project objectives can become unclear to the team, particularly as the project moves into Detailed Design.

Poor communication is the most common source of problems related to team management. Meetings must be held routinely to keep team members informed so information can be exchanged. Team meetings should serve as forums for getting problems out on the table so they can be resolved; however, the project manager must also be accessible to team members who may not feel comfortable airing problems or potential problems in meetings. Meetings are discussed in more detail later in this chapter.

Scope changes by the owner can adversely affect the project budget and schedule. Team members must be cautious of expanding the scope of a project in an attempt to please the owner. The scope must be locked in at the beginning of the project and should not be changed without a written agreement between the project sponsor and the project manager. The written agreement must include an appropriate change in the budget and schedule that matches the change in scope.

Although the project manager is responsible for overall coordination of the entire project team, individual coordination between team members is also necessary. The project manager must foster an environment of cooperation that encourages the free exchange of information among team members.

The project manager must have management support from his or her own organization. The project manager works for the business to ensure the project meets the stated business objectives. The project manager can obtain and retain management support best by keeping them informed of the status and needs of the project team. Assistance cannot be given unless the need is known. Management should be included as an integral part of project reviews. Management must also resolve conflicts between priorities, especially regarding project priorities within the design firm.

To assist the project manager in his or her role of performing team management responsibilities, the project work plan must be kept up-to-date. It must be formally modified when changes are made in the scope of work, members of the project team, services and tasks to be performed, individual responsibilities, schedule, and budget.

The team must be managed in an open manner. Discussions of roles and relationships, and the rationale behind project decisions, should be done in team meetings rather than private conversations. The project manager must be consistent in making the day-to-day decisions that alter roles and relationships within the team. The concept of “team” should be instilled in the attitude of all individuals. The project manager must emphasize commitment, clarity, and unity of the team to minimize the number of trivial conflicts. Since each person is unique, outlooks, priorities, interests, and judgements will differ. Because of the diversity of individuals, the project manager must deal with the human aspects in his or her role as leader of the project team. Some leadership qualities are inherent in a project manager and others require development through training and experience.

Engineering and construction projects have always faced the challenge of managing remote project participants.

Advances in technology beginning with the telephone to the “Cloud” of the 21st century have improved the project manager’s ability to plan and coordinate the work of the project. Those same advances have introduced and compounded remote team management challenges including project work occurring 24 hours a day.

The principles that apply to managing a colocated team apply to a dispersed team. The practices described in defining, planning, and executing the project aid and strengthen the project manager’s ability to manage a remote team effectively. The project manager needs to set clear expectations for each team member. This should include expectations about the work assigned and also about team behavior. The project manager needs to ensure the team is focused on the outcomes at an individual level and project level.

e-content: https://www.mikogo.com/downloads/docs/effectively-manage-remote-team.pdf

Successful team management requires the team to be an integral unit of the organization. When key team members are not assembled and integrated early in the project life, opportunities to develop and select the best alternative for a project scope can be missed or not fully optimized. A team must have a well-defined project charter that includes the project’s mission with clear objectives, common goals, and strategies. The roles and responsibilities of each team member must be clearly defined, communicated in writing, understood, and agreed to by team members. The best tool for this is a responsible, accountable, consulted, informed (RACI) chart. The RACI chart details specific project deliverable responsibilities and designates who is responsible, who is accountable, who is consulted, and who is informed for the assigned deliverable. An example RACI chart with a template is provided in the document,

04.e_RACI-Chart-Excel.xls. For more details regarding RACI charts and their use, see www.racichart.org. Team member's authority, as applicable for the project, should also be documented. The project manager must learn the needs of team members and encourage team participation. Team members will put extra effort into accomplishing work when they know the project manager cares about them and their careers. This can be accomplished only by effective communication and feedback throughout the project. Trust is instilled among team members and the project manager by creating an environment of understanding and teamwork. Open and frank communication is necessary to instill integrity and support for each other. Trust is essential to effective and successful teams.

It is the project manager's responsibility to ensure that individuals are assigned primary responsibility for discrete work and how that work integrates with, is dependent on, or supports other functional team project managers. Most workers want to do what is expected of them and will do the work, provided there are clear instructions and understanding of responsibilities. This requires a collective culture of mutual agreements between the project manager and team members. All individuals must have the common goal of creating a team that plans and executes the work with a clear knowledge of what they are going to do, who is going to do it, and when it will be done. Sometimes it is necessary to know where it will be done or how it will be done. For example, for some instances it may be necessary to know what method of analysis will be used in a design.

A significant risk to the project and one of the best ways to derail it is changing key team members during the project. A decision to change key team members, particularly the project manager, should be decided primarily by the project sponsor and key stakeholders since this decision creates a large impact on scope, cost, and

schedule decisions and progress already accomplished. Project continuity and accountability represent one measure to achieve project success. Unfortunately, sometimes the project manager is pulled off a project that is near completion and reassigned to another project. Reassignment of the project manager near or prior to the end of the project can create many problems to the successful completion of the project.

Organizational Structures

Each project manager is affected by the environment in which he or she works. The organization of a company can have a large impact on the ability to manage a project. Figures 4-1 through 4-5 show various organizational structures of companies. A project manager may work for a company that is organized as shown in these figures, or he or she may manage a project for a client whose company organization is similar to one of these organizational structures.

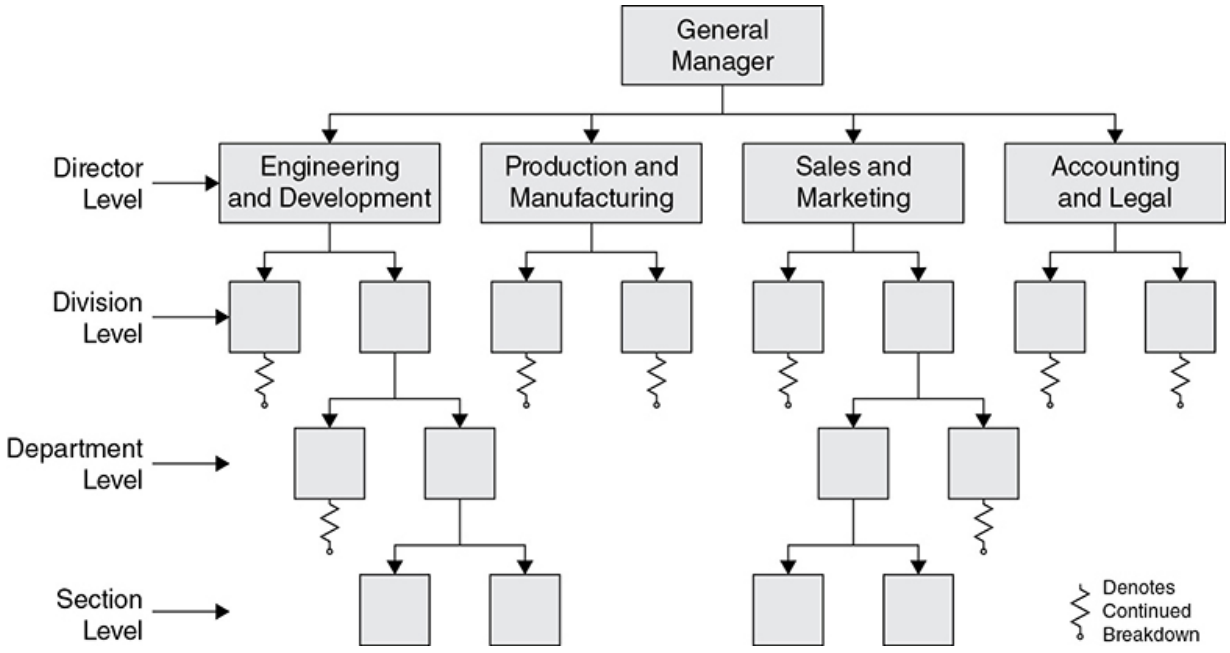


FIGURE 4-1 Traditional management organization (production line/business oriented).

If a company is product oriented, it will be organized around manufacturing and marketing of the product, with the priority of decisions focused on products. A company that is service oriented will be organized around providing customer service. The design and construction of a project is a means to an end for the company to provide a product or service and does not represent the primary function of that company. This secondary emphasis on a project can hamper the work of a project manager.

The organizational structure shown in Figure 4-1 is an example of a business with an emphasis on manufacturing and marketing of products. The engineering portion of the company exists to support the manufacturing operation. Manufacturing exists to produce the product for the marketing group to sell. Questions related to the engineering and construction of a project for this company would typically be directed to the engineering department. However, the answers to these questions often come from the manufacturing department, which, in turn, may have to obtain input from the marketing group. This requires a channel of communication between various parties that can cause misinterpretation of information and a delay in obtaining answers. A project manager performing work for a company that is organized as shown in Figure 4-1 should include a contingency in the project schedule for delays of owner responses, and should be alert to the potential for scope growth.

An example of a functional engineering organization is illustrated by the electrical power company shown in Figure 4-2. The company's emphasis is on generation, transmission, and distribution of electrical power services. Utilities and governmental agencies are usually organized in functional departments. This type of organization is efficient

for the design and construction of projects involving a single function, such as the design and construction of a transmission line or a substation. However, if a project involves design and construction of a unit of a power station, plus two transmission lines and a substation, it can be difficult to identify the project within the organization. There is a tendency for the project to pass from one department to another if a single project manager is not assigned overall responsibility. This can lead to lost information and schedule delays. Even if a single project manager is assigned, coordinating across department lines can be difficult. The project manager is also challenged with keeping project tasks a priority for team members with a functional workload not related to the project.

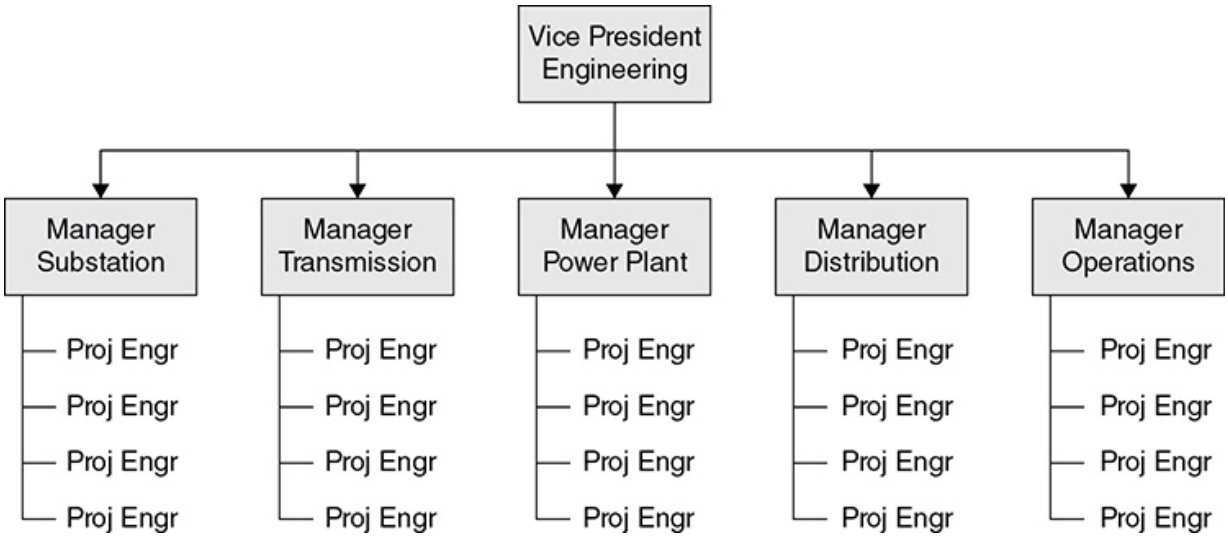


FIGURE 4-2 Functional organization (electrical power company).

Figure 4-3 shows a typical work environment of a consulting engineering company that provides design services for projects. The company's emphasis is discipline oriented, involving a group of specialists who share knowledge and technical expertise. Overemphasizing separate disciplines can encourage competition and

conflicts at the expense of the whole organization, resulting in focus on internal department operations rather than external relations and cross-functional project work. When emphasis is focused on internal departments, decision making and communication channels tend to be vertical, rather than horizontal, with little attention paid to costs, schedules, and coordination.

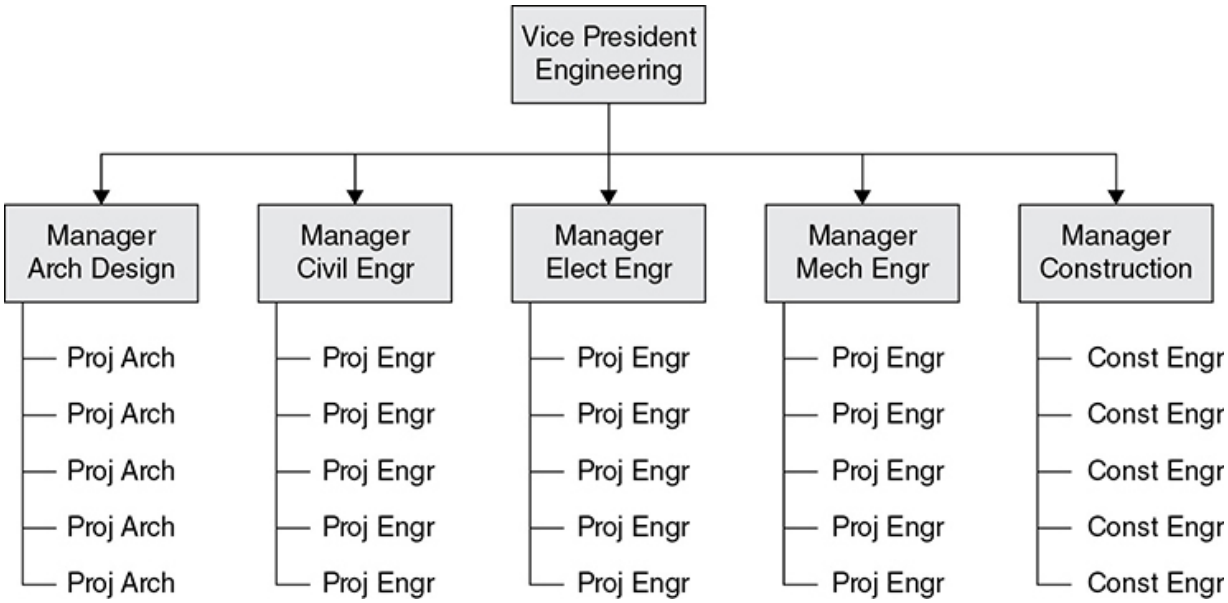


FIGURE 4-3 Discipline organization (design firm).

Many consulting engineering companies are organized as shown in Figure 4-3. For small projects with short durations, this type of organization is efficient. However, project management can be hindered because some of the engineers have a dual role, as both a designer and a project manager. As the number of disciplines increases, coordination of complex projects becomes more difficult. For example, a complex project may involve architectural, civil, structural, mechanical, and electrical engineering work. The work may begin with the architectural layout, followed by the various engineering designs. As the work moves from discipline to discipline, the project identity can be lost, and it becomes difficult to know where the project is or its

status. By the time the project reaches the last discipline, there may not be enough budget or schedule left to complete the work. Discipline organizations develop a strong resistance to change.

Another type of organizational structure for a consulting engineering company is shown in Figure 4-4. The company is organized into functional departments: buildings, heavy/civil, process, and transportation. The disciplines are dispersed among the functional departments and serve on design teams for projects that are assigned to the department. Lead designers are appointed as team leaders to manage the design effort. Each designer remains in his or her functional department to provide technical expertise for the project. However, if there is a decline in the number of projects in one or more departments, one or more designers may be transferred to another functional department. This can be disruptive to the management of projects.

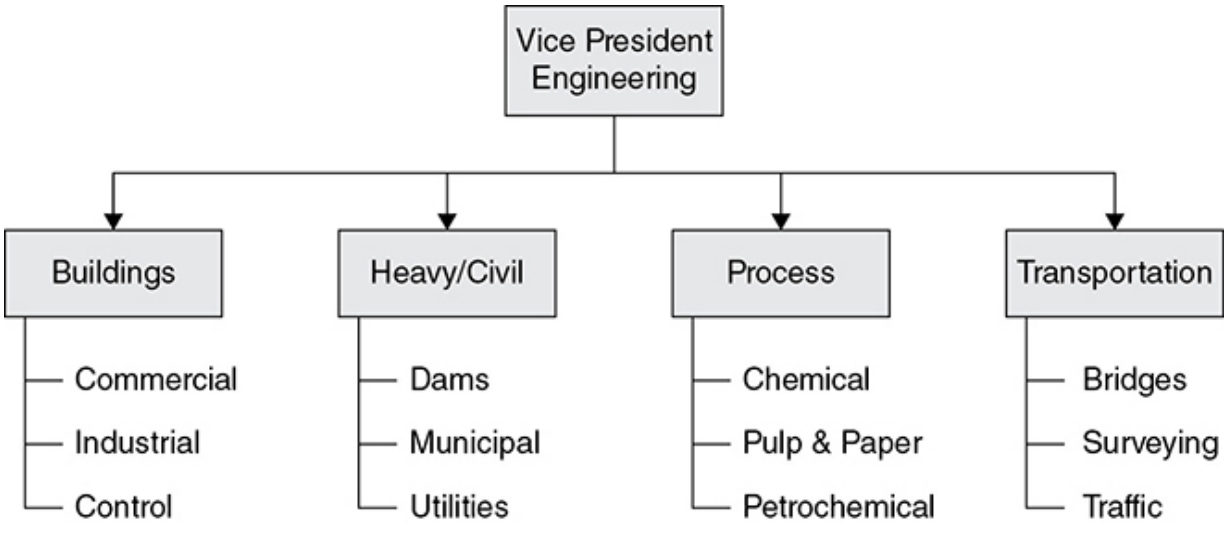


FIGURE 4-4 Functional organization (design firm).

To increase emphasis on project cost, schedule, and general coordination, a matrix organization as shown in Figure 4-5 is often used. The objective is to retain the design disciplines in their home departments so technical expertise

is not lost, and to create a projects group that is responsible for overall project coordination. To accomplish this, the designer has two channels of communications: one to the technical supervisor and another to the project manager. Issues related to technical expertise are addressed vertically while issues related to the project are addressed horizontally.

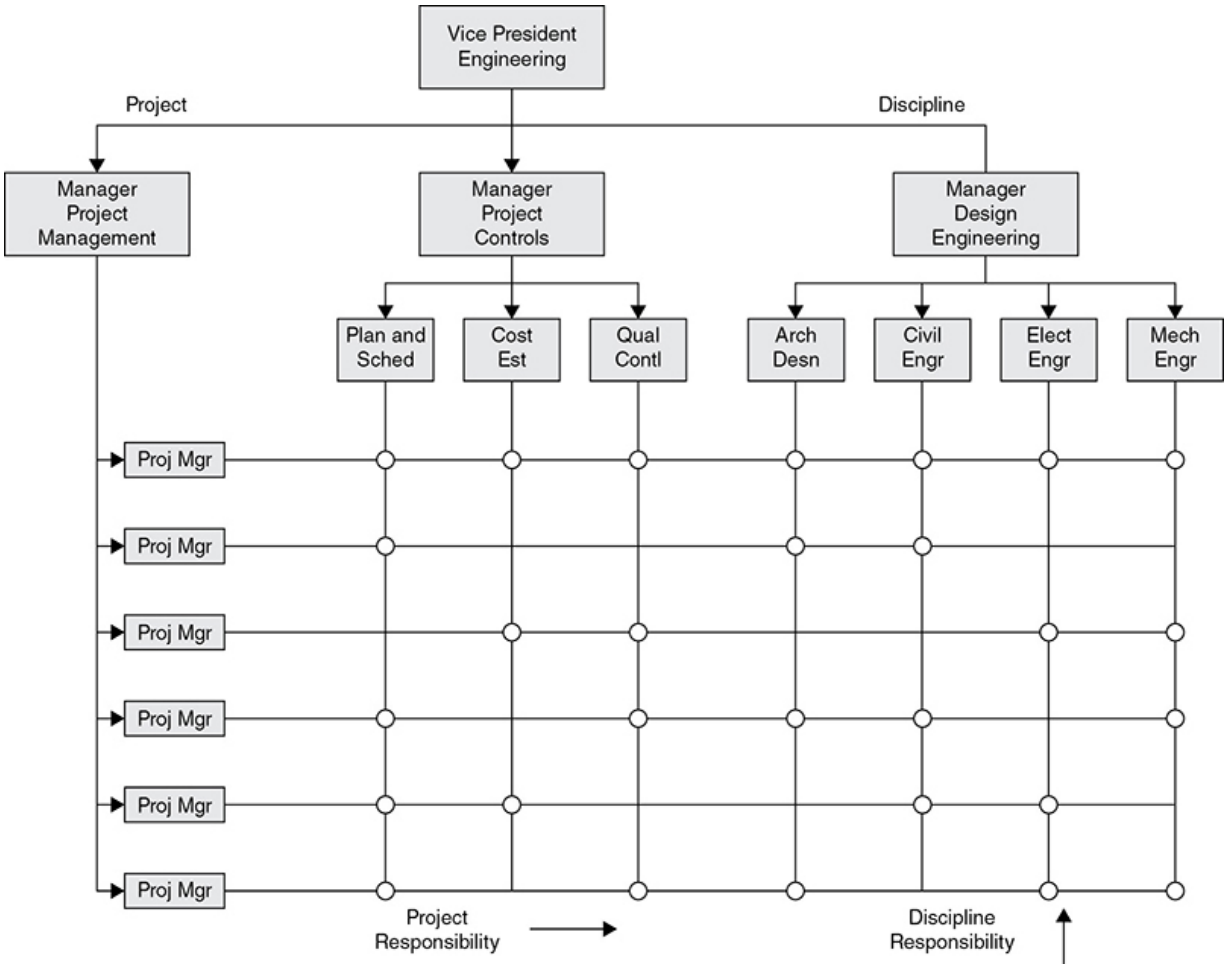


FIGURE 4-5 Matrix organization (design firm).

The matrix organization provides a work environment with emphasis on the project. Each project is defined by a horizontal line on the matrix. The project manager is responsible for overall project coordination, interfacing of disciplines, client relations, and monitoring of overall project

costs and schedules. The various design disciplines are responsible for providing technical expertise, quality performance, and the cost and schedule for their particular part of the project. No one person works for the other on the project team; instead, everyone works for the project. The project manager is the leader of the team and serves as a focal point for integrating responsibility.

A matrix defines lines of communications but does not indicate the authority for conflict resolution. A matrix may be defined as a “strong matrix,” where project managers have the authority to decide what is good for the overall project. At the opposite end of the spectrum is the “weak matrix,” where discipline managers have the authority in decision making. A discipline supervisor may be more concerned with his or her technical area than the overall project. Designers are usually concerned with producing the best design possible, sometimes at the expense of project cost or schedule and without regard to the effect on other departments.

The success of project management in the matrix organization depends on the philosophy of the company and the attitude of the employees. Too much emphasis on disciplines can lead to time and cost problems. Likewise, too much emphasis on projects can lead to inefficiencies and quality problems due to losing contact with the technical departments. Accordingly, there must be a balance between managing the project and providing technical expertise. The key fact is that functions provide the expertise to the teams and the teams do the project work. Mutual respect among disciplines is essential. The project manager relies on the expertise of each team member and recognizes that everyone is a key player on the team of a successful project. A “can do” attitude must exist, with a drive to complete a quality project in an efficient manner that meets the needs of the owner. What is good for the project is good for the

entire company. Effective communications among team members are a must.

As a project moves from the design phase to the construction phase, a work structure must be developed around the work that must be accomplished in the field. A project organization must be developed that is matched to the project to be constructed. The owner should consider embedding their representative in the design firm’s project team. This can foster ownership throughout the team and significantly improve communication. Management of the project is best done where the actual work is being performed.

Project Teams

Project teams must be assembled to accomplish the work necessary to complete engineering and construction projects. Team members are vital to the success of the project. The project manager depends on the team because he or she typically does not have the expertise nor the physical capacity to do all the work required to complete the project. For any team, there must be a leader to guide the overall efforts. In many respects, the project manager acts as a coach, answering questions, making sure the team understands the desired outcome of the project, and ensuring that team members know what is expected of them and the importance of sharing information. The project manager must make sure that his or her team understands and is focused on the desired outcome of the project. The project manager also acts as a facilitator in project communications for conflict resolution and team performance.

Project teams are made up of all the participants in the project, including in-house personnel and outside consultants. Team members report either part-time or full-

time to the project manager and are responsible for some aspect of the project's activities. Teamwork must be well coordinated with effective interaction to manage and control risks and to achieve the shared objective of completing the scope, budget, and schedule constraints of the project. Managing project teams is a fundamental skill within the area of human resources management. The Project Management Institute (PMI) defines human resources management as the art and science of directing and coordinating human resources throughout the life of a project, by using administrative and behavioral knowledge to achieve predetermined project objectives of scope, cost, time, quality, and participant satisfaction.

For a successful project, the project manager must build and lead an effective project team. Team building is the process of influencing a group of diverse individuals, each with his or her own goals, needs, and perspectives, to work together effectively for the good of the project. The team effort should accomplish more than the sum of the individual efforts. Every team needs motivation. Team motivation is the process by which project managers influence the team members to do what it takes to get the job done. The key problem is "How do you motivate team members when they are borrowed resources?" Usually, members of the project team are individuals who are assigned from other departments to the project manager's project. Because these individuals are borrowed from other departments or hired from outside organizations, the project manager must devise a method to motivate them to be dedicated to the project while remaining loyal to their home departments and organizations. This presents a real ongoing challenge to the project manager.

The project manager faces other challenges to building an effective project team. Project teams must become a cohesive and effective unit quickly due to the time

boundaries of a project. For larger projects, the entire team may not be assigned to the project when Detailed Design begins. Besides balancing loyalty to the project versus loyalty to the functional department, the project manager has to adjust the size and makeup of the team based on the resource plan for the project while minimizing impacts to team performance. This can be a stumbling block for many project managers. How will additional resources be added to the project? Does the project manager have that authority or does the project manager have to utilize internal human resources systems to acquire, manage, and release resources? Does the project manager have authority to sign contracts on behalf of the project? Answers to these questions will introduce risks to the execution of the project and to developing the team and keeping morale high.

Teamwork

Teamwork is not a new concept; it has been used for centuries. Essentially, a team is a group of people that work together to achieve a common goal. An effective team can accomplish more and better work than any one person acting alone. Projects require people with diverse expertise and different experience. Each member of the team brings an expertise that contributes to successful completion of the project. There are four types of people:

- Those who make things happen
- Those who watch things happen
- Those who do not know what is happening
- Those who do not want to know what is happening

Every project manager wants people who are proactive to make things happen. However, there are people who are passive and tend to not take actions until they are given

precise directions, or until they feel safe in doing work. Unfortunately, there are people who do not appear to know or understand what is happening or what needs to be done. Sometimes there are people in upper management that do not want to know what is happening in a project; they do not want to be bothered and only want the project team to do their assigned tasks and resolve problems.

Often the project manager does not have the opportunity to select every member of the project team. Instead, assignment of team members is made by upper management. Therefore, the project manager has to work with all types of people. When assembling a strong team, the project manager should understand team members' capabilities, skills, knowledge, experience, and culture. Do they have the right knowledge, systems, tools, and procedures already developed and are they applicable for the project or do they need to be developed? The project manager needs to evaluate the team's skill sets and available tools to determine if they are appropriate for the project. The project manager should include allowances in the project execution plan (budget and schedule) to provide for training, tools, and other team member needs to meet the project objectives. For example, if a team member will be required to perform pipe stress analysis as part of their respective work package, the project manager must confirm that the team member is appropriately trained in and has access to the appropriate analysis software. These costs may need to be incurred by the project. Additionally, time and expense may be required to train new team members. This effort often requires an experienced team member to carry the load of accomplishing both their project responsibilities and training the new resource.

An added challenge that can add risk to the project is the availability of sufficient and competent resources. When available labor is limited or tight, labor rates can quickly

escalate beyond expectations, and the compensation included in the budget may not always provide the best competency. In other words, “you get what you pay for.”

Reorganizing, downsizing, and merging of businesses have created new emphasis on teamwork such that it is now an essential aspect of project management. Many companies outsource work to finish projects. Everyone agrees that teamwork is important; the real task is organizing a successful team to achieve a successful project.

Teamwork starts with the sponsor of the project who defines goals, objectives, needs, and priorities. For successful projects, teamwork starts with the team’s formation at the beginning of the project and continues throughout the life of a project. A well-organized team resolves disputes, solves problems, and communicates effectively regardless of location. Effective teamwork discourages fault finding and accusations and promotes unity and a common focus on the same set of project goals and priorities. Although everyone is a key player on a successful team, every team must have a leader. The project manager is the leader of the team.

Teams for Small Projects

A team is two or more people working together to accomplish a common goal. When managing multiple small projects, the project manager is usually required to share team members with other project managers. Generally, the project duration is short with minimal contact between the project manager and team members. Sometimes the team members are specialists who are hired by contracts from outside sources to perform a specific task or function.

Since the project manager of a small project is generally responsible for managing multiple projects at the same

time, it is often difficult for him or her to give the needed attention to each project, which complicates scheduling and resource control. Only minimal staff can be afforded on small projects. This means that the few individuals assigned must take responsibility for multiple functions. In this type of work environment, the skill of the project manager to maneuver through the various departments within his or her organization to get people to do the work on the project is crucial in completing the projects on time and within budget. The project manager must clearly set priorities for each project and clearly communicate them to the various project teams. Team members must understand their responsibility to act and not delay in performing their tasks. There is less potential for comprehensive look-ahead planning and attention to those functions not currently experiencing problems. The ability to meet project deadlines is highly dependent on the schedules of others.

On engineering work, it is difficult to have a core discipline team assigned to each project. As a consequence, time is wasted while team members wait for information. Since small projects have short durations, there is often insufficient time for detailed planning and in-process correction of problems. The learning curve for personnel is still climbing when the project is over.

Although managing multiple small projects may not have the formality of managing a single large project, the principle of working with people in the spirit of cooperation and teamwork still applies. Typically, the project manager relies on frequent phone calls or e-mail in lieu of formal face-to-face team meetings. The project manager should be cautious of too much oversight for small projects. A small variation for a small project is actually exceedingly small when compared to a small variation for a large project.

For small projects, the project manager’s best approach is to have a clear and precise execution plan that is

understood by the project team. For multiple small projects assigned to a project manager, the basic project variables (cost, time, resources, and quality) should be integrated into a decision-making assessment format for evaluation. Assignment of numerous small projects might be evaluated and prioritized by factors most important to the owner. The priority of a project may be driven by safety, environmental, or other compliance requirements, economic impact resulting from a proposed plant shutdown, routine maintenance, or growth and expansion projects. Once each project is addressed in terms of the project scope, dependencies, resources, and time duration for the activity or deliverable, these items can be integrated and incorporated into an execution plan for the multiple projects. The objective is to optimize the combination of owner priorities with the various functional team resources to perform the tasks. Professionally managed project teams contribute to a company's cost-effectiveness, no matter how large or small the project.

With a good integrated execution plan that includes the portfolio of projects assigned, the project manager should be able to forecast capital cost expenditures for the projects for their duration. Additionally, the project manager should be able to load the required resources for each project to accomplish the functional tasks optimally, often without paying an overtime premium or outsourcing and contracting activities and deliverables. A good execution plan may reveal benefits to the owner for trade-offs between cost and schedule or vice versa, or to contract services rather than perform the work with internal resources.

Working with Multiple Teams

As a project progresses through design into construction, the work of the owner's, designer's, and contractor's teams

must merge into a collective effort. Although each of these teams have their own objectives, the diverse expertise that each possesses must converge into an overlapping environment as illustrated in Figure 4-6.

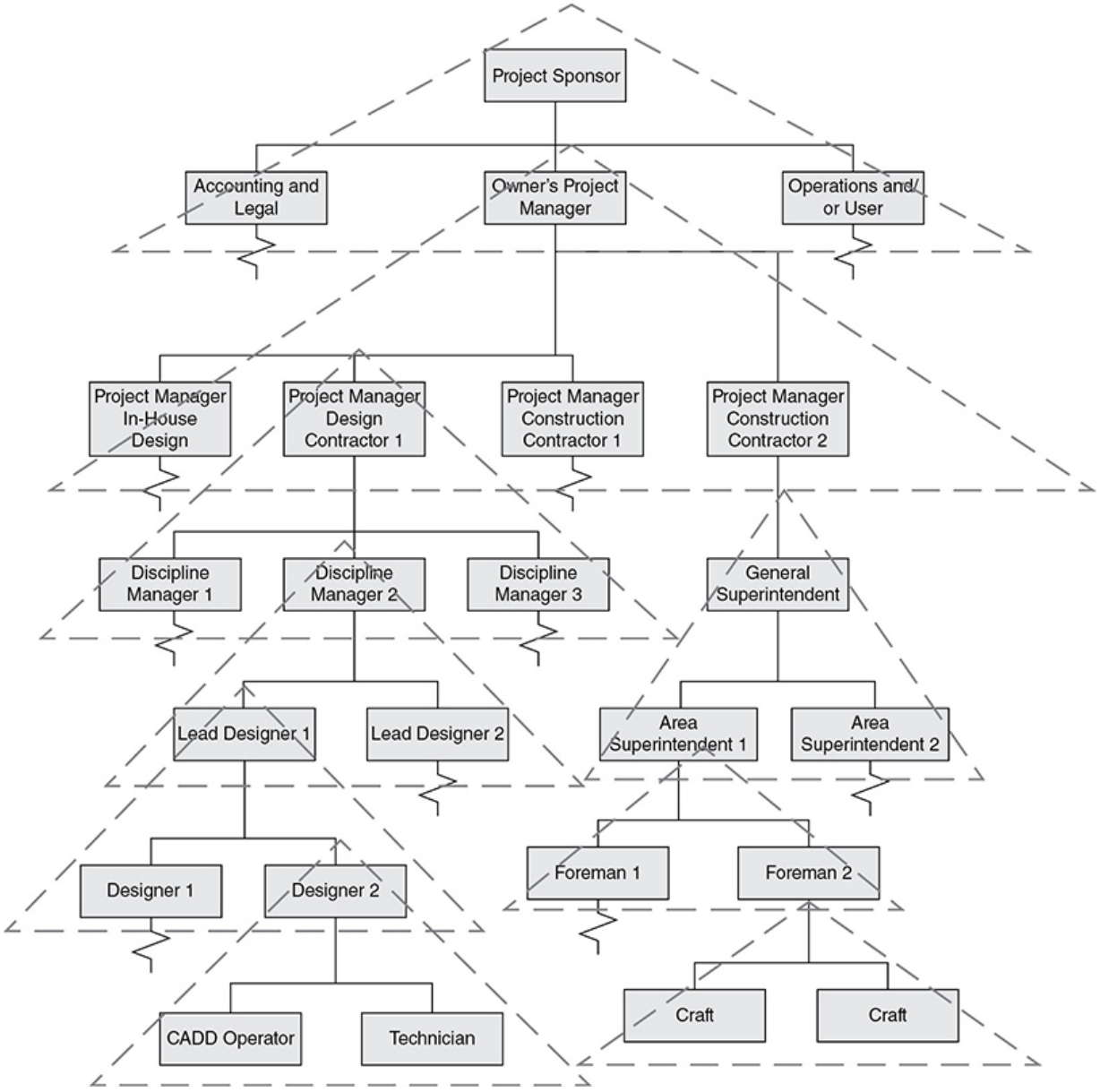


FIGURE 4-6 Overlapping environment of multiple teams.

Each triangle in Figure 4-6 represents a team. Although each team performs a different function, each team must develop an attitude of shared ownership in the project. The

project manager from each organization must create and foster an environment where team members contribute to solving problems and doing their jobs well, rather than trying to do just what they feel is necessary to get by. The team building and teamwork that was started at the beginning of the project must be continued into the construction phase.

Regardless of the size and number of teams, there must be a single head project manager to make final decisions and keep focus on the project. The owner's project manager has overall responsibility and final authority for the total project. Serving on the owner's project management team are functional project managers who are responsible for leading lower levels of teams that are responsible for engineering design and construction of the project. As illustrated in Figure 4-6, there is a project manager for in-house design, a project manager for each design contractor, and a project manager for each construction contractor. Each of these project managers leads the team for his or her organization. Below these managers are lower tiers of teams who are led by work managers. As shown in Figure 4-6, the manager of the lower-level team serves as a member of the higher-level team. There must be one head of each team.

Owner's Team

As shown in Figure 4-6, the project manager of the owner's team is the highest level in the project team. The owner's project manager generally has limited staff support from his or her company. For a small project, the owner's project manager may be the only person in the owner's organization that works on the project. For larger projects, there may be several assigned support personnel from the owner's organization, such as clerical staff, project engineers, contracts, procurement, and safety personnel.

The owner’s project manager leads a team that consists of each design project manager and construction project manager that is assigned a contract from the owner. A design project manager here is meant to include engineering design and other functions such as land acquisition, environmental design, regulatory permitting, etc. The owner’s project manager is responsible for the accomplishment of all work, even though he or she has limited resources under his or her direct control because most of the work has been contracted to various organizations. Therefore, much of the work of the owner’s project manager is administering design and construction contracts and updating the project sponsor in the owner’s organization.

The role of owner’s project manager is important to the successful completion of a project. Generally, he or she wants a competent designer that has experience in developing plans and specifications for the type of project needed by the owner. It is important to have a designer that can relate the design and construction requirements in terms that can be understood by the owner, in particular, the operations people in the owner’s organization that will use the project when it is completed. The owner’s project manager also needs an experienced construction contractor that does quality work, is reasonable in costs, and will finish the project within the time required by the owner. A good working relationship among all parties in the project requires good communications regarding the status and progress of work.

Design Teams

As discussed earlier, the project team is initiated during Phase 2, Conceptualization and Alternative Analysis, and continues to be developed in Phase 3, Detailed Scope. The design firm must form a team to meet the requirement of

the owner as specified in the contract. The design team may be engaged to assist in the analysis of alternatives or in the development of the project execution plan. Thus, the design team is involved in the early stage of a project when the project scope is not fully defined.

For the design firm, members for the design team are selected based on the specific expertise needed for a particular project. The team is composed of individuals with diverse backgrounds that may include specific design disciplines [architectural, civil, mechanical, electrical, structural, computer aided design and drafting (CADD), etc.], project control individuals (cost control, estimating, scheduling, quality control, safety, etc.), nontechnical people (land, purchasing, legal, financial, permitting, regulatory, etc.), and the sponsor's representative (the project manager).

Some owners are not aware of or do not follow any type of project process, which leads to unclear or poorly defined scope of work for the design firm. Sometimes the budget is simply the amount of money the owner has available to spend, and there is no tie of the cost budget to the scope of work. Occasionally, the only known information about the schedule is the finish date of the project. All of these issues create challenges and difficulties for project managers responsible for engineering design of a project. Table 4-2 gives common problems of engineering project managers when a disciplined project process is not followed.

1. Project scopes are not well defined
2. Too much growth from the beginning to the end of projects
3. Project budgets are not tied to scope
4. Inconsistency of workload, either too busy or nothing to do
5. Trying to handle too many projects at the same time
6. Shifting priorities from one project to another project
7. Poor communications, misunderstandings, and too much rework
8. The company is not organized to handle projects
9. No system exists to handle projects
10. No overall, understandable work plan exists

TABLE 4-2 Common Problems Related to Not Following a Project Process

Every design team must have a sponsor's representative, who may be the owner's project manager or appointed by the owner's project manager. This individual must communicate to the project team, the corporate policies, and the funding limit of the owner. He or she must have the responsibility and authority to act on behalf of the owner.

The owner's project manager plays a key role in resolving issues related to the project requirements and costs that will impact the sponsor's organization after the project is completed, when it will be used by the sponsor. The project sponsor reviews and approves the evolving scope, budget, and schedule. As a team member, the project manager approves any changes in scope, budget, schedule, risk register, and contingency before commitments are made. The project manager should be an active participant on the design team, answering questions and providing information needed by the team to accomplish the work. Unfortunately, the project manager is sometimes not involved until the project gets into trouble. Early involvement of the project manager can prevent future problems. The design project

manager must make this individual feel that he or she is an essential part of the project team.

Selecting those design team members identified in the project execution plan is an important step in project management because it begins the team building process. How team members are selected varies, depending on the policies of the design project manager's organization and the persuasiveness of the project manager to get the people on the project that he or she wants. To illustrate selection of design team members, consider a design firm that is organized as shown in Figure 4-5. The project manager will review the project's needs to identify required discipline expertise and required personnel.

Obviously, the project manager always wants the best and most qualified workers assigned to his or her project. However, the assignment of team members is often based on who is available at the time assignments are made. If the project manager feels a person who is assigned to the team lacks the required skills, then the project manager must act as a coach to assist the team member and/or arrange for additional training to ensure the work can be completed. However, if additional training proves insufficient, the project manager must expend the appropriate amount of effort to replace the resource. The project manager must select a winning team and have systems, tools, and processes in place for team members to follow. Finding sufficient quantity and quality of labor may become a risk register item that if not managed well can impact cost, scope quality, and schedule.

Construction Teams

The work environment and culture of a construction project is unique compared to most working conditions. A typical construction project consists of groups of people, normally from several organizations, that are hired and assigned to a

project to build the facility. Due to the relatively short life of a construction project, these people may view the construction project as accomplishing short-term tasks. However, the project manager of the construction team must instill in the team that building long-term relationships is more important in career advancement than trying to accomplish short-term tasks.

Even small-sized construction projects involve a large number of people. Organizing their efforts is complex, even if they all work for the same organization. Sources of information, location, timing, and problem complexity change as people enter the project, perform their assigned duties, and depart.

With all the diversity involved in a construction project, people must be managed so they work together efficiently to accomplish the goal. This requires skilled people who are willing to sacrifice short-term gratification for the long-term satisfaction of achieving a larger goal. Common sense and flexibility are essential to working with construction teams. The key to a successful construction project is properly skilled construction managers. These individuals possess the ability to recognize the degree of uncertainty at any point in the execution of the project, to anticipate issues or conflicts, and to manage the efforts of others to achieve clearly defined objectives that result in successful completion of the final product.

The organizational chart for a construction project consists of lines and boxes that show the division of work and the relationship of the workers to formal authority. The boxes in the chart depict the tasks to be performed and the lines depict the coordination required.

The number of construction teams for a project depends on the number of contracts awarded by the owner. For each construction contractor, and subsequent tier of subcontractors, a construction team is formed to perform

the work in accordance with the contract documents issued by the owner.

The Project Manager's Responsibilities Related to Teams

When working with team members, the project manager must work across many boundaries in the organizational structure to develop the project team into a cohesive group. This must be done quickly despite constraints imposed by others. The project manager must combine administrative and behavioral knowledge to work well with people. People skills are vital for effective management of team members. The project manager must create a professional environment that enables the team to work together so members will motivate themselves to peak performance.

Attributes of the project manager include the following:

- Organizes thoughts and actions
- Identifies problems and finds solutions
- Works well under pressure
- Accepts responsibility
- Motivates people with a "can do" attitude
- Anticipates and forecasts future events
- Works well with others, inside and outside of the company
- Is honest, fair, and has respect for others
- Communicates well—writing, speaking, and listening
- Leads and encourages the team
- Leads forward, not reports backward

The project manager is responsible for resolving conflicts between team members in addition to organizing,

coordinating, and directing the project. The project manager is the team leader who is responsible for developing the project requirements. This is accomplished by effective communication.

When working with teams, the project manager acts as the leader in acquiring resources, selecting team members, developing the sponsor’s requirements, defining scope and quality, defining budgets, and determining schedules. The project manager must establish a control system to complete the project in accordance with the expected requirements. The project manager is expected to control project activities within a defined scope, budget, and schedule. Situations will arise when design differences must be resolved. Trade-offs will have to be made to comply with the budget and schedule.

An important responsibility of the project manager is decision making. During team meetings, numerous decisions must be made. The process used in making decisions can have a direct impact on team performance. In some situations, the decision can be made solely by the project manager, possibly with input from one or more team members. However, there are other situations when the decision making should involve the entire team. The project manager must establish a process for decision making that places responsibility for the decision at the lowest possible level of the work. For example, the decision may be to resolve the best way to perform a design or produce drawings while another may involve generating ideas, solving a problem with one correct answer, or deciding issues with multiple correct answers. The project manager must develop a leadership style that is respected and accepted by the project team for decision making.

It is the project manager’s responsibility to ensure that each team member is assigned primary responsibility for discrete work. Recognizing there are numerous work items

in a project, the project manager must devise methods to ensure there will be no overlap or gaps in the work of the project team. Each team member should be asked to clearly define the work they expect to perform for the project. Team members should also identify potential gaps or overlaps in their work that may be performed by others. For example, will the anchor bolts be designed by the structural engineer who will be designing the superstructure or by the foundation engineer who will design the substructure? There is a risk that anchor bolts may be designed by both engineers or neither of them. After review by all team members, the project manager should develop an overall work plan that integrates the work of all team members. Then regularly scheduled meetings should be held to ensure no overlaps or gaps in the work of the team.

Sometimes when a new team is formed, the project manager may feel that one of the team members is lacking in the required skills to perform the work. To address this issue, the project manager should meet with the team member to discover his or her work experience relative to the project. This meeting should ascertain the confidence level of the team member in his or her ability to perform the work. It may be necessary to identify internal training or mentoring that may be available to assist the team member. The team member can be asked to investigate seminars that may be available to assist in performing the work. The project manager should show support in assisting the team member in his or her career growth and professional development. Periodic checks with the team member may be necessary to ensure work is progressing as expected.

The composition of a multifunctional team represents individuals with diverse backgrounds, including civil, mechanical, electrical, structures, etc. The project manager must devise methods to ensure mutual respect among team

members and to reinforce the understanding that everyone on the team is an important player in the success of the project. The project manager needs to ensure that each discipline is given adequate recognition during team meetings.

Meetings should be conducted in a manner that shows the importance of integrating the various functions on the project. The project manager should show a genuine interest and appreciation for diversity of functional disciplines. A team environment should be created that fosters mutual respect of all disciplines. The project manager needs to instill a team culture that everyone is a key contributor to a successful project. It is helpful for the project manager to identify the impact of each team member's work and how it affects other members on the team.

An example team meeting agenda might include the following topics:

- Progress reports from each functional team project manager
- Discuss key milestone activities and deliverables on the critical path
- Critical precedence deliverables needed by dependent functional team members
- Discuss achievements, obstacles, concerns, risk
- Discuss concerns for cost, schedule, quality of work
- Discuss roadblocks for escalation to owner's key stakeholder
- Schedule post-meeting followup with appropriate functional groups to address issues or risk management items

Key Factors in Team Leadership

Developing a culture where each team member feels that he or she is a part of the team and wanted by the team is essential to a successful team. Individuals who feel they are an important part of the team will develop a sense of pride because they are a part of the team and will become enthusiastic and motivated to assist others to ensure the successful performance of the entire team.

To be an effective leader, the project manager must possess hard and soft skills. Hard skills include technical expertise and knowledge about the work performed by the project team. These skills are generally attained by formal education and further enhanced by on-the-job experience. Soft skills involve people issues that are not normally attained in formal education, but acquired by experience in working with people. As the project manager rises in the ranks, soft skills become more important to effective leadership. Most people are hired on their hard skills, but promoted on their soft skills.

Project managers typically begin their career in a technical area where hard skills are important. They are promoted based on performance of their technical skills and seldom ask for help, especially if they are good problem solvers. They may become overly independent and fail to cultivate relationships with people who could become useful to them in the future. They rely on their technical skills rather than learning how to influence people. Much of the work of project manager is working with people with diverse backgrounds and expertise to solve problems and get the work done.

The behavior and leadership style of the project manager has a significant influence on the team. The project manager must have high ethics and a sense of fairness and honesty while dealing with members of the team as well as

others who are not on the team. The project manager's ability to adapt their management style for individual team members helps motivate them. In many respects, the project manager is the role model for the team. It is difficult for people to be highly motivated and productive when respect between the leader and team is lacking. The project manager must communicate the desired goals, objectives, values, and outcomes of the project. The team can then translate these issues into producing quality work. The project manager must also keep members informed of the status of the project.

Each project manager develops a leadership style as he or she progresses in his or her career. However, the common end result of any project manager is to lead the team that maximizes performance of individual team members and for the team as a group. For any project manager the key factors shown in Table 4-3 are important for successful team leadership.

1. Show interest and enthusiasm in the project and the project team
2. Be available to answer questions and assist team members in their work
3. Provide the resources needed by the team members to perform their work
4. Show trust and confidence in the team's ability to accomplish the work
5. Ensure that everyone on the team knows what is expected of him or her
6. Give credit to a team member when he or she has performed outstanding work
7. Hold each team member responsible for their work
8. Conduct regularly scheduled team meetings to maintain open communication
9. Exercise caution when dealing with topics that may be sensitive to team members
10. Be ethical in dealing with team members
11. Show interest and expectations in producing quality work
12. Show honesty and integrity in all relationships with team members

TABLE 4-3 Key Factors in Team Leadership

Team communications are vital to a successful team because highly motivated and dedicated workers want, and need, to be informed. Regularly scheduled team meetings

are essential. There may be numerous meetings between key team members to exchange detailed information, but a regularly scheduled weekly team meeting should be held for sharing status, making decisions, and documenting information. Because team members are frequently located at different physical locations, regular face-to-face meetings are necessary to keep the sense of team unity.

A well-defined scope for the team guides the progress of work and provides clear goals that can be used as guidelines for decision making. The project manager must ensure the scope is defined and understood by each team member before work is started. A firm scope that is clearly understood provides empowerment to team members. It also allows more independence and autonomy of individual team members to perform their work in the most efficient and expeditious manner because their assigned work and desired outcome is known. Individuals who know their responsibilities and the required outcome of their work are free to be innovative, creative, and will interact with each other, thereby producing high-quality work with performance. The result is a successful project.

Team Building

Effective teamwork is a key element in any successful project. Teamwork must be started early in the process, and it must be continuous throughout the life of a project. Experienced engineers and project managers all agree that teamwork is necessary, but the real question is “How does one organize a successful team?”

Effective communication is essential to team building. In simple terms, effective communication means the other person has received and understood the information that is being given to him or her. The giver of information must obtain feedback from the receiver to ensure effective

communication. The project team cannot function when there are breakdowns in team communication. Misinformation or incomplete information is a major deterrent to team building. Effective communication ensures that everyone knows what is expected and when it is expected.

All participants on the team have a common customer, the sponsor or user of the finished project. Team building starts with the sponsoring organization, with its project charter and mission statement. The project sponsor must be informed on established objectives, and he or she needs to be clear in their commitments. The project sponsor, working in conjunction with the project manager, must have a good prequalification process for selecting designers, contractors, and other third-party participants. In addition, the sponsor must know and communicate his or her goals and aspirations for the project and must set priorities related to cost, schedule, safety, and the expected level of quality. Everyone on the project must realize that the project sponsor pays for everything and is therefore the common customer of all parties.

Designers want an educated sponsor who is knowledgeable in the process of designing and constructing the project, but sometimes that is not the case. Sometimes the project manager must help the project sponsor to understand the importance of sequencing work and the impact of decisions that must be made in designing and constructing the project.

From the first day of the project, there must be continuity in the project team. High turnover of team members creates wasted time in educating new people and lost knowledge of previous developments in the project.

The contractor should be brought into the project at the earliest possible date. Construction contractors have excellent knowledge of costs and methods of construction

that are extremely helpful during the design phase of a project. People experienced in construction can provide valuable input in the constructability of a project.

Many private-sector projects are financed by lending institutions. Too often, for these types of projects the lender is not an active participant in the team, and everyone suffers from it. Unfortunately, the lender stays too far from the project and does not become involved until problems arise. There are other parties that are sometimes not brought into the team from the beginning of the project. For example, the purchasing agent is an important participant in teams that must procure large amounts of material or major equipment. Early involvement of the person who will be involved in issuing purchase orders, tracking vendors' shipping dates and delivery dates, and receipt of procured material and equipment has a significant impact on meeting installation deadlines in a project.

Keywords for team building are pressure, responsibility, honesty, kindness, respect, and communication. Engineering and construction projects usually require tight schedules, which create pressure on the project team to complete the work at the earliest possible date. This requires cooperation among team members who must assume responsibility and perform their work in the most expeditious manner. The ground rule should be "Everyone is a contributor and winner on a successful team." The team must stop worrying about the 1% that is wrong and focus on the 99% that is right. The project team must have open communication and avoid hiding mistakes and pointing blame. A successful team can achieve a successful project and have fun doing it.

Team building is especially important for teams that consist of people who have never worked together. For example, a team that consists of multiple engineering disciplines combined with people from purchasing, quality,

and cost control. To facilitate team building, the project manager needs to hold a pre-project meeting with all team members to allow them to get acquainted informally. The project manager needs to emphasize the importance of each team member and how they are an important part of the project. Adequate time should be allowed during team meetings to emphasize the importance of integrating the team's work. The project manager should create a work environment of mutual respect by giving credit and recognition to each member of the project team and encouraging cooperation.

Some companies have begun the team building process by holding a weekend retreat for team members, including their family members. The retreat is usually held in a resort setting to allow interaction of team members related to their personal interests. This allows everyone to realize that team members have similar aspirations and common interests. For example, understanding that others on the team have children with special talents or must care for elderly parents can provide a sense of bonding and mutual respect, which is the first step in effective team building. The retreat can also include understanding the personality profiles of team members. Each team member processes information differently. Each behaves differently under pressure compared to low stress times. Some members prefer written communication while others prefer face-to-face or telephone conversations. Understanding these and other aspects of each team member can be the "glue" that holds the team together during the stressful times of the project.

Motivating Teams

For years, managers and supervisors have struggled with methods of motivating workers. In the early 1950s, A. H. Maslow developed a theory of motivation called the

hierarchy of needs. Maslow's theory has been used by managers, as well as educators, to try to understand why people behave the way they do, how to motivate them, and how to enlist their commitment.

Maslow proposed that humans are a wanting animal, and their wants become needs. It is the quest to satisfy their needs that drives or motivates people. The needs include basic physical and psychological needs, which are perceived in the human mind and satisfied by material things. Maslow proposed that the needs of humans follow a hierarchy, beginning with comfort and basic survival, such as food, clothing, and shelter. Once this first need is satisfied, humans seek to satisfy the next higher level of need: safety and security. After this need is satisfied, individuals seek progressively higher levels of need, including belonging, ego, and finally self-fulfillment. Self-fulfillment is the highest level of need and may include an urge to have increasing influence or give back to the world, such as establishing an endowment. Figure 4-7 is a graphical representation of the five levels in Maslow's hierarchy of human needs.

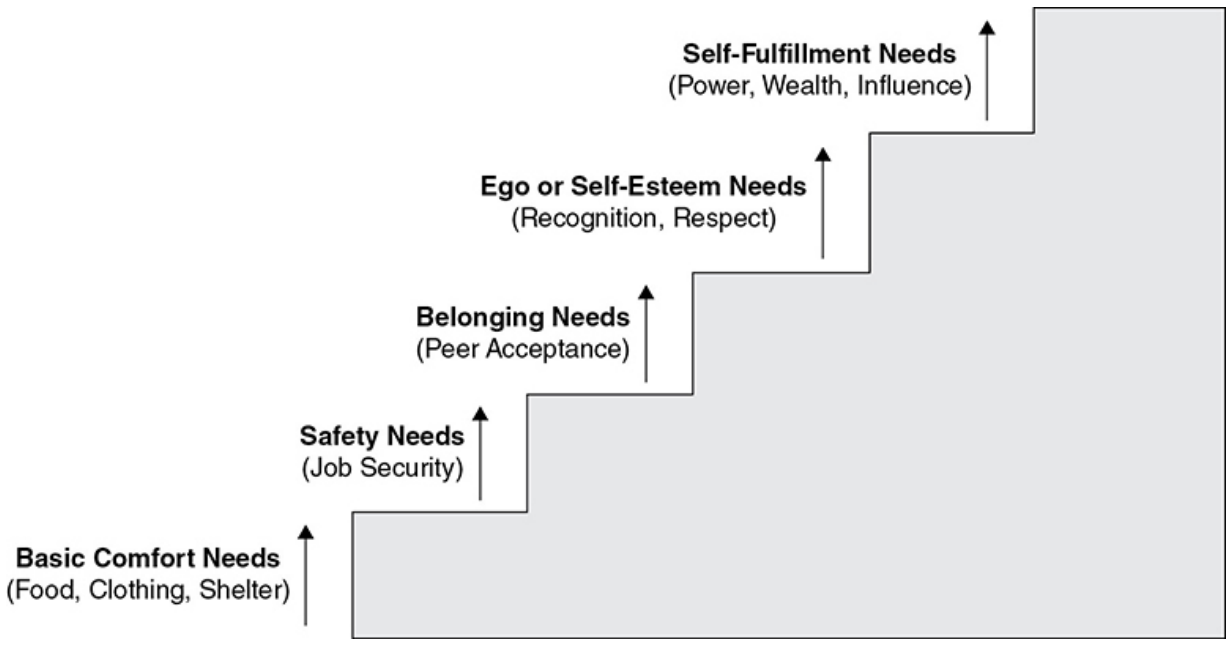


FIGURE 4-7 Maslow's hierarchy of needs.

As the lower levels of needs are satisfied, it is only natural for a person to become motivated to achieve the next higher level in Maslow's hierarchy of needs. A project manager must use his or her skills to determine the specific needs of team members in order to motivate them to their full potential.

Determining the needs of people is not easy to accomplish in the day-to-day work environment. Sometimes it may be necessary to spend time in an informal setting to build a relationship that provides understanding of what is important to a team member. For example, a team member may be concerned about having adequate time to attend a child's school function or care for an ill family member. A team member in this situation may be motivated by being allowed flexible work-hours with the understanding that the time will be made up at nights or on weekends.

Effective methods should be used by the project manager to identify the needs of team members, so he or she can be responsive to those needs in motivating the team. It may be necessary to converse with each team member outside the formal work environment to better know them. The project manager needs to get to know team members in a personal, nonintrusive, manner to show special interest in them. It is important to reinforce confidence in team members and let them know that the project manager wants to assist them in their work. It is desirable to determine what is important to team members as related to their work. Sometimes it may be advantageous to discretely ask team members what is important to them outside their work. When working with people, it is necessary to be sensitive to each team member and show genuine interest in supporting their work.

The project manager must also realize that the needs of people can change. For example, personal finances or problems within the family can change the needs of a person rapidly. Each project manager must devise a way to

ascertain the needs of their team members. Once the needs are identified, then an appropriate method of motivation can be determined. Attempting to motivate without sincerity or integrity can cause teams to fragment or disintegrate. Thus, the project manager must use good people skills to motivate team members.

Conflict Management

Due to the dynamic nature of project environments, it is inevitable that conflicts among team members will arise. It is important during the initial team building meeting or retreat to discuss and plan for handling conflicts. Engaging the team to discuss their experience with conflicts and their resolution results in a conflict resolution plan to follow when the inevitable conflict arises. For example, discussing how to avoid using the wrong version of a drawing or design document can reinforce the team's commitment to follow the document control procedures established for the project.

Conflicts can arise over the distribution of resources, access to information, disagreement about decisions, or the perception by an individual that he or she is not respected or fully a part of the team. Conflict can have a negative influence by fostering interpersonal hostility, reduced performance, and dissension in the team.

Conflicts can arise due to different agendas among team members since some of the team members may work for different companies. For example, on the owner's project management team there will be members from one or more design firms as well as one or more construction companies. Likewise, the design team's project manager may have team members who are in-house as well as design consultants who are under contract to perform special parts of the design. The construction contractor's project manager

usually has many diverse personnel from both in-house and subcontractors.

It should be recognized that conflicts are often a result of changes, for example, modification of drawings, reassignment of a team member, or changes in meeting dates that are not communicated to other team members. The project manager and team should evaluate each conflict resolution to capture lessons learned, both positive and negative, for the benefit of future project work. A good project manager must and can manage conflicts. Table 4-4 gives examples of potential conflicts that may arise during the design of a project and strategies to resolve or prevent the conflict.

Potential Conflict	Strategy to Resolve the Conflict
Changes in the design parameters after partial completion of design	Hold routine team meetings to discuss impact of changes on other members of the project team
Changes in dates or time of design team meetings	Maintain consistent times and agendas of design team meetings
Confusion about revisions of drawings or specifications during design	Establish and maintain a master directory of drawings and specification revisions
Changes by one team member that adversely affect other team members	Develop a procedure to discuss changes before they are approved
Recurring complaints about changes related to design of the project	Create a log of potential changes for review before submitting a change in design

TABLE 4-4 Examples of Conflicts and Resolutions of Conflicts during Design

To manage conflict, the project manager must use techniques to deal with disagreements, both technical and personal in nature, that inevitably develop among team members. Project managers and team members may perceive those conflicts are bad, shouldn’t exist, are caused by troublemakers, or should be avoided. However, all project participants should recognize that conflicts are inevitable and actually can be beneficial if resolved before

they escalate to a crisis and if resolved in an appropriate manner. Resolution of conflicts can lead to innovation and to ideas about how to improve work efficiency.

Withdrawal or giving up is a poor way of managing conflicts. It is a stopgap attempt to resolve a conflict and does not solve the problem. Withdrawal is a passive approach to solving a problem and only temporarily delays the inevitable future reoccurrence of the problem. Another method, smoothing, is a more active technique in managing conflicts. However, smoothing only temporarily avoids the conflict by appeasing one or more of the parties involved in the conflict. Smoothing does not provide long-lasting solutions.

Compromising is another approach to settling conflicts. This approach involves bargaining between the disputing parties to reach an acceptable agreement. The disputing parties make trade-offs that often fall short of ideal solutions. Too often, compromising does not result in a definitive resolution and leaves opportunities for a reoccurrence of the conflicts. Depending on the circumstances, however, compromising may be the best method of resolving conflicts.

Confronting and problem solving is a method of resolving conflicts that requires participation by all parties involved in the conflict. It requires an open dialogue to identify the root problems and a joint effort to use problem-solving techniques to objectively resolve the conflict. The potential to find final, mutually acceptable solutions is generally higher when the project manager and team use this method.

For some situations, it may be necessary for the project manager to exercise authority to force a resolution of the conflict. Forcing a resolution can only be used when the project manager has the authority and is willing to use his or her power to settle the conflict without producing hurt

feelings. The project manager must understand that forcing a solution may create resentment or other adverse reactions that can affect the team's future performance. Table 4-5 compares methods of conflict resolution.

Withdrawal	Passive method No real resolution to conflict
Smoothing	Active Temporary resolution to conflict
Compromise	Active May or may not result in lasting resolution to conflict
Confront	Active High potential to find mutually acceptable resolutions to conflict
Consensus	Active Techniques used include voting, trading, and averaging May yield a better solution to conflict
Authority	Project manager must possess the authority Should be used rarely Potential for adverse reactions from team

TABLE 4-5 Comparison of Conflict Resolution Methods

Developing a Consensus

Sometimes multiple solutions to a problem exist, each of which may yield the same result. Team members may not agree on any one particular solution. Some members may be indifferent regarding a particular solution, while others may have strong feelings about a solution. The project manager must work with the team to develop a consensus regarding selection of the best solution. For these situations, the project manager must help the team members to focus on solving the problem.

Voting, trading, or averaging can be helpful in reaching a consensus. The project manager must lead the team in seeking facts to avoid dilemmas and indecisions. During

discussions, conflict should be accepted as helpful, and every effort should be made to prevent threats, offensive comments, or defensive actions. Team members should avoid personal interests and behaviors that exclude the opinions and positions of other team members. Instead, they should exhibit mutual respect for each other with a special effort to focus on what is best overall for the project.

The project manager and the team must guard against using consensus for every decision to be made on a project. During team formation early in the project or during the facilitated team retreat, the project team should formulate team rules including how conflicts will be addressed. Documenting these agreements and respecting them helps teams resolve conflicts without negatively impacting the project. When will compromise be used? When will the project manager use his or her authority to resolve the conflict? Under what circumstances will consensus be used? What issues require the project sponsor’s involvement?

Team Conduct

A team is most simply defined as two or more people who, by working together, accomplish more than if they worked separately. Projects typically consist of multiple design and construction packages, each with specific assignments and responsibilities. For a successful team, specific rules are required.

Goals for a particular team explicitly direct the project requirements of each specific group. For example, the safety team should know that it is supposed to keep health and accident incidents to a quantified level, or the scheduling team should know the number of days allowed to develop the Critical Path Method (CPM) schedule. Teams need to know the required time to do their work and the desired outcome of their work.

In addition to knowing the goals, the team must also know how it is expected to operate. The design and construction teams should know from the beginning the extent of their power and authority to act. For example, some teams may be expected only to solve problems, while others are only required for routine reviews, and others exist to make decisions.

Every project requires a set of rules to be obeyed. Without rules, disorder and frustration will likely occur. Rules should not be viewed as restrictive. Instead, a good set of rules provides freedom for the team members to perform their work because they know what is expected of them. Generally, when the rules are unclear or absent, teams limit themselves from reaching their full potential.

Working relationships must be clearly defined and understood. To be effective, each team should know where it fits in the overall scheme of other operating teams. The leader of each team must answer questions regarding internal team relationships. Team members must show trust and respect for other team members, but close personal friendship is not always necessary. In engineering and construction projects, teams often function on the basis of professional relationships. Interrelationships between teams is the responsibility of upper management.

Personal values of individual team members often play an important role in teams. Each team member brings his or her own set of principles and values to the team. The extent and determination to which they hold these values influences how well the team will be able to work together. Team members should not have to compromise their personal values and principles. The team leader must be committed to respecting team members, promoting openness and flexibility. Situations will arise when compromises are necessary to resolve issues.

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CHAPTER 5
Project Document Control

Importance of Document Control

All projects generate documents, beginning with the feasibility phase through project construction and closeout. As projects increase in size and complexity, the greater project team can generate hundreds of thousands of documents. Even small- to medium-sized projects can produce tens of thousands of documents in drawings and specifications alone. All of the documents contain information and data necessary to define, design, construct, and eventually operate the facility. The volume of the information that is developed during a project's life must be managed, which requires document control. At its simplest, document control is a filing or management process for the project. At its most defined, it is a system of processes and procedures planned and incorporated into the project. Good document control sets the stage for reduced errors and miscommunication and forms the basis for better cooperation among the project participants.

The information contained in the mass of project documents must be distributed to the proper recipients to ensure uninterrupted performance of the work, to minimize errors and rework, to maintain compliance, and to confirm that proper progress is being made toward the project objectives. Poor document control causes the following:

- Lack of visibility to the status of activities and the overall project and contributes to unnecessary redundancy
- Loss of information due to misplacing vital documents, accidental deletion of documents, sequestering documents by team members, or corrupted documents
- Restricted or limited cooperation and collaboration between team members
- Weak or compromised data security

The topic of document control is too expansive to cover in a single chapter. This chapter introduces the project manager to several key aspects of project document control. The information here should assist the project manager with planning for and implementing suitable document control practices and tools for their project.

How Document Control Helps the Project

For large and complex projects, coordination and interfaces are crucial to smooth project development and execution. When documents reference each other or industry standards, they must present a consistent and comprehensive message among all documents. It is quite easy to introduce conflicting information and requirements without a disciplined and coordinated approach to managing documents. This is true for reports and studies, specifications and drawings, and standards and references. Document control helps the project by:

1. *Facilitating communication*—to ensure all parties are on the same page, with the same information and every stakeholder is referencing the same material.

Document control can ensure that important documents are available, that project participants are aware of them, and everyone has access to the documents that span across multiple disciplines.

2. *Aiding cross-referencing between documents*—information can be spread across multiple documents creating gaps, overlaps, and confusion for the *execution team*.
3. *Keeping stakeholders informed*—to provide accurate updates and status information to keep the project aligned with objectives.
4. *Improving project quality*—ensure consistency between documents and ensure the desired quality is communicated across the project.
5. *Providing a record of the project communication*—knowing who said what and when helps avoid disputes between project participants.
6. *Maintaining a universal understanding of project information*—facilitating a consistent understanding of written and verbal communication by the project team.
7. *Ensuring continuity*—as the project progresses and the team make up changes, project documentation provides the validated information for project work.
8. *Preventing schedule delays*—providing prompt, relevant, and accurate information to participants so key milestones and interactions meet desired deadlines. Monitoring any delinquencies in responding to required reviews and approvals.
9. *Reducing or preventing claims*—allows the project team to confirm what was communicated between the parties and establishes when and how facts and data were shared.

Project Documents

Documents take many forms, but usually a project document is considered to be physical or electronic, written or graphical matter that conveys information about the project or project-related issues. Some documents serve as an official record and are archived for future use such as as-built or as-constructed drawings. Some are temporal and have a limited life span or purpose such as sketches, memos, or transmittals. Documents include references such as ASTM or ACI standards, owner's standards (drawings and written specifications), or reference drawings from ancillary facilities. Documents also include reports, studies, letters, memos, requests for information (RFIs), contracts, change orders, permits, and other documents. A list of project documents can be found later in this chapter.

Project Document Control

Project document control is a management discipline whose purpose is to enforce processes and practices for the creation, review, modification, issuance, distribution, accessibility, and archival of project documents. Document control includes logging correspondence, documenting the transmittal of information between parties involved in a project, archiving documents for later reference, tracking updates to revised documents, and recording responses. An often forgotten purpose of document control is keeping records legible, readily identifiable, and retrievable especially for ISO 9001 compliance.

Document control provides a way to ensure that information remains relevant, up-to-date, accessible, and aligned to the project strategy. Documents go through various versions during their creation and lifecycle. Many documents eventually become legal instruments that

require control between contracted parties. Some documents must be reviewed, corrected, approved, and distributed at regular intervals. Some documents have a life span beyond the closeout of the project, while others become obsolete and are destroyed. Changes to documents must be tracked to ensure they are communicated to all the necessary stakeholders on the project. Just as a project progresses through multiple phases during its lifecycle, documents also progress through multiple phases. Examples of multiple phases of documents include creation, development, review and comment, issue, (red line), update (As Built), and archive. Because documents cycle through these various phases, the project team needs to develop a communication and document management plan to ensure documents are managed in an efficient manner.

Basically, all project documents need to be controlled, some more than others and at different times throughout the lifecycle. As the project progresses through the lifecycle, some documents will require more control. For example, engineering drawings and specifications will require tighter control as the project moves into detailed design and even stricter control as the project moves into the construction phase.

The complexity of the document control system is dependent on the size and complexity of the project. Too much control can impair the execution of a small to medium project, however, not enough control can lead to gaps in project execution and can lead to numerous scope changes, cost overruns, schedule delays, or claims. The amount of document control can also vary through the lifecycle of the project, increasing as the project advances into each subsequent phase.

Project Communication Plan

The project communication plan determines who needs what information, how the information will be distributed, and when its completion is required to execute the project most effectively. The project communication plan focuses on providing the right information at the right time to the right stakeholder. Elements of a project communication plan include the following:

- **Target audience**—who are the stakeholders or recipients and what are their needs?
- **Type of information**—what type of information, preferred format, and how detailed should these need to be?
- **Frequency**—how often does communication need to take place?
- **Owner**—who are the responsible persons, aside from the project manager, that will do the communication?
- **Channel**—what type of channel or technology will the sender use?
- **Effort calculation**—how much time will the sender need to communicate?
- **Goal**—what is the objective and desired result of the communication?
- **Date**—when are the important communications expected?

This plan should include a project document management plan containing a list of the documents to be generated during the project, distribution lists for these documents, and the distribution methods for each type of document. A communication plan template can be found at https://www.hhs.gov/sites/default/files/ocio/eplc/EPLC%20Archive%20Documents/11%20-

%20Communications%20Plan/eplc_communications_management_template.doc.

Document control facilitates accurate, current, and clear communication of these records to the project team and stakeholders. Because information sharing is fundamental to project success, the document control leader becomes an essential team member. Clear communication is one of the top project lessons learned for most projects; however, communication failures are consistently repeated from project to project. Rigorous document control can serve as risk mitigation for claims generated between contractual parties of the project and prevent misunderstanding and miscommunications, which create these claims in the first place.

Document Control Strategy and the Document Management Plan

The key objective for a project document control strategy should be accurate and timely access to information that is essential to project success. The project's document management strategy should identify all of the documents that will be generated by the project. What strategy will be used to manage the considerable number of documents? At a minimum, the strategy should consider the size and nature of the project, the source of documents, which documents are project specific, and which documents will be required for the operation and maintenance of the facility.

Document control strategy should be formed based on the scope of documents and deliverables expected to be generated by the project. The document control effort should be appropriate for the project. For heavy civil projects including buildings, infrastructure, and industrial types, document control requires dedicated staff. The

project may be so document intensive that it requires a unique software system to facilitate and enforce document control procedures. For smaller projects, if the project team members are disciplined in following document control procedures, a simple approach may be all that is necessary. These and other aspects need to be assessed as part of the project document control strategy.

After the project team forms a strategy for document control, the document management plan can be developed. Since document control can be used for several purposes, the project team must define the purpose of the document management plan. A document management plan encompasses the collection of project documents, provides the specific plan or workflow for each document type, and describes the process necessary to manage the quantity of information generated by the project. It is a plan for each type of document that will be associated with the project. It details the numbering and naming of files, lists who has responsibility for the documents, and specifies how the project team will handle their respective documents. Project document control can consist of an elaborate computer system, such as New Forma, which requires IT support or it can be as simple as an index of documents with their location. At its basic level, document control is maintained through the discipline exercised by the project team members. Document control is a shared responsibility of all project team members.

The documents created by the project team and other stakeholders come in many forms (e.g., letters, emails, drawings, specifications, RFIs, etc.). Essentially, all of these documents are legal documents since projects are undertaken via contractual arrangements. Ranging from informal email correspondence to formal transmittals, the legal net is widely cast should a legal dispute arise. Documents associated with contracts may not be changed

unilaterally once the contracts are formally executed. Changes must be carefully and accurately documented and promptly communicated to all the parties of the contract. Hence, document management encompasses monitoring the completion of deliverables, recording changes to documents, tracking correspondence, identifying possible sources of claims, and facilitating claim prevention.

Each document type requires a specific plan. Table 5-1 provides key elements of document control that should be considered in developing the document control plan [DocControlPlan.doc]. A document control plan for an environmental restoration program can be found at www.osti.gov/servlets/purl/10190137.

1. Who is the author?
2. Who reviews the document?
3. Who is the intended audience?
4. Who approves the document?
5. What is the purpose of the document?
6. Does the document require versioning?
7. How will the document be named?
8. Where will the document be stored?
9. What is the retention for the document?

TABLE 5-1 Planning Considerations for Project Document Control

Document control creates a log of correspondence between the various stakeholders and captures when documents are sent and received. Timing of sending and receiving project documents can create delays, gaps, or errors in scope and adversely affect quality; therefore, progress on some project deliverables is measured by the completion and transmittal of those documents. Some documents are issued multiple times, which requires version

control. Versioning should be part of the document control plan and monitored using a document control register.

Drawings and other graphical documents should be provided with a revision number, and the changed portion of the drawing should be encircled or clouded to indicate where any change was made. Specifications are referenced by page number, article, section, paragraph, and line number and should contain a version table at the beginning of the specification. Changes to drawings and specifications usually come in one of two forms, either an engineering modification or a request for proposal. In the case of the engineering modification, the change is minor and does not impact cost or schedule. The request for proposal usually involves a change in the scope of work, adding, deleting, or significantly altering the work from what was originally planned.

If the project participants are disciplined about filing these documents using a simple file structure, numbering and naming schemes, a small project can avoid the use of excessively expensive and elaborate software systems. Even a dedicated software system will require discipline on the participant's part and dedicated staff to maintain it. It cannot be overemphasized; the key element to any document control management plan is discipline.

Meaning of "Controlled Document"

A controlled document is one which follows formal procedure for updates and transmittal to project participants. The control process ensures the change or update is recognized among the project participants. Depending on the nature of the change or update, the parties previously issued the controlled document may have additional compensation due or must agree to accept the change or update. The treatment of changes should be described in the contract documents. The project team in

developing the document management plan must establish and document a procedure defining which documents will be categorized as controlled documents, establishing the required controls, and determining what information will be retained for project records. Examples of data to track for controlled documents include the following:

- Identification—naming, numbering, and versioning
- Document author
- Storage location
- Review and approval status
- Protection
- Retrieval
- Retention requirements
- Disposition

An uncontrolled document is one that can be updated or transmitted without any formal procedure. Informal emails or telephone conversations would fall in this category; however, the authors of such documents should keep a log of these informal documents because they can become critical in certain circumstances namely construction claims and legal disputes.

Projects generate an enormous number of documents. Table 5-2 is a partial list of project documents that requires some form of control during a project. The table provides the document name and the type of document.

Document Name	Document Type
1. Accident Reports	Legal
2. Action Items	Control
3. Addendum	Legal
4. Agreements	Legal
5. Amendments	Legal
6. Baseline Schedule	Control
7. Basis of Design	Control
8. Basis of Estimate	Control
9. Basis of Schedule	Control
10. Bid Opening/Analysis Report	Control
11. Bid Schedule	Control
12. Certificate of Completion	Contractual
13. Certificates of Insurance	Contractual
14. Change Order Log	Control
15. Change Orders/Requests	Control
16. Conditional Waiver of Lien	Contractual
17. Consent of Survey for Adjustment of Retainage	Contractual
18. Consent of Survey for Final Payment	Contractual
19. Construction Change Directive	Contractual
20. Construction Photo Log	Control
21. Construction Progress Reports	Control
22. Construction Schedule	Control
23. Contractor Accident Reports	Legal
24. Contractor Submittals	Contractual
25. Contracts	Contractual
26. Conversations	Control
27. Correspondence	Control
a. Letters	Control
b. Memos	Control
c. Emails	Control
d. Telephone Conversations	Control
28. Correspondence Log	Control
29. Daily Reports	Control
30. Deliveries Log	Contractual
31. Distributions List	Control
32. Document Log	Control
33. Drawings List	Contractual
34. Emails	Control
35. Engineering Reports	Control
36. Field Notes	Control
37. Force Account Worked Daily Record	Contractual
38. Forms	Control
39. Inspector's Daily Reports	Control
40. Instructions/Training	Procedural
41. Legal Document	Legal
42. Lien Waiver	Contractual
43. Manuals	Procedural
44. Meeting Minutes	Control
45. Memos	Control
46. Monthly Pay Estimate/Request	Control
47. Monthly Progress Reports	Control
48. Notice of Award	Contractual
49. Notice of Beneficial Use	Contractual
50. Notice of Completion	Contractual
51. Notice to Proceed	Contractual
52. Payment Log	Contractual
53. Photographs	Control
54. Procedures	Contractual, Procedural
55. Procurement Log	Contractual
56. Product/Vendor Submittals	Contractual
57. Progress Schedules	Control
58. Proposals	Contractual
59. Publications (Brochures)	Control
60. Punch List	Control
61. Purchase Order Log	Contractual
62. Quality Documents	Control
a. Non-Conformance Reports	Control
b. Field Test Results	Control
c. Lab Test Results	Control
d. Inspection Reports	Control
63. Quality Plan	Control
64. Recovery Schedule	Control
65. Reports	Control
66. Requests for Information (RFI)	Contractual
67. RFI Log	Control
68. Schedules	Control
69. Shop Drawings	Contractual
70. Site Visits	Control
71. Specifications	Contractual
72. Stored Materials	Contractual
73. Studies	Control
74. Subcontracts List	Contractual
75. Substitution Requests	Contractual
76. Telephone Log	Control
77. Templates	Control
78. Transmittal Letters	Control
79. Transmittal Log	Control
80. Vendor List	Control
81. Videos	Control
82. Visitor Log	Control
83. Weekly Progress Reports	Control

TABLE 5-2 List of Controlled Project Documents

Document Control Participants

On larger projects, document control is usually managed under the project controls group but can report directly to the project manager or be a part of a larger company document control group. For large and complex projects, the project document control group may consist of several personnel to log and file the information and even coordinate document reviews. For smaller projects, document control may be the responsibility of the project controls manager, the project manager, or the project administrative assistant. Regardless of the project size, document control involves the entire project team including dedicated document control specialists to manage documents for the entire project.

A dedicated document control specialist ensures documents are properly named, numbered, categorized, and filed in an organized manner. Document specialists ensure the proper distribution of documents and coordinate document reviews. Documents can be generated by any team member, so disciplined adherence to the process by each team member is required. Casual correspondence such as emails and telephone conversations can easily bypass a formal document control system. If decisions, agreements, or commitments are made using these casual communication forms, they can be lost to the project. When communication between team members, stakeholders, and contractual parties occurs outside of the document control process, it introduces problems ranging from confusion and rework to claims and legal issues. As the size and makeup of the team changes through the various phases of the project, important information can be deleted, buried, or abandoned in personal files. Each project team member has responsibility for the documents they generate and must

ensure they are handled properly according to the document control plan.

A project stakeholder is a decision maker, person or entity with an interest or involvement in the project. Stakeholders directly affect and are affected by decisions made on the project and should be governed by the document control plan. Stakeholders can be internal or external to the project or project team, the sponsoring company, or the companies contractually involved in the project. Because of their influence through decision making and the effects of their decisions, communication with stakeholders must be carefully logged and filed, and properly distributed. Formal correspondence between the various stakeholders needs to be maintained to facilitate open factual communication. Regardless of the extent of their involvement with the project, each stakeholder has the potential to critically affect the project either positively or negatively. Their contribution is critical to the project's success.

Control of the Official or Record Document Files

Document control will need to be exercised by all the parties involved in a project. This means that the owner, the designer, and the contractor(s) each needs to have a document control system in place. It is in the owner's best interest to maintain all project files within their system. For the owner, the project sponsor will need to maintain records between the architect, engineer, owner-furnished equipment suppliers, and construction contractors. Contracts should designate how documents will be transmitted between the parties and specify a final disposition of the documents when the project is complete.

The document control plan should clearly define what constitutes an official file or record file. These include but

are not necessarily limited to issued for construction (IFC) drawings, conformed contract documents including specifications, and approved permits. The record document should be a hard copy or nonnative electronic version that cannot be altered or corrupted. The record file should have appropriate security to ensure information integrity. Record files stored in the document management system should not be removed. Copies can be made, but the official document cannot be removed. This restriction is essential to maintaining project information and preventing unauthorized changes or data corruption.

Document Workflow for a Project

Workflow for documents describes the sequence of steps a document follows within the life of a project. Figure 5-1 provides a basic illustration of a document workflow. All documents are initiated by the author. The document may be formal correspondence with a stakeholder or contractual party; it may be an engineering drawing or specification; or it may be an application for an environmental permit. Regardless of its purpose, the document is created. A document review may follow and may be formal or informal. The outcome of the review may require modification to the document before it receives approval for use. Upon approval, the document is issued based on the responsible, accountable, consulted, informed (RACI) chart for the project (see Chapter 4, Team Selection and Development). Once issued, the document may require periodic updates, for example, as-built drawings as the work occurs. Finally, the disposition of the document is determined. The document may have been needed only for some part of the project and can be deleted. It may be required for the operation and maintenance of the facility and is retained by the owner according to their document retention procedures.



FIGURE 5-1 Basic document workflow.

Workflow is most commonly associated with coordinated document reviews. Reviews can occur in sequence or parallel and consist of the distribution of the documents within a work group such as engineering, fabrication, manufacturing, the owner's organization, or the contractor. During the design phase, drawings and specifications from the engineer or equipment suppliers need to be reviewed by a subset of the project team. Many times, this review will be conducted in a sequential fashion, usually by engineering disciplines. Figure 5-2 illustrates a simple design review workflow. The workflow criteria dictate the sequence in which the review will take place. The workflow captures who commented on the document, what changes are required, and who approves or rejects the document. If the workflow occurs in parallel, one person is designated to aggregate the review comments and approve or reject the document. All reviews initiate and complete with document control.

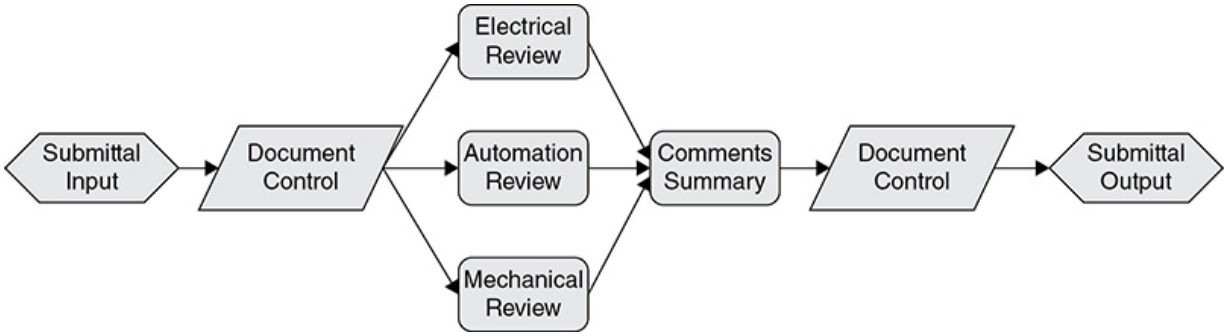


FIGURE 5-2 Design review workflow.

The Document Control Register

The document control register logs all communications between project stakeholders and all documents generated

on the project. A document control register can be as simple as a list or as complicated as a dedicated software package. Most projects will need at least a worksheet or small database to record this information. The log should contain at minimum the document name, document type, date the document was created, and revision number. Other data can include the document author, document subject, date recorded, etc.

A master document register (MDR) takes the document control register one step further. It contains any document generated by any stakeholder, all correspondence, and records including vendors, suppliers, and contractors. The master document register needs to include the originator and recipients of the documents. It should also record any actions or follow-up required.

Procedures for Managing and Controlling Project Documents

The project should establish a document management procedure within the document control plan. The document control plan is a section of the project execution plan. The procedure should include the following:

- Objectives and value drivers
- Purpose and scope
- Definitions
- Assumptions, issues, and concerns
- Document management process
- Organization
- Roles and responsibilities

The document management procedure should include processes to address the following:

1. Transmittals—distribution of the document between work groups such as drawing revisions between the engineer and the contractor.
2. Drawing reviews—how will the design team review and comment on drawings to ensure cohesive design?
3. Document approval—how the document is approved, content, format, usage, etc.
4. Document updates and amendments—how updates and changes be made and how will ancillary documents be added?
5. Distributions—how documents for review, approval, and use will be made available to the pertinent team members or stakeholders?

File Naming and File Naming Conventions

To make documents easily retrievable, a file naming convention can be critical. Files with similar information should be filed together in folders with logical titles. Folders should be created that reflect the purpose or intent of the files contained in them. Files should have a brief title identifying the contents and include the date and version number. (e.g., 220131Monthly Report.pdf). If numerous updates are anticipated, placing the date in the year, month, day format can help sort the files chronologically. Documents like monthly reports, schedule updates, estimate or budget updates can stay organized using this method. Below are some components for naming files:

- Project name or ID number
- Work Breakdown Structure designation
- Date in yyyymmdd format
- Version
- Phase name

- Content type (e.g., correspondence, transmittal, estimate, report, etc.)

When developing the document management plan, file naming and versioning should be discussed and included in the resulting plan. Once defined, strict adherence to the naming structure mitigates the risk of losing or misplacing project information. Following the established file naming structure improves project information sharing and communication.

File Types for Saving and Sharing Files

During the execution of a project, documents are generated using various programs including word processing, spreadsheets, CADD, etc. All project stakeholders may not have all of the software that generated the native document. File size and file security must also be considered. Photography and graphical documents tend to be especially large files. Transmitting large documents or large packages of documents to remote sites must be considered in the document control plan. Sharing native files increases the risk that data will be inadvertently destroyed or changed. Given all of the issues with native files, a portable document format is recommended. The contracts between the various parties should specify file types used for file sharing.

Reviews: Drawings, Designs, Models

A design review is part of the document review process because the design is contained in the drawings. A design review considers all of the pieces of the project and their integration to form the constructed project. A design review covers each area of the project—site work, foundations, utilities, buildings, mechanical, electrical, instrumentation, and controls. Design reviews can occur face to face or

virtually and can include a 3D model of the facility. If the 3D model is included, then a model review also occurs. The model review evaluates interfaces between design components, interference, or obstructions that prevent the facility from operating as intended. This review is an opportunity for the entire engineering design team and owner's representatives to see the complete drawing package and find inconsistencies and interface conflicts between disciplines. A drawing review, also a subset of the document review process, occurs within the design discipline producing the drawing. A drawing review checks the bill of materials against what is drawn; confirms quantities, confirms dimensions, and notes. Drawing reviews can also occur face to face or virtually.

Transmittals and How They Should Be Used

A transmittal is a document that chronicles what documents are transferred between parties, when they were transferred, to whom they were transferred, and why they were transferred. Transmittals can be used to transfer single documents or a package of various document types. It is a good and common practice to use transmittals to transfer drawings and specifications. However, transmittals also should be used to transfer any documents with the exceptions of letters and memoranda. For some documents that also require review, comment, and approval, transmittals can be used to facilitate this additional condition. A record of transmittals should be kept in a log for traceability.

Documents versus Drawings on the Transmittal Form

Documents and drawings are handled differently, because when changes occur, usually, drawings convey more information.

1. Written or narrative documents require highlights of what was changed or updated. Usually, the changes are noted by page, section, paragraph, and sentence.
2. Transmittals will record the specific section, article, page, and paragraph of the document that has changed.
3. Drawings have revision records in the title block, and the changes are identified by using clouding to indicate the revision.
4. Drawings usually progress through several stages and design statuses until they are issued for construction and revised as needed during construction.

Document Control and the Transmittal Log

A critical function of document control is the documentation and transfer of project information between project participants. A transmittal system is the primary method of managing this process. Projects usually consist of multiple contracted companies providing specialized services to the project. When documents are distributed between these companies, they can be grouped together and transmitted in packages by separate transmittal to each participant. The transmittal form is used to list each of the documents included in the package, usually providing some details about each document. The transmittal form will also indicate when the package was sent and who was the recipient. This method provides for the receiving company to decide the distribution of the documents within their team. A transmittal log records all of the transmittals and any actions associated with them.

Risk Mitigation through Document Control

Document control plays a key role in mitigating risks for the project in three broad areas—contract administration, quality management (compliance to specifications and standards), and reporting and compliance.

How does document control relate to contract administration? Parties contractually involved in the project need to be able to determine they have the most up-to-date and complete documents and need to be able to identify and reference any changes from original documents. When contractual parties act on outdated or incorrect information, it creates opportunity for claims and other legal action. Change requests and amendments to the various contracts can alter the completion date or the completed cost of the project. When documents experience changes, the impacts to scope, cost, schedule, and quality need to be clearly identified and promptly communicated. Many times, the changes generated by the document creator seem minor or of little impact to the project, but to the receiver, the changes may create major impacts. Following a proper document control process can aid in determining what has changed and how the change will impact the project outcome.

Quality management is affected by document control through updating, protecting, and retaining documents that have been deemed as critical to the project. Quality management on a project requires the project team to take samples, perform tests, and provide inspections. The results, properly documented, disseminated, and stored, provide proof of compliance with specifications, standards, and requirements. Failure to provide such documentation may result in fines, penalties, delays, loss of permits, or legal action.

How does document control facilitate reporting? Project status and progress reporting includes reports on daily, weekly, monthly, quarterly, and sometimes annual basis. Reports on scope changes, equipment and material deliveries, testing and inspection affect the work on a project. All of these reports start at the point of the work being performed. If these low-level reports are late, incomplete, or contain bad information, higher-level reports will contain the same information. This leads project participants to make poor decisions affecting the overall cost, schedule, and quality of the project.

Other Considerations for Project Document Control

1. Document workflow usually concerns the sequence of document review and approvals.
2. Drawing reviews are usually conducted at set points of drawing development and are conducted with all of the design disciplines attending so that design interfaces and interference of design components can be evaluated jointly.
3. Distribution lists are for issuing documents internally within the organization. Usually, the number of copies transmitted can be identified in the project communication plan, but each participant will need to determine if additional copies are required for internal distribution. For example, distributing an executed contract for structural analysis services within the design firm may require two printed copies. One is sent to the project manager and the other is sent to the design lead. An electronic copy is sent to document control for cataloguing and storage. Undisciplined and uncontrolled electronic distribution

has created issues with the control of project documents.

Common Challenges

Common challenges found on projects include document version control, document organization into a coherent filing system, and comprehensive capture for all the documents that are generated and shared.

Version control should start when documents are created. When documents are created, they should be assigned version numbers and dated. Some documents are created on multiple occasions such as daily inspection reports and need to be unique and distinguishable. Usually, forms or documents that are similar but contain unique data will be provided sequential numbers, so audits can be performed to account for all of the documents. Some documents will be updated throughout the project duration and require revision control with transmittals describing the changes to the document. This is critical to the recipients, so they are not overburdened rereading an entire document to find changes. Drawings typically have three phases: development of the drawings during design, using the drawings for bid tender or project pricing, and during construction. Design versioning is typically alphabetic using A, B, C, etc. to distinguish versions of each drawing. Bid tender or project pricing practices will vary between companies. Some firms will set the revision to zero (0) for bidding while others will use the last version designation from design. When the drawings reach the IFC phase, the drawing revision status is set to zero (0). This also indicates that the drawings cannot be changed without notification. The final revision phase is during construction. Changes are indicated using clouding to clearly show the contractor the change made to the drawing.

Organizing the filing system needs to begin during the project definition phase and be a specific part of the document management plan. Documents need to be organized to facilitate archival and retrieval. The file organization should include physical and electronic organization. Documents can be organized by document type, work breakdown structure, or some other logical structure. The key is to make them easily retrievable and searchable. Documents can also be organized in chronological order, which becomes more significant during construction.

Capturing all the documents being generated is often the most difficult task of document control. Because documents are created by multiple sources and can be transmitted or communicated without awareness by the project team, the project manager must emphasize discipline and adherence to the document control plan. Issues, ideas, and sketches generated during the design and construction of a project can be communicated physically, verbally, or via email and may not be properly recorded. A standard method for recording these documents needs to be established and enforced. Some projects will create a project email address and have all participants courtesy copy (cc) to the project email address. The document control specialist is responsible for this email address. Table 5-3 summarizes challenges and lists possible mitigation steps.

Challenge	Mitigation
1. Capturing all documents to ensure proper routing	Utilize project document control email address Reducing the inclusion of casual discussions
2. Casual, undocumented, and uncommunicated decisions	Prevent decisions from being made via email by using formal processes
3. Horizontal communication when vertical communication is required	Have and use a RACI chart
4. Loss of email service due to system crash, ransomware, or other cyber attack	Have a backup plan based on physical documents

TABLE 5-3 Document Control Challenges with Electronic Documents

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CHAPTER 6
Early Estimates

Importance of Early Estimates

This chapter presents methods and techniques used to develop an early cost estimate. Early cost estimates are important because at the end of the detailed scope phase, or funds authorization, the early cost estimate becomes the project budget. As presented in Chapter 1, the project budget is one of the principal components of a project. For engineering and construction projects, accurate early cost estimates are extremely important to the sponsoring organization and the project team. For the sponsoring organization, early cost estimates are often a basis for business unit decisions, including asset development strategies, screening of potential projects, and committing resources for further project development. Inaccurate early estimates can lead to lost opportunities, wasted development effort, and lower than expected returns on investment that can have long-term adverse financial impacts to the business.

An early estimate is also important to the project team because it sets the budget and becomes one of the key project parameters—one of the three vertices of the project triangle (refer to Figure 1-1). The estimate used for funds authorization at the end of phase 3, detailed scope, establishes the project budget. It helps formulate execution strategies and provides a basis to plan detailed engineering

and construction. The early estimate often serves as a baseline for identifying changes as the project progresses through development into design and on to construction. In addition, the performance of the project team and overall project success is often measured by how well the final cost compares to the early cost estimates.

The cost of construction work is a major portion of the total cost of any project. Much of the construction work on many projects is performed by subcontractors who are awarded a contract by the general contractor. This chapter also presents an overview of construction costs. A more detailed coverage of estimating construction costs is presented in *Estimating Construction Costs*, 6th ed., published by McGraw-Hill, Inc.

Achieving accurate early estimates is often seen as paramount to successful project management. Many books are published about the topic of cost estimating. Accurate early estimates are made more achievable when a long-term investment is made in mining, distilling, and evaluating past project data and information. Combining internal past project data with current market data into a common database provides useful information for the estimating team to prepare any estimate, not just early estimates. The database of combined past and current information provides easy access to cost information for the estimating team to prepare more accurate estimates for any type of project. No quick solution can really be effective. Developing dedicated estimating staff that develop estimates throughout the project lifecycle is another long-term but critical element. Successful estimating also depends on discipline to follow estimating processes including feedback at the end of the project to update cost data, identify errors, and areas for improvement. The most important factor for accurate early estimates is scope definition. An estimate is really only as good as the level of

detail of the scope. Without that, no early estimate will be meaningful.

Key Estimating Terms

Terminology is important when discussing estimating. Each owner company, design firm, and construction company generally have terms for estimating that are defined, understood, and consistently used by their organization. For this book, the definitions from the Association for Advancement of Cost Engineering (AACE) International will be used as follows:

- Accuracy measures the difference between an item's estimated value and the final actual value. It is typically stated as a +/− range for a given confidence interval. Accuracy fluctuates with the level of scope definition, identified risk items, and other factors present at the time the estimate is prepared.
- Allowances are additional resources included in estimates to cover the cost of known but undefined requirements for an individual activity, work item, cost account, or cost subaccount associated with the project scope. Allowances are most often used in detailed estimates and are assignable to a specific estimate category. Any surplus or shortage in the allowance amount should be adjusted to or from contingency.
- Assumptions are items that are incompletely defined in the project documents and require the estimator to use judgement in developing an estimated value for the item. Assumptions inform the project sponsor of the parameters used to develop a particular estimate. Assumptions are assumed to be true and valid and should use the most probable situation rather than a best-case or worst-case condition. For example,

construction work is assumed to occur during summer conditions. If project delays or constraints cause construction to occur in winter conditions, the estimate of costs would be higher due to productivity losses, special construction requirements, or overtime requirements.

- Base estimate is an estimate that excludes inflation or escalation, contingency, management reserve, and currency exchange. Base estimate may be called a deterministic estimate.
- Contingency is an amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, and/or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs. Contingency is for known unknowns and is necessary to meet the original project objectives.
- Cost of capital is usually used in capital budgeting to express as an interest rate percentage of the overall estimated cost of investment capital at a given point of time.
- Direct cost for construction is the cost of installed equipment, material, and labor directly involved in the physical construction of the permanent facility.
- Escalation is the provision in actual or estimated costs for an increase in the cost of equipment, material, labor, etc., over that specified in the purchase order or contract due to continuing price level changes over time.
- Estimate accuracy is a probabilistic evaluation of the variance of the estimate from the final actual cost of the project. The range of values is based on risk events and uncertainties associated with the project cost estimate. Estimate accuracy is usually stated as a +/− range (percentage or values) for a specific confidence

interval. For example, for a 90% confidence of underrunning the estimate, the estimate is $-15\% \leq X \leq +20\%$, where X is the estimate value.

- Management reserve is an amount added to an estimate to allow for discretionary management purposes outside of the defined scope of the project as otherwise estimated. Unlike contingency, the estimated reserve is not expected to be spent unless management so directs. A reserve is not necessarily included in all estimates. One use of management reserve can be to cover high-risk cost items that may impact the approved project budget. For example, management reserve can be allocated to cover named storms, managing public opposition, and labor strikes. Management reserve is established based on the owner's standards or choices.
- Project budget is the maximum amount of money the owner is willing to spend for design and construction to economically justify the project—the sanctioned amount. The budget establishes the basis for cost control for the project. The project budget consists of the base estimate plus contingency (as quantified during risk analysis). The project budget is distributed to each component of the Work Breakdown Structure (WBS) to establish the baseline for project monitoring and control.
- WBS contains the project scope with a hierarchical structure. It is an essential tool for project scope definition that decomposes the project into the smallest quantifiable components. These components contain the deliverables and associated activities that can be assigned to a single team member, with an estimated duration and cost. The WBS integrates the work with the project organization structure.

Development of Project Estimates

The preparation of estimates, assessing risk, and assigning contingency for budgeting is one of the most difficult tasks in project management because it must be done before the work is started. It is a process that involves a series of successive approximations beginning with the owner's feasibility study and continuing through design development and construction.

The preparation of cost estimates to establish project budgets is important to each party because the decision to proceed, at each phase in the project, is based on the estimated cost that was determined in the preceding phase. AACE International defines a budget estimate as an estimate generally prepared to form the basis for authorization or appropriation of funds. Refer to the section on the Classification of Early Estimates later in this chapter for more information. The owner's organization must determine a realistic maximum and minimum cost of the entire project, which includes the cost of design and construction. The designer's organization must determine the cost of performing design tasks and producing the contract documents. It must also determine the probable cost of construction as a part of the design process. The construction contractor's organization must determine the cost of all material, labor, and equipment to build the project on the job site. Figure 6-1 shows the relationships between each party's estimate.

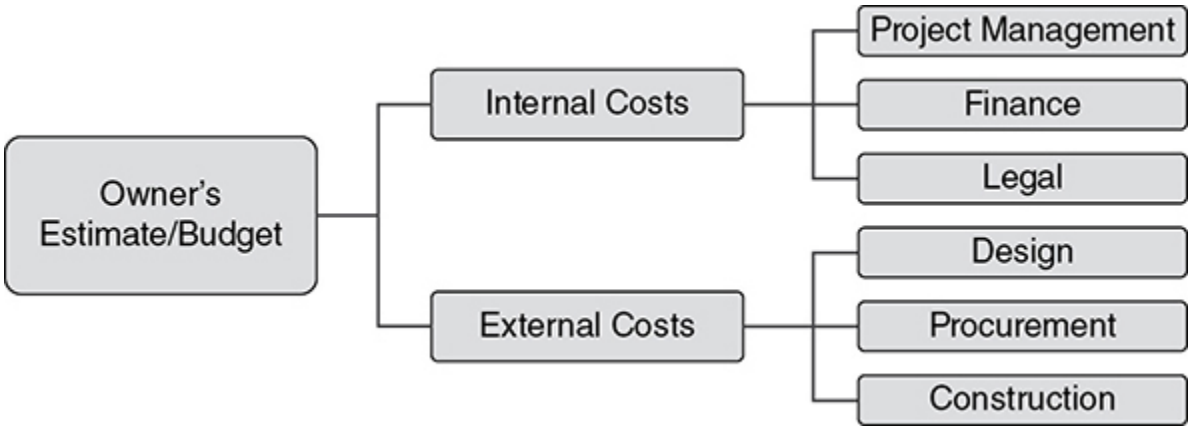


FIGURE 6-1 Hierarchy of estimates and budgets.

Each contractor on a project must develop a base estimate, consider risk, and assign contingency for the work they will be performing on a project. Since the owner's organization has overall project funding responsibility, the owner's management must consider both the contractor's and owner's risks in order to determine the overall budget for the project. However, the owner has made the decision to fund the project based on estimated costs not on firm bids from contracted parties.

Project estimating and budgeting begins with the owner during the study of needs, priorities, and scope. As discussed in Chapter 2, the project budget is derived from scope definition; therefore, a special effort should be made early in the development of a project to define the scope as detailed and accurately as possible. The control of project scope growth and cost overruns can be greatly enhanced if the owner obtains the early advice and expertise of experienced design and construction professionals, who have the knowledge of construction costs. All parties must realize that the estimated cost, at any time, is based on the amount of information that is known about the project when the estimate was prepared. Project estimates should be provided with an accuracy range based on the confidence interval for the estimate. The estimate is an approximation;

therefore, it cannot be an exact number and should not be stated as such. Too often this concept is not fully recognized. A project manager can play an important role as mediator in the early stages of the development of a project by testing, scrutinizing, and identifying the variances that should be applied to an estimate.

Methods are available to assess the completeness of project definition prior to funding authorization. This assessment provides a check on the amount and specificity of information documented for the project including the project objectives statement, project execution plan, detailed estimate, detailed schedule, risk management plan, and project staffing plan. By measuring the completeness of project development, the owner has a relatively objective gauge of the likelihood that the project is set up for success. One method is the Project Definition Rating Index (PDRI), which is discussed in Chapter 9, Design Proposals. PDRI is an objective measure of the completeness of project definition supported by research and empirical data. The Work Breakdown Structure (WBS) is another method to measure the completeness of project definition and more specifically the definition of scope. Chapter 3, Work Plan Development, discusses the purpose of a WBS and provides examples.

The owner's organization must prepare estimates to determine the overall project budget, which includes the approved cost for design and construction. If the scope is not well defined or the owner's organization does not have the expertise to perform such an estimate, the owner can enlist a designer to perform these services on a cost-reimbursable basis. Because the project sanction budget is prepared prior to any detailed design work, it should include a reasonable amount of contingency funds to allow some flexibility in decision making during design development.

The designer’s organization must prepare a budget based on the estimated costs to provide design services. In addition, as a part of the design process, the designer must prepare the estimated construction costs of the various design alternatives that are being evaluated to meet the owner’s needs for the project. This is necessary before completion of the contract documents. It is the designer’s responsibility to keep design costs and estimated construction costs within the owner’s overall approved project budget. This requires extensive cooperation and involvement with the owner because the scope must sometimes be readjusted to meet the owner’s approved budget, or the budget must be readjusted to meet the owner’s needs. This decision must be made by the owner’s organization.

The construction contractor’s organization must prepare a bid that is submitted to the owner, compared to the estimated costs, to build the project in accordance with the contract documents. For competitive-bid projects, the contractor is not obligated to a cost that is within the owner’s approved budget because this information is usually not known to the contractor. For negotiated cost-reimbursable projects, the contractor’s organization works closely with the owner to determine construction alternatives with costs that are within the owner’s overall approved budget.

Owner’s Estimate for Budgeting

Every project must be shown as economically feasible before it is approved by the owner’s management. Economic feasibility is determined by an economic analysis for projects in the private sector or by a benefit/cost ratio for projects in the public sector. An economic analysis can be performed once an owner’s estimate has been prepared.

Estimating costs during the inception of a project by the owner, prior to any design, is difficult because only limited detailed information is known about the project. However, this cost estimate is important because it is used to set the maximum project budget that will be approved for design and construction. At this stage of project development, the only known information is the number of units or size of the project, such as number of square feet of building area, number of cars in a parking garage, number of miles of 345-kilovolt (KV) transmission line, or number of barrels of crude oil processed per day. At some point in time an estimate has to be frozen and converted to a project budget.

Preparation of the owner's estimate requires knowledge and experience of the work required to complete the project. Cost information from professionals who are knowledgeable about design and construction is essential. Cost information for preparation of the owner's budget is usually derived from one or more of the following sources: cost records from previous projects of similar type and size, pricing manuals that are published annually by several organizations. Also, the owner can utilize scope documents that define component activities and deliverables, and obtain competitive costs for labor and materials for each component from the marketplace.

For buildings, public works, and heavy construction projects, the *Means Cost Guide* is commonly used. The Richardson's manual for construction estimating is a common reference for petrochemical and processing projects. These pricing manuals provide costs per unit for various types of projects, such as cost per square foot of building area for offices, warehouses, and maintenance buildings. The costs are derived from previous projects that have been completed at numerous geographic locations. Figure 6-2 illustrates examples of information that is available for several types of buildings. It shows the low,

average, and high cost per square foot, based on the level of quality. The budget for a proposed project can be calculated by multiplying the cost per square foot by the total square feet in the project. The cost of land, permits, and design fees should be added to the calculated cost of construction. A reasonable percentage multiplier should also be applied for contingency since the design is not prepared for the project during the owner's budgeting process. Adjustments for time and location should also be made as discussed in the following paragraphs. The effects of inflation on materials and workforce availability should also be addressed. Chapter 8, Risk Assessment and Analysis, provides more information.

	Office Buildings			Motels		
Component	Low $/SF	Median $/SF	High $/SF	Low $/SF	Median $/SF	High $/SF
Foundation	6.90	7.00	8.40	1.60	2.45	2.80
Floors on grade	5.45	5.50	6.80	6.90	8.75	9.45
Superstructure	26.00	29.60	35.45	19.15	23.30	38.00
Roofing	0.35	0.45	0.55	4.20	5.95	6.05
Exterior walls	8.60	17.05	22.75	4.90	7.80	9.70
Partitions	7.60	9.30	12.35	4.55	6.40	9.20
Wall finishes	4.10	6.55	8.75	1.30	4.55	4.80
Floor finishes	3.60	6.85	9.00	4.20	6.20	7.95
Ceiling finishes	2.70	4.90	6.55	3.60	8.05	8.60
Conveying systems	9.70	11.75	14.45	2.00	3.15	4.10
Specialties	1.15	1.40	4.65	1.95	2.35	7.00
Fixed equipment	1.85	4.90	6.55	2.00	2.90	3.40
Heat/vent/air cond.	15.50	16.65	21.35	5.45	9.70	10.95
Plumbing	6.15	6.65	8.50	7.80	9.45	10.75
Electrical	8.05	8.30	10.95	7.35	13.05	14.35
Total $/SF	107.70	136.85	177.05	76.95	114.05	147.10

Component	Secondary Schools			Hospitals		
	Low $/SF	Median $/SF	High $/SF	Low $/SF	Median $/SF	High $/SF
Foundation	2.35	3.25	4.75	7.60	8.40	11.65
Floors on grade	6.40	7.70	10.50	0.55	0.70	1.05
Superstructure	19.15	21.55	30.20	29.85	32.45	44.65
Roofing	3.00	3.60	4.30	5.70	6.50	9.10
Exterior walls	6.55	9.70	14.00	28.00	32.45	43.95
Partitions	10.35	11.45	14.90	12.60	19.25	43.25
Wall finishes	5.35	5.95	9.00	11.80	13.90	19.45
Floor finishes	5.45	6.90	9.20	4.55	4.80	7.00
Ceiling finishes	5.60	6.40	8.15	3.75	3.85	6.20
Conveying systems	0.00	0.00	0.00	22.65	22.75	34.20
Specialties	3.00	3.35	4.55	5.45	5.70	8.05
Fixed equipment	5.00	5.85	10.50	9.10	9.20	13.40
Heat/vent/air cond.	15.85	18.30	25.30	37.90	44.65	63.10
Plumbing	8.85	10.50	16.10	15.95	28.65	28.80
Electrical	17.95	21.00	28.90	23.55	30.65	42.70
Total $/SF	114.85	135.50	190.35	219.00	263.90	376.55

FIGURE 6-2 Illustrative examples of cost-per-square-foot information available from pricing manuals.

The costs in Figure 6-2 do not include site work or utilities outside of the building.

Importance of the Estimator

The skills, knowledge, and experience of the estimator are crucial for preparing accurate estimates for capital projects. Tools can aid the estimating process, but cannot replace the judgment and experience of a competent estimator. Skills can be learned in the classroom, but knowledge is gained by experience.

Most efforts to promote the practice of good estimating have focused on developing cost information, performing quantity takeoffs, adjusting costs for time/size/location, and creating estimating tools. Often, there is heavy emphasis on

automating the estimating process because of the many calculations that are involved in preparing estimates. Spreadsheets and commercial software can greatly assist in preparing estimates, but there are other factors that are equally important, including knowledge of materials, methods of construction, common sense, and good judgment. Automated estimating procedures cannot replace experience. A competent estimator has the skills to run spreadsheets and computer software, but also knows when to do periodic “do these numbers look right” checks of an estimate. There are times when the estimator uses his or her experience to see the big picture and realize what is important and apply judgment and do reality checks of numbers in the estimate.

Levels of Accuracy

A range of accuracy, usually a plus or minus percentage, should be assigned to any estimate by the estimator based on his or her best assessment of the project’s true cost. There is no industry standard that has been agreed on regarding the amount of plus or minus percentage that should be applied to an estimate. To discuss this issue, it is helpful to divide projects into two general categories: building projects and industrial projects.

Building projects generally have two types of estimates: approximate estimates (sometimes called preliminary, conceptual, or budget estimates) and detailed estimates (sometimes called final, definitive, or contractor’s estimates). For large owner organizations, the approximate estimate is prepared by the owner throughout the project definition phase studies of the project’s needs, priorities, and scope definition. For small owner organizations, it is usually prepared in cooperation with the design organization that is contracted by the owner to design the project and

prepare the contract documents. The level of accuracy of the approximate estimate can vary significantly, depending on the amount of information that is known about the project. With no design work, it may range from +50% to −30%. After preliminary design work, it may range from +40% to −20%. On completion of detailed design work, it may range from +15% to −10%.

Figure 6-3 illustrates how the accuracy of project estimates changes during the project lifecycle phases. The selected alternative should have a cost estimate that falls within the owner's range of economically feasible expenditure amounts. A quick reference for estimates can be found at 04.06.e.Est Ref Sheet.pdf.

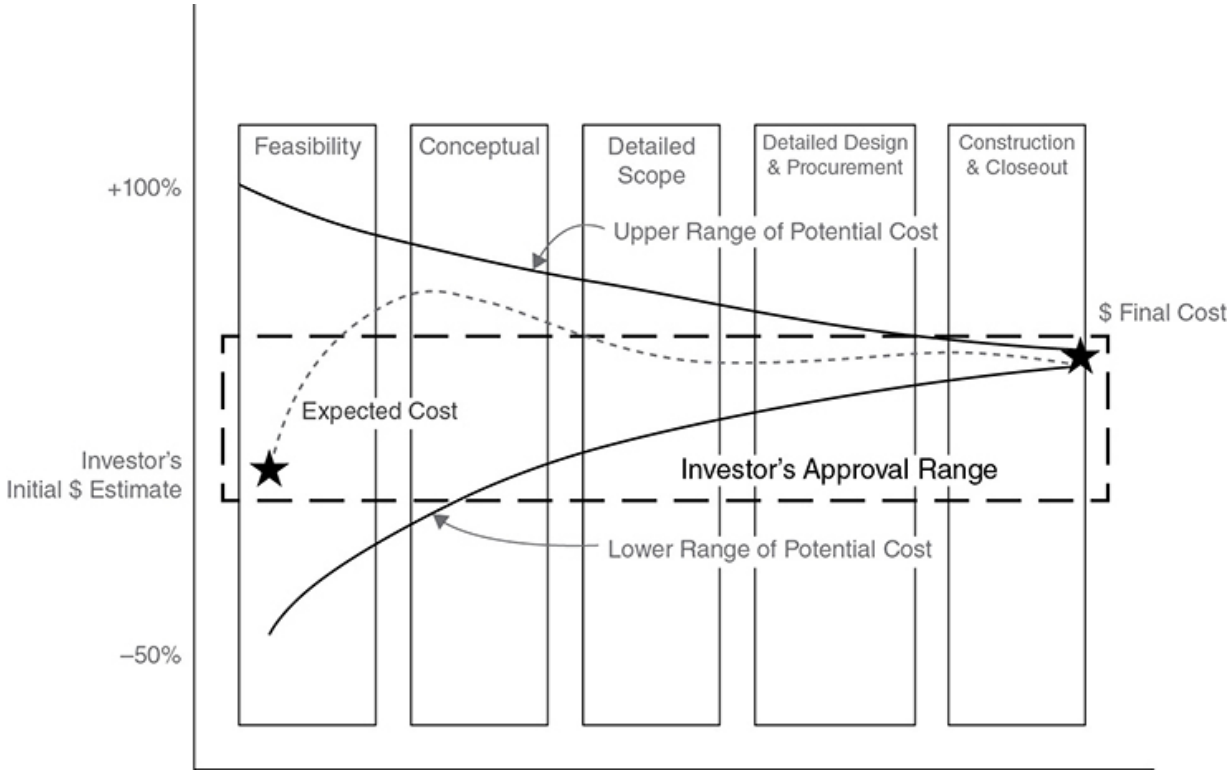


FIGURE 6-3 Changing cost estimate accuracy through project phases.

For building projects, the designer prepares an engineer's estimate, which is a detailed bottom-up estimate prepared

from a complete set of contract documents. It is used to compare the detailed estimate prepared by the construction contractor using the same information prior to submittal of the bid or formal proposal to the owner. The detailed estimate is important to both the owner and the contractor because it represents the bid price, the amount of money the owner must pay for completion of the project, and the amount of money the contractor will receive for building the project. For a building project that has a complete set of well-defined contract documents and no unusual features, the competitive bidding of numerous contractors will often result in less than a 1% variation in the lowest two bids.

For petrochemical and processing projects, estimating is difficult because of the wide range of variations in the number and sizes of piping, instrumentation, equipment, and other components that are required to process the product that the plant is built to produce. Because of the complexity of the project, estimating is done in stages as the design progresses and more information becomes known about the project.

Although there is no industry agreement, the petrochemical and processing industry generally develops project budget estimates in stages. For example, the feasibility estimate is the first estimate and is usually done within an owner's organization as a part of the feasibility plan. Estimates at this stage are commonly referred to as *order of magnitude* cost estimates. The estimate is prepared as a ratio of costs of previously completed similar projects, contractor quotes, or owner cost records, such as cost per horsepower, cost per barrel of throughput, or cost per pound of finished product. The level of accuracy can be approximately ±50%.

After the major equipment is identified and process flow sheets are developed, an *equipment factored* estimate can be prepared. This estimate is based on applying factors to

in-house priced major equipment in order to compensate for piping, instrumentation, electrical, and other construction costs that are required to complete the cost estimate. The level of accuracy at this stage can be approximately ±35%.

After completion of piping and instrumentation drawings, a preliminary *control estimate* can be developed. The documents and data for this estimate usually include equipment sizing and layout, process flow sheets, piping and instrumentation drawings, building sizes, and a milestone schedule. The level of accuracy is usually ±15%.

The final estimate is performed near the end of engineering design when most of the costs have been identified and is called the *definitive estimate*, commonly referred to as an Approved for Expenditure estimate or AFE Definitive estimate. It is based on process flow sheets, mechanical flow sheets, equipment layout, isometrics, and building plans. The level of accuracy of an AFE Definitive estimate is usually ±10%.

Classification of Early Estimates

There are many estimates and reestimates for a project, based on the stage of project development. Estimates are performed throughout the life of a project, beginning with the first estimate through the various phases of design and into construction as shown in Figure 6-4. Initial cost estimates form the basis to which all future estimates are compared. Future estimates are often expected to agree with (i.e., be equal to or less than) the initial estimates. However, too often the final project costs exceed the initial estimates. Often, the cost of a project increases because the project team has not clearly defined the scope of work completely and the result is a cost overrun. When the accuracy range and confidence level or probability of an estimated component could be a project cost driver, the

project manager should collaborate with the project sponsor for the need to spend more time and money to better define a cost component rather than add an arbitrary contingency amount or percentage to cover a perceived expected cost. The project sponsor should understand all risks defined by the project team and ensure an appropriate level of effort is taken to develop an accurate cost estimate.

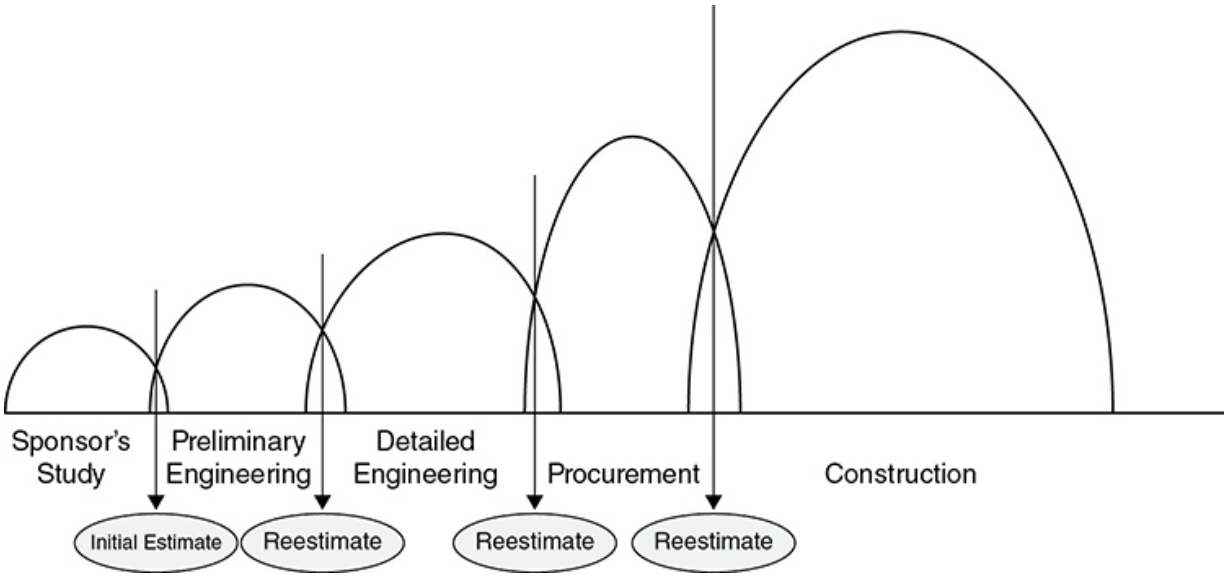


FIGURE 6-4 Estimates and reestimates through project lifecycle phases.

Various names have been given to estimates by several organizations. However, there is no industry standard that has been established for defining estimates. In general, an early estimate is defined as an estimate that has been prepared after the business unit study but prior to completion of detailed design.

Individual companies define estimate names and percent variations that they use. Various organizations have also defined classifications of cost estimates. Two examples are the cost estimate classifications by the Association for the Advancement of Cost Engineering International (AACE

International) shown in Figure 6-5 and by the Construction Industry Institute (CII) shown in Figure 6-6.

Estimate class	Level of project definition	End usage (Typical purpose of estimate)	Expected accuracy range
Class 5	0% to 2%	Screening or Feasibility	–20% to +200%
Class 4	1% to 5%	Concept Study or Feasibility	–15% to +120%
Class 3	10% to 40%	Budget, Authorization, or Control	–10% to +60%
Class 2	30% to 75%	Control or Bid/Tender	–5% to +30%
Class 1	65% to 100%	Check Estimate or Bid/Tender	–5% to +10%

FIGURE 6-5 AACE International Cost Estimation Classifications (17R-97).

Estimate class	Percent range	Description/methodology
Order of Magnitude	+/–30% to 50%	Feasibility study—cost/capacity curves
Factored Estimate	+/–25% to 30%	Major equipment—factors applied for costs
Control Estimate	+/–10% to 15%	Quantities from mech/elect/civil drawings
Detailed or Definitive	+/– <10%	Quantities from mech/elect/civil drawings

FIGURE 6-6 Construction Industry Institute cost estimate definitions (CII SD-6).

In general, an early estimate is defined as an estimate that has been prepared before completion of detailed scope. This definition applies to class 5, class 4, and early class 3 estimates of AACE International. This definition also applies to order-of-magnitude and factored estimates described in CII publications.

An estimate prepared during the detailed design phase serves as a validation to the budget estimate used to authorize the project funding. If this cost estimate is materially different than the budget estimate, the project key stakeholders would need to act quickly to recycle the project, possibly cancel the project, or advance the project with changes to the business objectives (e.g., revenue

projections) contained in the sanctioned project. If the cost estimate during detailed design differs in minor amounts, these cost changes can be shown as deviations from the control estimate established at the end of detailed scope.

It is important to understand that the level of *project definition* determines the estimate class. For example, if the desired accuracy for the estimate is Class 3, then the level of scope definition needs to be 10% to 40% defined.

Estimating Precision and Rounding

It is appropriate to briefly discuss estimating precision and rounding when preparing and presenting estimates. The primary rule is to reflect the reliability of the least precise value. For example, an estimator is preparing a Class 5 (conceptual) estimate for a new office building. The desired size of the building is 12,000 square feet (SF) and the company's estimating data yield $567/SF construction cost. Performing the multiplication yields $6,804,000. This estimate should be rounded down to $6,800,000 because the least accurate value used in the calculation is 12,000 SF which contains two significant figures.

Construction Cost Analysis and Estimating by Phillip F. Ostwald contains an excellent discussion on rounding values in estimating.

Estimating Work Process

Estimating is a process, just like any endeavor that requires an end product. Information must be assembled, evaluated, documented, and managed in an organized manner. For a process to work effectively, key information must be defined and accumulated at critical times. The primary factors in preparing estimates are shown in Table 6-1.

1. Standardization of the cost estimate preparation process
2. Alignment of objectives between the customer and team
3. Selection of estimate methodology commensurate with the desired level of accuracy
4. Collection of project data and confirmation of historical cost information
5. Organizing the estimate into the desired format
6. Documentation and communication of estimate basis, accuracy, etc.
7. Review and checking of estimate
8. Feedback from project implementation

TABLE 6-1 Primary Factors in Preparing Estimates

These concepts are illustrated in the estimating work process of Figure 6-7. The first step in the estimating work process is alignment. Alignment between the customer and the estimating team must be established before starting an estimate. As discussed on the following pages, alignment is accomplished by early communications to ensure a clear understanding of the customer's expectations and the estimating team's ability to meet those expectations. Close alignment helps mitigate estimate inaccuracies that can result from misunderstandings and miscommunications. It also enables establishment of the estimate work plan and staffing requirements. The estimate kick-off meeting provides an excellent forum for establishing alignment.

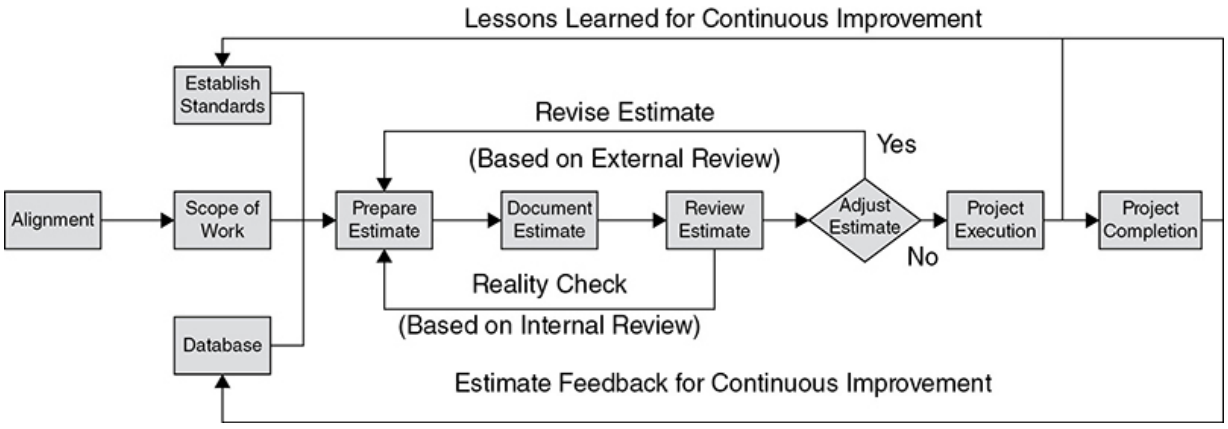


FIGURE 6-7 Estimating work process.

A successful process provides a clear understanding of the work to be performed and the products that will be produced. The level of scope definition for early estimates is low compared to later estimates. There must be a mutual understanding between the business unit and the estimator regarding the level of scope definition. The estimator must communicate to the business unit the expected range of accuracy based on the level of scope definition.

Prior to starting the estimate, a work plan for preparing the estimate should be developed. The work plan can be developed after alignment and scope definition. The estimate work plan identifies the work that is needed to prepare the estimate including who is going to do it, when it is to be done, and the budget for preparing the estimate. The plan also includes the tools and techniques that are appropriate for the level of scope definition and the expected accuracy of the estimate. The leader of the estimating team is responsible for developing the estimate work plan, which is discussed in the following pages.

While preparing an estimate, there must be two-way communications between the estimating team and the party that requested the estimate. The estimating team must keep the requesting party informed of the work being performed, and the requesting party must respond to questions that may arise from the estimating team. The estimating process can assist the requesting party in identifying areas of uncertainty and additional information that may be needed or assumptions that must be made in lieu of definitive information about the project.

After the estimate is completed, a document should be prepared that defines the basis of the estimate. Estimate documentation is essential for presentation, review, and future use of the estimate. The documentation for an estimate improves communications among project participants, establishes a mechanism for estimate reviews,

and forms a basis for early project cost control. The basis document typically describes how the estimate was developed and defines the information used in support of development. It commonly includes a description of the scope included, methodologies used, references and defining deliverables used, assumptions and exclusions, clarifications, adjustments, and some indication of the level of uncertainty. The estimating team should develop a standard cost estimate presentation format that is easily understood by internal business and engineering management.

Contingency is likely the most misunderstood and incorrectly used element in an estimate. Contingency is a real and necessary component of an estimate. Assessing risk and assigning contingency to the base estimate is one of the most important tasks in preparing early estimates. Typically, risk analysis is a prerequisite to assigning contingency. Based on the acceptable risks and the expected confidence level, a contingency is established for a given estimate. The lead estimator for a project must assess the uniqueness of each project and select the technique of risk analysis that is deemed most appropriate.

No estimating process is complete without the continuous feedback loops shown in Figure 6-7. To improve early estimates, the estimating process must be a continuous cycle. Actual cost information from completed projects must be captured in a feedback system that can be integrated into the cost database for use in preparing future estimates. Lessons learned during project execution must also be documented and incorporated into estimating standards and procedures. The lessons learned during construction must be communicated back to the estimating team, to enable them to establish better standards for preparing future project estimates.

Importance of Team Alignment in Preparing Early Estimates

Early communication between the team and the customer is essential to the success of any estimate, particularly *early estimates.* This early communication is necessary to ensure a clear understanding of the customer's expectations and the team's ability to meet those expectations. Table 6-2 is a list of benefits of team alignment.

1. Establishes a clear understanding between the customer and the team of the project's parameters
2. Assists in determining the level of effort required of the estimating team to deliver the estimate
3. Enables the estimating team to establish a work process and staffing plan to provide the deliverables required to meet the customer's expectations
4. Highlights issues that might not otherwise have been considered in the development of the estimate
5. Improves and documents the level of scope definition and the information that is known about the project
6. Assists the customer's understanding of what is included in the estimate and what is not included in the estimate
7. Establishes the responsibility of all project team members and the customer in the preparation of the estimate
8. Serves to establish a cohesiveness between the project team and the customer

TABLE 6-2 Benefits of Team Alignment

To achieve alignment, a special effort must be made to resolve all issues that can impact the team's work and the customer's understanding of the contents of the estimate. This can be accomplished by two-way, open communications before starting the estimating process.

The level of scope definition of the project is one of the key issues that must be resolved early, because the accuracy of the estimate is dependent on scope definition. The customer must provide the level of accuracy and detail that is expected in the estimate. The estimating team must

clearly communicate to the customer what will be provided in the estimate and if the requested level of accuracy can be met given the definition of project scope. The customer must also define the required deliverables of the team and the type of decisions that will be made based on the estimate. Critical questions that must be addressed early are shown in Table 6-3.

1. How thorough is the scope definition of the project?
2. What level of accuracy and detail is the customer expecting?
3. What deliverables are required from this effort?
4. What decisions will be made based on this estimate?

TABLE 6-3 Critical Questions for Preparing Early Estimates

The estimate kick-off meeting is an effective method of achieving alignment by addressing the issues shown in Table 6-4. The estimate kick-off meeting between the customer and the team provides an exchange of information regarding the customer's expectations and the team's ability to meet those expectations. Regularly scheduled progress meetings after the kick-off meeting ensure continued alignment throughout the estimating process.

1. What are the customer's driving principles and expectations?
2. What is the level of scope definition of the project?
3. What level of accuracy and detail is the customer expecting?
4. What deliverables are required from this effort?
5. What decisions will be made based on the estimate?
6. Does the project have unique or unusual characteristics?
7. What is the estimate due date and the anticipated project start/completion date?
8. What level of confidentiality is required by the team?
9. Who are the customer's contacts with the team?
10. What other organizations need to interface with the team?
11. Are there other information sources that can aid the estimating team?
12. What is the budget for developing the estimate and who is paying for it?
13. Have similar projects/estimates been developed previously?
14. What customer-furnished items are to be excluded from the estimate?
15. What customer-furnished costs are to be included in the estimate?
16. Are there specific guidelines to be used in preparing the estimate?
17. Are there special permitting requirements that may affect the cost and schedule?
18. Are there any special funding requirements that might influence the final total installed cost?
19. Are there other issues that could affect the cost or schedule of the project?
20. What level of effort is required to meet the desired accuracy?
21. What are the customer's driving principles and expectations?

TABLE 6-4 Checklist of Issues for the Estimate Kick-Off Meeting

Project management should initiate open communication between the customer and the team to assist in identifying and documenting the issues to be resolved. Early involvement of the customer reduces the potential of giving conflicting instructions and directions to the team. Alignment requires a cooperative effort between the team and the customer. Common pitfalls in alignment of early estimates are shown in Table 6-5.

1. Early estimates that are heavily influenced by a preconceived number developed by individuals outside the estimating team
2. Failure to include the business decision maker early in the estimating process
3. Failure to resolve issues early
4. Excessive constraints on the estimating team, such as inadequate time for preparing the estimate or lack of cost data
5. Failure to hold an estimate kick-off meeting
6. Failure to identify information required of the estimating team to prepare the estimate
7. Inadequate understanding of the expected accuracy based on the level of information, estimate methodology, or other factors that impact the estimate
8. Failure to identify costs and scope to be captured in the estimate
9. Failure to identify the scope that is not to be included in the estimate
10. Failure to communicate the estimating methodology to be used in preparing the estimate

TABLE 6-5 Common Pitfalls in Team Alignment for Preparing Early Estimates

Scope Definition and Early Estimates

Good scope definition is extremely important in preparing estimates. However, early estimates are usually prepared based on very limited scope definition and scant information regarding specific needs of the proposed project.

It is common knowledge that the accuracy of any estimate depends on the amount of information that is known about the project when the estimate is prepared. Any cost estimate usually is assigned a range of accuracy (+/− percentage). These ranges narrow as the quantity and quality of information increase through the life of a project. This infers that estimate accuracy is a function of available information (scope definition), a generally accepted fact in engineering and construction. During the past 30 years, numerous papers have been published, emphasizing the importance of scope definition. The lack of scope definition has been identified as the root cause of cost overruns, late completion dates, excessive rework, unnecessary disputes,

poor team alignment, and other problems associated with engineering and construction projects.

It should be recognized that determining the level of scope definition is a progressive activity. It starts at the inception of the project when the project is only an idea of the project sponsor for a product to be produced. As engineering progresses, the level of scope definition increases. Consequently, early estimates are often subject to high variability. Although good scope definition is important in preparing estimates, the skills and experience of the project team and the estimating procedure also play an important role. Figure 6-8 illustrates the importance of having the team involved early in a project's life, when the level of scope definition is low. The business unit must rely on the experience and skills of the team to produce accurate early estimates, because early in the project the level of scope definition is low, and it is often poorly defined. The estimator must address limited scope definition and clearly communicate to the customer the level of scope definition that was used in preparing the estimate. Regardless of the skill, knowledge, or expertise of the estimator, the estimator or estimating team cannot compensate for a lack of scope definition.

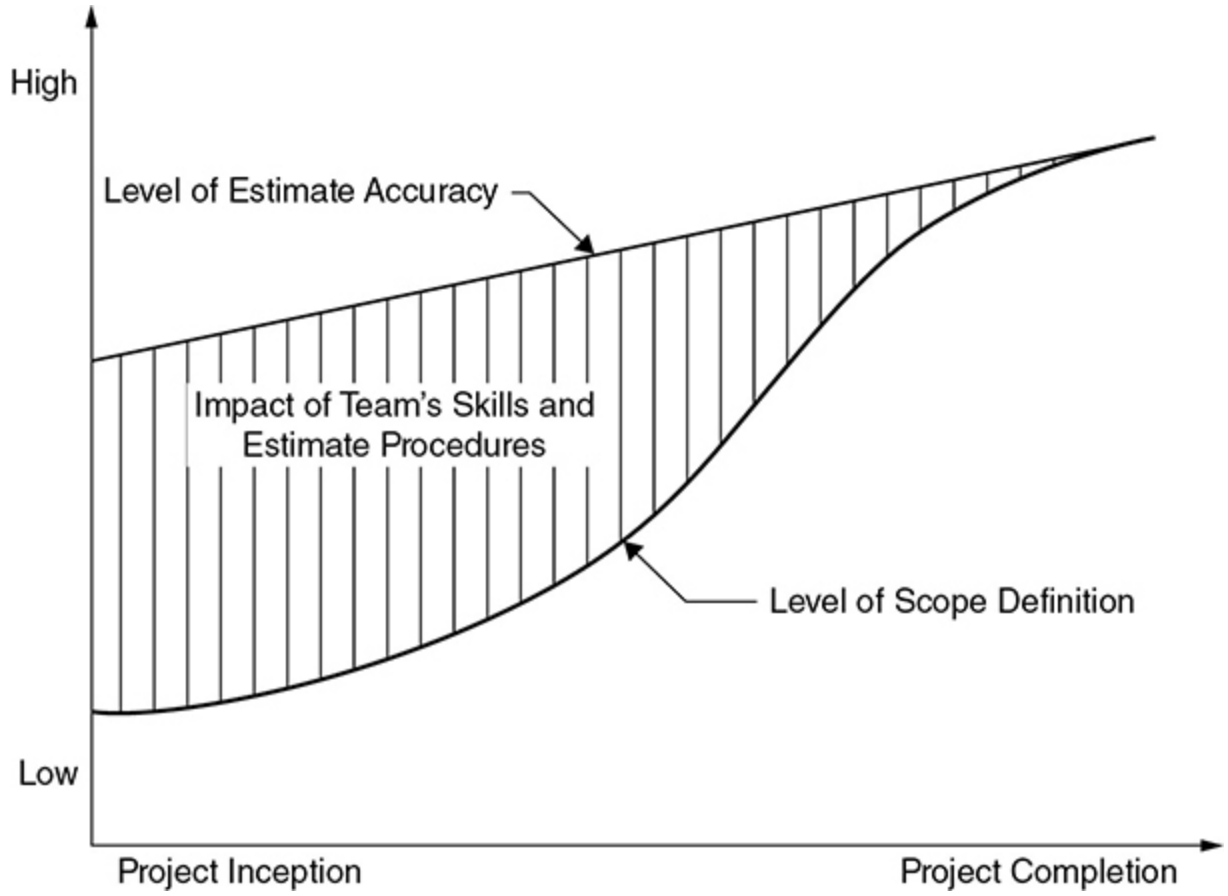


FIGURE 6-8 Relative impact of team's skills and estimating procedures on estimate accuracy.

Preparing Early Estimates

Issues that should be discussed, defined, and documented when preparing estimates are shown in Table 6-6. As the estimate is being prepared, it is important to perform periodic "reality checks" to make sure the costs developed are within reason. Based on estimator experience and familiarity with the project, this may include the following:

1. Work plan for preparing the estimate
2. Costs/scope to be included, or excluded, in this estimate
3. Estimating methodology, tools, and techniques
4. Expected accuracy of the estimate
5. Impact of time allowed for preparing the estimate
6. Information needed by the estimating team to prepare the estimate
7. Roles and responsibilities for preparing the estimate
8. Format for presenting the estimate to the customer
9. Schedule for preparing the estimate that includes
   a. Kick-off meeting, estimate reviews and approvals
   b. Milestones for delivery of information and deliverables

TABLE 6-6 Issues for Preparing Early Estimates

- Simple “intuitive” checks for reasonableness
- Comparisons with similar projects
- Comparisons with industry data ($/square foot, cost/megawatt, indirect/direct costs, etc.)
- Check ratios such as lighting costs/fixture, fire protection, costs/sprinkler, etc.

Once the estimate is complete, a detailed review should be made of the entire estimate package, including the backup materials, assumptions, unit prices, and productivity rates. The estimate should also be checked against the project schedule requirements to ensure they are compatible, such as construction assumptions, overtime rates assumed during outages, and price escalation.

Organizing to Prepare Estimates

The lead project estimator is responsible for initiating and leading the effort to develop a plan for preparing the estimate. In almost all situations, higher-quality estimates can be produced by professional cost estimators with an engineering or technical background. Like any technical

specialty, estimating requires specific skills, training, and experience. Involvement of the estimating team early in the project is essential in the business development process.

Cost estimates for projects in the engineering and construction industry are prepared by individuals with many different job titles, responsibilities, and functions. Depending on the size and needs of each company, those preparing cost estimates may be working alone or as part of a group. They may be centralized in one location or in multiple locations. In some situations they may be integrated with different organizations, or they may work in one homogeneous group.

There are advantages and disadvantages to centralizing or decentralizing the estimating staff. *Where* an estimate is prepared is not as important as *who* is preparing the estimate and the *process* used in preparing the estimate. It is important to implement and maintain effective control over the estimating process. Procedures must be in place for the following reasons:

- Disseminating knowledge and sharing expertise among the estimating staff
- Assigning and sharing the workload among estimators to improve efficiency
- Reviewing, checking, and approving work for quality control

Timely exchange of information is critical to ensure current price data, databases, and feedback. Preparing estimates requires expertise from multiple disciplines. An effective organization includes members of key disciplines, estimators, and management personnel who are knowledgeable in estimating. An effective team must be organized to prepare, review, check, and approve the work.

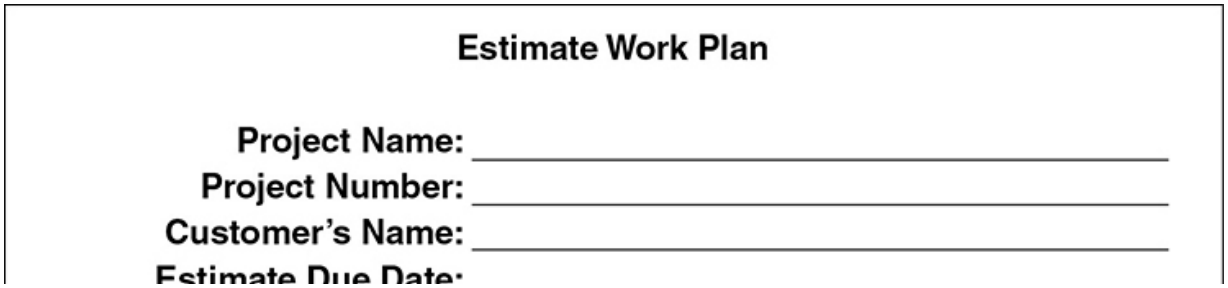
This same team must also capture lessons learned to improve the estimating process and efficiency.

Establishing an Estimate Work Plan

An estimate work plan should be scaled based on the size or extent of the project. For some projects, a single individual, utilizing standard forms and following a standard process, can provide a concise estimate plan. The point is that the plan should be documented and followed.

For larger projects, effective management of the estimating effort requires planning, scheduling, and control. The leader of the estimating team is responsible for developing an estimate work plan for the project. The estimate work plan is a document to guide the team in preparing accurate estimates and improving the estimating process. It identifies the work that needs to be accomplished to prepare the estimate: who is going to do it, when it is to be done, and the budget for preparing the estimate.

The estimate work plan is unique for each project, based on specific project parameters and requirements. Figure 6-9 illustrates the type of information that should be included in an estimate work plan. The work plan should contain sufficient detail to allow all members of the estimating team to understand what is expected of them. After the work plan is finalized, it serves as a document to coordinate the estimating work and as a basis to control and maintain the estimating process.


Estimate Work Plan

Project Name: _____

Project Number: _____

Customer's Name: _____

Estimate Due Date:

Estimate Due Date: _____

Type of Estimate Required
- Desired Level of Accuracy
- Level of Effort Required
- Deliverables of Estimate

Estimating Services to Be Provided
- Deliverables of Estimate by Internal Resources
- Deliverables of Estimate by External Resources

Budget for Preparing Estimate
- Anticipated Work-Hours for Estimating Staff
- Dollars Budget for Non-Salary Estimating Staff

Required Staffing for Preparing Estimate
- Principal Estimator (leader of estimating team)
- Internal and External Resources
- Availability of Personnel for Staffing

Schedule for Preparing Estimate
- Anticipated Start Date
- Requirements of Review Date
- Customer Due Date

Estimating Methodology
- Tools
- Techniques
- Method
- Procedures

Estimate Control
- Level of Scope Definition
- Checklists
- Review Process

Presentation
- Format for Presenting Estimate
- Audience for Presentation

FIGURE 6-9 Typical information to be addressed in the estimate work plan.

In preparing early estimates, the skill level of the estimator and his or her experience with the type of facility

to be estimated is extremely important. The quality of any estimate is governed by the following major considerations:

- Quality and amount of information available for preparing the estimate
- Time allocated to prepare the estimate
- Proficiency of the estimator and the estimating team
- Tools and techniques used in preparing the estimate

Typically, the technical definition and the completion date for an estimate are determined by others outside of the estimating team. Therefore, these two elements may be beyond the control of the estimator. However, the estimator does have control over the selection of the tools and methodology to be used in preparing the estimate. The approach to selecting the method of estimating should be commensurate with the owner's expected level of accuracy and constraints of time.

The estimating team should develop a standard cost estimate presentation format that includes the level of detail and summary of engineering design, engineered equipment, bulk materials, construction directs and indirects, owner's costs, escalation, taxes, cost of capital, and contingency. Computer methods, including spreadsheets or estimating programs, provide consistent formats for preparing and presenting estimates. Uniform formats provide the following benefits:

- Reduces errors in preparing estimates
- Allows for increasingly detailed information in the estimate
- Enhances the ability to compare estimates of similar projects

- Promotes a better understanding of the contents of an estimate
- Provides an organized system for collecting future cost data

Presentation of the estimate is important. The estimating team must develop a format that is easily understood by business managers and engineering managers, as well as by external clients. Using a standard format for presentations promotes better communication among all participants in the project and a better understanding of what is included in the estimate. This understanding is necessary, so good decisions can be made based on the estimate.

Methods and Techniques

Selection of the methods for preparing early estimates depends on the level of scope definition, time allowed to prepare the estimate, desired level of accuracy, and the intended use of the estimate. For projects in the process industry, the following methods are commonly used:

- Cost-capacity curves
- Capacity ratios raised to an exponent
- Plant cost per unit of production
- Equipment factored estimates
- Weighted unit cost estimates
- Adjustments for size, time, and location
- Parametric estimates
- Computer-generated estimates

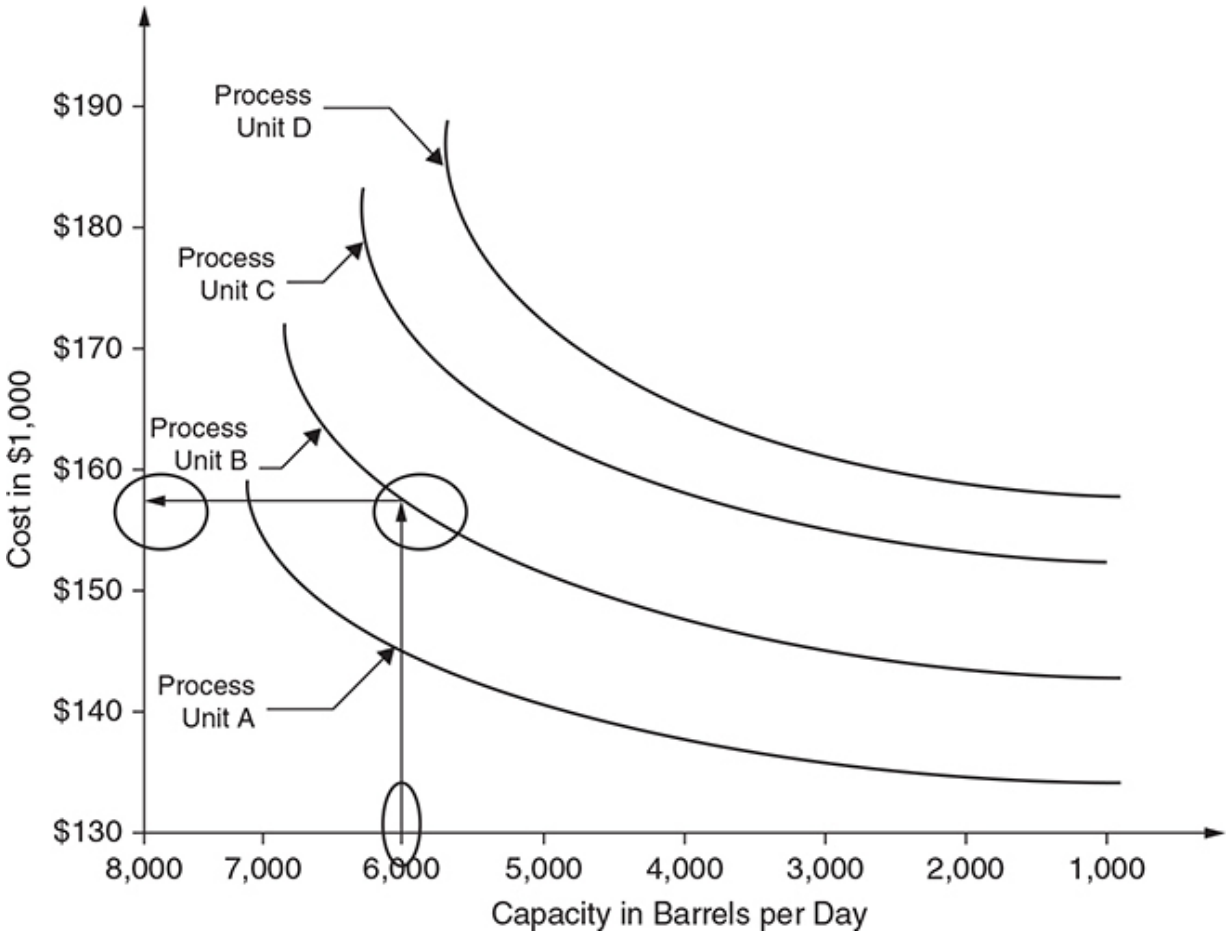
Cost-Capacity Curves

A cost-capacity curve is simply a graph that plots cost on the vertical axis and capacity on the horizontal axis. These curves are developed for a variety of individual process units, systems, and services. The minimum information needed to prepare an estimate by cost-capacity curves is the type of unit and capacity. For example, the type of unit may be a coker unit or hydrogen unit and the capacity may be barrels per day or cubic feet per hour. Examples of additional information that can enhance the quality of the estimate may include adjustments for design pressure, project location, and project schedule.

Cost-capacity curves are normally prepared by a conceptual estimating specialist who develops, maintains, and updates the cost-capacity curves on a regular basis. These curves are developed and updated utilizing return cost data from completed jobs. This information is normalized to a location, such as the U.S. Gulf Coast, and for a particular time frame expressed as a baseline, such as December of a particular year.

The estimated cost is determined by locating the capacity on the horizontal x-axis and then following a straight line up to the point of intersection with the curve. The estimated cost is then read from the vertical y-axis by a straight line from the y-axis to the point where the x-axis intersects with the curve. The total installed cost derived from the curve may be adjusted for escalation to the present day or to some point in the future and may be further adjusted to reflect other geographic locations.

Example 6-1 The figure shows cost-capacity curves for process units in a chemical plant. What is the estimated cost for a project that has a process unit B with a capacity of 6,000 barrels per day?



Locating the 6,000 barrels per day capacity along the abscissa, draw a vertical line upward until it intersects the process unit B cost curve. Then, draw a horizontal line to the left to read the estimated cost as $158,000.

Capacity Ratios Raised to an Exponent

Capacity ratios raised to an exponent is another estimating technique for conceptual estimating. This approach considers the effect of economy of scale on the total installed cost. For example, if the cost of process unit B with capacity B is known, then the estimated cost of process unit A is calculated by multiplying the cost of process unit B times the ratio of the process unit capacities raised to an exponent (X) as shown in the following equation:

$$\text{Cost of process unit A} = (\text{Cost of process unit B}) \times \left(\frac{\text{Capacity of process unit A}}{\text{Capacity of process unit B}}\right)^{x}$$

Essentially, this method is a mathematical solution to the cost-capacity curves presented earlier in this section, which was a graphical technique. The exponent represented by *X* is mathematically derived from historical records from completed projects. It represents the nonlinear relationship between cost with size, based on economies of scale.

Historical data can be captured from completed projects and a least-squares fit of the data or other methods of curve fitting can be used to determine an appropriate value of *X* for similar types of projects. Thus, the exponent distinguishes the curve of one process unit from another. Typically, the range of the exponent *X* is between 0.55 and 0.88, depending on the type of process unit. When utilizing this equation to develop a cost estimate, if the exponent for the particular process unit is unknown, an exponent of 0.6 is used, which represents a standard or typical exponent for process plants.

Example 6-2 The cost of a 375 cubic feet per hour (ft^3/h) process unit is $5,920,000. From historical cost records, the capacity ratio exponent of a process unit is 0.69. Estimate the cost of a similar process unit with a capacity of 450 ft^3/h.

$$\text{Cost of process unit A} = (\text{Cost of process unit B}) \times \left(\frac{\text{Capacity of process unit A}}{\text{Capacity of process unit B}}\right)^{x}$$

$$= \$5,920,000 \times \left(\frac{450\frac{ft^3}{h}}{375\frac{ft^3}{h}}\right)^{0.69}$$

$$= \$5,920,000 \times 1.13405746$$

$$= \$6,710,000$$

Plant Cost per Unit of Production

This conceptual estimating technique is used to estimate the total plant cost based on the average plant costs per unit of production on previously completed projects. This is a very simple and broad estimating approach where the only information available is the product description and the plant capacity. For example, cost records may show the average cost per unit for cogeneration facilities to be $1,000 per kilowatt ($1,000/KW) of production. Thus, for a future 300-megawatt (MW) cogeneration facility, the estimated cost would be calculated by multiplying the $1,000/KW times the 300 MW of power to derive a total estimated cost of $300,000,000.

This estimating technique assumes that the relationship between plant cost and production capacity is linear and, therefore, would apply best within a fairly narrow range. Ideally, average plant costs per unit of production capacity are best developed over various capacity ranges, so that the estimator can select the relationship that is applicable for his or her estimate.

This method of preparing early estimates is similar to the square-foot estimating method used for projects in the building sector. The total estimated cost of a particular building project is determined by multiplying the average cost per square foot of previous projects by the total square feet in the proposed building.

Equipment Factored Estimates

For the process industry, equipment factored estimates are derived by applying various factoring techniques to estimated equipment costs. The factors used are developed and updated utilizing return cost data from completed projects. This information is normalized to a location, usually the U.S. Gulf Coast, and for a particular time frame, such as December of a particular year. The estimated total installed

cost of a normalized unit is defined to include the following costs:

- Direct equipment costs
- Direct bulk material costs
- Subcontract costs
- Construction labor costs
- Construction indirect costs
- Home office services costs

One example of the factoring technique is the “equipment cost” to “total installed cost” factor (TIC). This factoring technique is relatively simple for projects where equipment costs have been estimated. As the name implies, TIC factors are developed by dividing the equipment costs of a particular process unit into the total installed cost of that unit. The estimated cost of the project is determined by multiplying the equipment costs by the TIC factor, or multiplier. The factors for process plants generally range between 2.5 and 6.0, depending on the nature of the process unit. Conditions that affect the equipment to TIC factors are as follows:

- Equipment sizes
- Pressure
- Metallurgy
- Degree of prefabrication
- Site conditions
- Equipment costs
- Special conditions (large structures, pits, buildings, etc.)
- Explanation of engineering costs included

Another equipment factored estimating technique develops equipment costs manually or by utilizing commercially available computer software systems. Bulk material costs are factored from the estimated equipment costs, using historical cost data for the same or similar type units. Field labor work-hours are estimated for each individual equipment item, and the work-hours for installing bulk materials are estimated as a percentage of the bulk material costs for each category of materials. The resultant field labor work-hours are adjusted for productivity and labor costs by applying local labor rates to the estimated construction work-hours. Construction indirect costs are developed for the major categories by percentages of direct labor costs. Home office costs are estimated as a percentage of the total installed cost. The equipment factored estimating techniques described can be utilized when there are sufficient technical definitions available consisting of the following:

- Process flow diagram
- Equipment list
- Equipment specifications
- Project location
- General site conditions (assumed if not specified)
- Construction labor information
- Project schedule

Weighted Unit Cost Estimating

The other source of cost information is company records from previous projects. Although the total cost of previously completed projects will vary between projects, unit costs can be calculated to forecast the cost of future projects. The term *weighting* is commonly used to refer to the procedure of analyzing historical cost data to determine a unit cost for

forecasting future project costs. A unit cost should be developed that emphasizes the average value, yet accounts for extreme maximum and minimum values. Equation 6-1 can be used for weighting cost data from previous projects:

$$UC = \frac{A + 4B + C}{6} \tag{6-1}$$

where UC = forecast unit cost
A = minimum unit cost of previous projects
B = average unit cost of previous projects
C = maximum unit cost of previous projects

Example 6-3 illustrates the weighting procedure. The procedure can be applied to other types of projects and their parameters. Examples are apartment units, motel rooms, miles of electric transmission line, barrels of crude oil processed per day, and square yards of pavement.

Example 6-3 Cost information from eight previously completed parking garage projects is given in the following table. Calculations are rounded to the nearest $10.

Project	Total cost	No. parking slots	Unit cost	
1	$1,698,000	145	$11,710	← lowest value
2	1,100,000	60	18,330	
3	2,547,000	110	23,150	← highest value
4	1,390,000	70	19,860	
5	750,000	50	15,000	
6	3,850,000	200	19,250	
7	896,000	75	11,950	
8	2,025,000	130	15,580	
		Total =	$134,830	
		Average cost per parking slot =	$16,850	← average value

From Eq. 6.1, the forecast unit cost can be calculated as

$$UC = \frac{\$11,710+4(\$16,850)+\$23,150}{6}$$

$$UC = \$17,040$$

For a project with 175 parking slots, the estimated cost can be calculated as

175 cars @ $17,040 = $2,982,000

Adjustments for Time, Size, and Location

It is necessary to adjust the cost information from previously completed projects for differences in size, time, and location. The previous example illustrates adjustment relative to size. Time adjustments represent variation in costs due to inflation, deflation, interest rates, etc. Location adjustments represent variation in costs between locations due to geographical differences in costs of materials, equipment, and labor.

An index can be used to adjust previous cost information for use in preparation of the owner's estimate. Various organizations publish indices that show economic trends. The *Engineering News-Record* (ENR) annually publishes indices of construction costs for both time and location. Example 6-4 illustrates the combination of adjustments of cost estimates for size, time, and location. *Estimating Construction Costs,* 6th ed., published by McGraw-Hill, Inc., presents a comprehensive discussion of estimating project costs.

Example 6-4 Use the time and location indices below to calculate the forecast cost for a building with 78,400 square feet of floor area. The building is to be constructed 3 years from now in city C. A similar type building that cost $3,828,800 and contained 40,400 square feet was completed 4 years ago in city D.

Year	Index
4 years ago	4,374
3 years ago	5,028
2 years ago	5,199
1 year ago	5,461
Current year	5,761

Location	Index
City A	1,646
City B	1,805
City C	1,911
City D	2,091
City E	1,876

There is no method to predict future cost escalation with absolute certainty. For this example, a compound interest is calculated based on the trend in cost indices of the past 4 years. Using the compound interest equation $F/P = (1 + i)^n$, an interest rate can be calculated as follows:

$$\frac{5761}{4374} = (1+i)^4 \rightarrow i = 7.1\%$$

The combined adjustments of costs for time, location, and size can be calculated as follows:

Estimated cost		Previous cost		Time adjustment		Location adjustment		Size adjustment
"	=	$3,828,800	×	$(1.071)^7$	×	(1911/2091)	×	(78,400/40,400)
"	=	$3,838,800	×	1.6163	×	0.9139	×	1.9406
$11,004,000								

Parametric Estimating

Parametric estimating is commonly used to prepare conceptual cost estimates of building construction projects in the early stages of project development, after preliminary design is completed. Parametric estimating relates the total cost of a project to a few physical measurements, or "parameters." For example, the gross square floor area of a building is a typical overall parameter for a building project. Sometimes parametric estimating is referred to as *square foot* estimating, or simply *unit cost* estimating.

Unit costs for parametric estimating may be derived from internal company records of past similar projects, or from national pricing manuals that are available from several sources, such as ENR and *R. S. Means*. The cost data used in parametric estimating should be current with respect to time and the cost data should be from projects that are similar in type and size as the project that is being estimated. It may be necessary to adjust the unit costs based on time and size as presented in other sections of this chapter.

Figure 6-10 illustrates data for parametric estimating of a building, based on an office building with 10,000 square feet (SF) of floor space, two stories, and 8-ft walls. Some of the parameter *unit costs* are expressed in the gross enclosed square feet of floor area (such as electrical work), while some unit costs are expressed in square foot of the building components (such as square feet of roof), and some unit costs are expressed in the unit of measure of an individual component (such as linear feet of partition wall).

Office building, 10,000 sf, 2-story, 8-ft walls					
System/Component	**Specification**	**Unit**	**Unit cost**	**Cost per SF**	**% of Total**
Foundation					
Piers and footings	Poured concrete footings	SF ground	4.36	2.18	7.5
Slab on grade	Concrete, grading, and fill	SF slab	6.95	3.48	
Excavation	Excavation and backfill	SF ground	2.75	1.38	
Exterior Closure					
Exterior walls	Concrete block with stucco	SF wall	12.27	8.59	25.7
Elevated floors	Concrete, precast double tees	SF floor	9.96	4.98	
Roof	Concrete, precast double tees	SF roof	14.55	7.28	
Exterior doors	Wood/glass (1,250 SF ground/door)	each	2,145.00	0.86	
Exterior windows	Aluminum/glass (300 SF flr/window)	each	724.00	2.41	
Interior work					
Partition walls	Studs/gyp board (6 SF flr/LF partition)	LF wall	11.25	1.88	16.4
Interior doors	Hollow core (75 SF floor/door)	each	260.00	3.46	
Wall finishes	Paint, 2 coats	SF wall	1.25	3.33	
Floor finishes	Carpet	SF floor	37.98	4.11	
Ceiling finishes	Suspended acoustic ceiling	SF ceiling	2.58	2.58	
Mechanical					
Plumbing	Fixtures/feeds (160 SF flr/fixture)	each	1,450.00	9.06	26.8
Heating/cooling	HVAC system	SF floor	14.15	14.15	
Fire protection	Sprinkler system	SF floor	1.98	1.98	
Electrical					
Service/distribution	400 amp, panel board, leads	SF floor	5.47	5.47	23.6
Lighting & wiring	Fixtures, feeds, switches, wiring	SF floor	15.82	15.82	
Special electrical	Alarm system	SF floor	0.83	0.83	
			Subtotal of system/components:	$93.83/SF	100.0
			Add 20% for contingency:	$18.77/SF	
			Total building cost:	$112.60/SF	

FIGURE 6-10 Unit costs for parametric estimate of a building.

In parametric estimating the unit costs of all components are converted to equivalent costs per square feet of the building. For example, Figure 6-10 shows the unit cost of partition walls as $11.25 per linear feet (LF) of wall based on 1 linear foot of partition wall for each 6 square feet of floor

area in the building. The unit cost of this component of partition walls is converted to square feet of building as: [(10,000 SF)/(6 SF/LF)] × [($11.25/LF)/(10,000 SF)] = $1.88/SF. Thus, the $11.25/LF of partition wall is equivalent to $1.88/SF of floor area of the building.

Another example is interior doors, which are measured as "each" with a unit cost of $260/door. Figure 6-10 shows 75 square feet of floor for one door. The unit cost of interior doors at $260 each is converted to cost per square feet of building as: [(10,000 SF)/(75 SF/door)] × [($260/door)/(10,000 SF)] = $3.46/SF. An alternate calculation is [($260/door)/(75 SF/door)] = $3.46/SF. Thus, the unit cost of $260/door is equivalent to $3.46/SF of floor area of the building.

The interior wall finishes are based on painting 2 sides of the linear feet of 8-ft high interior partition walls. The unit cost for this building component is calculated as: [(1 LF of wall)/(6 SF of building)] × [(8 ft × 2 sides) × ($1.25/SF)] = $3.33/SF. Thus, the $1.25/SF of wall painting is equivalent to $3.33/SF of floor area of the building.

The parametric estimate is prepared by multiplying the square feet of the proposed building by the cost per square feet of each component. The sum of all components is the estimated cost. This method of estimating is commonly used by the owners for budgeting during the economic feasibility phase of a project and by architects and engineers during the design phase to evaluate the cost of design alternatives.

With good historical cost records on comparable structures, the parametric estimating method can give reasonable accuracy for conceptual cost estimates. With this method, an experienced estimator with access to well-documented records can quickly prepare an estimate and budget that will help in making decisions during the early phases of a project.

Computer-Generated Estimates

There are numerous commercially available computer software systems for estimating capital costs for a number of different types of industries, including the process industry, building construction industry, and the heavy/highway infrastructure industries. These systems can be simple or very sophisticated. Most of the software packages are furnished with a cost database, which is updated on an annual basis. The more flexible systems allow the purchaser to customize the database.

Sophisticated software packages are available to assist the estimator in generating detailed material quantities as well as equipment and material costs, construction work-hours and costs, field indirects, and engineering work-hours and costs. The detailed quantity and cost output allows early project control, which is essential in the preliminary phases of a project, before any detailed engineering has started. The accuracy of an estimate can be improved because some systems allow vendor costs, takeoff quantities, project specifications, site conditions, etc., to be introduced into the program. To maximize the benefits of these software programs, the use of system defaults should be minimized and replaced with the following definitions:

- Specifications, standards, basic practices, and procurement philosophy
- Engineering policies
- Preliminary plot plans (if available) and information relating to pipe-racks, structures, buildings, automation and control philosophy, etc.
- Adequate scope definition
- Site and soil conditions
- Local labor conditions relating to cost, productivity, and indirect costs

- Subcontractor philosophy

To become proficient in the use of computer software programs, frequent usage is required, and the user should compare the computer-generated results with other estimating techniques to determine the limitations and shortcomings of the programs. Once the shortcomings are known, corrective action to eliminate or minimize the shortcomings can be taken. To maximize the benefits of the use of software systems in developing early estimates, the following should be considered:

- Index or benchmark the unit costs and installation work-hours in the computer software's databases to match the company's cost databases.
- Establish system defaults that correspond to the company's engineering and design standards.
- Create a program that allows conversion of the output of the software programs to the company's account codes and format.

By adopting the above recommendations, confidence in the output of estimating software systems will improve. This will result in more consistency and reliability of computer-generated estimates.

There are other noncommercial computer software systems that are used in preparing early estimates, in particular, spreadsheet programs. Some of these systems, although not commercially available, have been developed by owner/operator companies and contractors.

Estimate Checklists

Checklists are valuable tools to reduce the potential of overlooking a cost item. Checklists act as reminders to the

estimator by

- Listing information required to prepare the early estimate
- Listing miscellaneous other costs that may be required in the estimate
- Listing the project scope that may be required but not identified in the definition provided for the estimate

A listing of information required to prepare an estimate in the process industry may include type of unit, feed capacity, and project location. For a computer-generated estimate, the required information includes soil and site data, building requirements, plot plan dimensions, and other specific engineering requirements. For projects in the building sector, a listing of information to prepare an estimate may include type of building, functional use of building, number of occupants, and project location.

Typical examples of miscellaneous cost items for projects in the process industry may include spare parts, catalyst and chemicals, permits, and training. Typical scope items that may be required, but not identified in the definition provided for the estimate, may include certain utility and auxiliary systems. Examples are special steam systems, refrigeration, lube and seal oil systems, and flare systems.

Checklists are useful during initial client/customer meetings where they serve as agenda items for discussion. Checklists also assist the estimator in preparing an *estimate work plan* by identifying important points to emphasize in the write-up for the execution of the estimate. Table 6-7 is an illustrative example of an early estimate checklist for a project in the process industry.

1. Process unit description (delayed coker, hydrogen plant, etc.)
2. Process licenser
3. Feed capacity
4. Production capacity
5. Product yield
6. Utility levels at process unit location
7. Feedstock specifications
8. Integration of multiple units
9. Process pressure and temperature operating levels
10. Provision for future expansion of capacity
11. Provision for processing multiple or different feedstocks
12. Single train vs. multi-train concept
13. Project location
14. Miscellaneous costs (spare parts, training, chemicals, etc.)
15. Other items, such as unusually high or low recycle rate

TABLE 6-7 Checklist for an Early Estimate in the Process Industry

Estimate Documentation

Effective communication is necessary during the estimating process. A support document, the Basis of Estimate (BOE), should be developed and available for presentation, review, and future use of the estimate. A thorough documentation of the estimate forms a baseline for project control, so decisions during project execution can be made with a better awareness of the budget, thereby improving the overall outcome of the project. Inaccurate cost estimates are often the result of omissions in the estimate, miscommunications of project information, or nonaligned assumptions. Using the BOE to document the estimate will minimize these inaccuracies.

A thoroughly prepared Basis of Estimate does the following:

- Documents the project scope

- Reflects the estimator’s knowledge of the project by showing an understanding of scope and schedule as it relates to cost
- Alerts the team to potential cost risks and opportunities
- Provides a record of key communications made during estimate preparation
- Provides a record of all documents used to prepare the estimate
- Provides support during dispute resolutions
- Establishes the baseline for initial scope, quantities, and cost
- Provides historical relationships between estimates during the project lifecycle
- Facilitates review and validation of the estimate

As the estimate is being developed, the act of preparing documentation facilitates communications among the parties involved: estimators, scope developers, project managers, and customers. Estimate documentation improves the outcome of the estimate through the following:

- Sharing information
- Identifying items that require clarification
- Helping the estimator obtain and organize information needed for the estimate
- Avoiding confusion over what is covered and not covered by the estimate
- Providing useful information for future estimates
- Highlighting weak areas of the estimate
- Increasing the credibility of the estimate

A portion of the documentation may be developed by sources other than the estimator. For example, written scopes are developed by those who are defining the project. Quotes may be obtained by procurement personnel, and labor information may be obtained from field personnel. However, the estimator has overall responsibility for collecting and organizing this information. Reviewing and clarifying the information with the originator improves the estimate accuracy.

A standard default format or outline should be developed to organize and prepare documentation for the cost estimates. A different standard can be developed for different types of estimates. The process of developing, utilizing, and storing the documentation for future use should be built into the cost estimate work process. The items that should be documented are shown in Table 6-8. The file 04.06.e.BOE Outline.docx provides an electronic Basis of Estimate outline.

1. Standard format for presenting cost categories (codes)—summary and backup levels
2. Basis of estimate—clear understanding of what constitutes the estimate
3. Level of accuracy—expected for the estimate
4. Basis for contingency—risk analysis, if applicable
5. Boundaries of the estimate—limitations of the estimate
6. Scope of work—the level of scope definition used in preparing the estimate
7. Labor rates—breakdown and basis of labor rate
8. Assumed quantities—conceptualized, etc.
9. Applied escalation—dates and basis of escalation
10. Work schedule—shifts, overtime, etc., to match the milestones (not contradictory)
11. Other backup information—quotes, supporting data, assumptions
12. Checklists used—a list of completed checklists
13. Description of cost categories—codes used in preparing the estimate
14. Excluded costs—list of items excluded from the cost estimate

TABLE 6-8 Recommended Documentation of Early Estimates

Estimate Reviews

Well-executed estimate reviews will increase the credibility and accuracy of the estimate. They also help the team and project manager to know the level of scope definition and the basis of the estimate. The review of estimates is an important part of the estimating process because it helps the customer to understand the contents and level of accuracy of the estimate, allowing the customer to make better business decisions.

The number of reviews will vary depending on the size of the project, type of estimate, length of time allowed for preparing the estimate, and other factors. For any estimate, there should be at least two reviews: an internal review during development of the estimate and a final review at or near the completion of the estimate.

About halfway through the development of the estimate, a “reality check” should be scheduled. The purpose of the midpoint check is to avoid spending unnecessary time and money in pursuing an estimate that may be unrealistic or based on assumptions that are no longer valid.

The internal midpoint estimate review is brief. Typically, the lead estimator, engineer, and project manager are involved. There may be times when it is advantageous to include the customer. This review is intended as a reality check of the data being developed to assess whether to proceed with the estimate. This is a “go–no-go” point where the results of the review will guide the estimator and the team to one of the following two steps:

1. Recycle back to the scope of work because the capital or scope has gotten outside of the boundaries established as a target for the project.
2. Give the team the “go ahead” to proceed with the remaining estimate process to complete the estimate.

The final estimate review is a more structured process. The depth of the review depends on the type or class of estimate that is being prepared. The meeting is intended to validate assumptions used in preparing the estimate, such as construction sequence, key supplier selection, and owner's cost. Engineering and the customer must accept ownership of the scope that is represented in the estimate.

The final estimate review may be a lengthy meeting. For a final estimate review, the attendees should include the lead estimator, process engineer, discipline engineer, operations/maintenance representative, engineering manager, and constructability leader. To be effective, the final estimate review meeting should be conducted with a written agenda. The meeting should be documented with written minutes that are distributed to all attendees. The estimator must come to the review meeting prepared with the basis of estimate including supporting documents.

Comparisons of the estimate with the Basis of Estimate information provide useful indicators for the estimate review. The estimator needs to assess each estimate to determine the appropriate checks that should be included in an estimate review meeting. In some situations, it may be desirable to use outside assistance for estimate reviews. For example, it may be helpful to obtain a review of the estimate by an experienced peer group to validate assumptions, key estimate accounts, construction sequence, potential omissions, etc. In other situations, it may be advantageous to engage a third party to perform an independent review. This will provide a check to compare the estimate with past similar estimates from the perspective of a different team.

Estimate reviews should focus on the big picture and follow Pareto's law, separating the significant few from the trivial many. Generally, an estimate is prepared bottoms up, whereas the review is conducted top down. Table 6-9 is an

illustrative example of presentation items for review of an early estimate for a project in the process industry.

1. Product mix, volume, and quality requirements
2. Facility location
3. Scope of work
4. Simplified flow sheet
5. Key assumptions used
6. Major undecided alternatives
7. Historical data used
8. Estimate exclusions
9. Estimator's experience and track record
10. Checklists used to prepare estimate

TABLE 6-9 Presentation Items for Review of an Early Estimate in the Process Industry

Risk Assessment

Assessing risk and assigning contingency to the base estimate is one of the most important and often misunderstood tasks in preparing early estimates. Risk assessment is not the sole responsibility of the estimators. Key members of the project management team must provide input on critical issues that should be addressed by the estimators in assessing risk. Risk assessment requires a participatory approach with involvement of all project stakeholders including the business unit, engineering, construction, and the estimating team. Depending on the project's size and/or complexity, a dedicated risk management leader should be engaged to facilitate risk assessment, contingency identification, and contingency management.

The business owner is responsible for overall project funding and defining the purpose and intended use of the estimate. Engineering design is responsible for providing

input on the design criteria and factors that are susceptible to changes that may impact the cost of the project. The estimator or risk leader is responsible for converting the information from the business unit and engineering into an appropriate procedure for assessing risk and assigning contingency. The estimator or risk leader must communicate the risk, contingency, and level of accuracy that can be expected of each estimate, including the estimate used for fund authorization.

Risk Analysis

Risk analysis follows risk assessment. It is a prerequisite to assigning contingency. Based on the acceptable risks and the expected or desired confidence level, a contingency is established for a given estimate. Risk analysis and the resultant amount of contingency help the business unit to determine the level of economic risk involved in pursuing a project. The purpose of risk analysis is to improve the accuracy of the estimate and to instill management's confidence in the estimate.

Since the owner's organization has overall project funding responsibility, it must consider both the contractor's and owner's risks. The owner's contingency should cover the entire project risk, after adjusting for any risk already covered by contractors.

Numerous publications have been written to define risk analysis techniques. Generally, a formal risk analysis involves either a Monte Carlo simulation or a statistical range analysis. There are also numerous software packages for risk analysis. The lead estimator or risk leader for a project must assess the uniqueness of each project and select the technique of risk analysis that is deemed most appropriate. For estimates prepared in the Feasibility or Conceptualization phases, the level of scope definition and

the amount of estimate detail may be inadequate for performing a meaningful cost simulation.

Contingency

Contingency is a real and necessary component of an estimate. The amount of contingency added to the base estimate provides a higher level of confidence that the actual or final cost of a project will be predictable. There are often many unforeseeable project costs necessary to meet the original project objectives. Engineering and construction are risk endeavors with many uncertainties, particularly, in the early stages of project development. Contingency is assigned based on uncertainty and impact to the project. It may be assigned for many uncertainties, such as pricing, escalation, schedule, omissions, and errors. Identifying, assigning, and managing contingency is discussed in Chapter 8, Risk Assessment and Analysis.

The practice of including contingency for possible scope expansion is highly dependent on the attitude and culture, particularly that of the business unit, toward changes. Chapter 8 discusses contingency and scope changes.

In simple terms, contingency is the amount of money that should be added to the base estimate in order to predict the total installed cost of the project. Contingency may be interpreted as the amount of money that must be added to the base estimate to account for work that is difficult or impossible to identify at the time a base estimate is being prepared. In some owner or contractor organizations, contingency is intended to cover known unknowns. That is, the estimator knows there are additional costs, but the precise amount is unknown. A better approach is to use an allowance for known unknowns, and a contingency is assigned for risk-based events (unknown unknowns).

CII Source Document 41 defines contingency as “A sum of money to cover costs which are forecast but are difficult or impossible to identify when proposing.” AACE International Document 10S-90 defines contingency as “An amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs.”

Traditional Methods of Assigning Contingency

The most effective and meaningful way to perform risk analysis and assign contingency is to involve the project management team. Estimators have insights and can assess imperfections (known unknowns) in an estimate to derive an appropriate contingency. However, the interaction and group dynamics of the project management team provide an excellent vehicle to assess the overall project risk. The integration of the project management team’s knowledge and the estimator’s ability to assign contingency provides management with an appreciation and confidence in the final estimate. The result is an estimate that represents the judgment of the project management team, not just the estimator’s perspective. Chapter 8, Risk Assessment and Analysis, more thoroughly covers uncertainty, risk events, and establishing contingency.

The lead estimator working with the project manager should decide the most appropriate way to conduct risk assessment and analysis for each project, based on information provided by the project management team and based on the intended use of the estimate by the business unit. For projects that will not utilize a dedicated risk management lead, the estimator must select a risk analysis method by which to establish a contingency for the project.

The estimator should communicate the method selected, risk, accuracy, and contingency for the estimate and document this information in the basis of estimate. Following are descriptions of three methods for risk analysis: (1) percent of base estimate; (2) expected net risk; and (3) simulation.

Figure 6-11 illustrates the risk assessment process. The estimator must select the method deemed most appropriate for each project, based on information provided by the project management team and based on the intended use of the estimate by the business unit. The estimator must communicate the method selected, risk, accuracy, and contingency for the estimate.

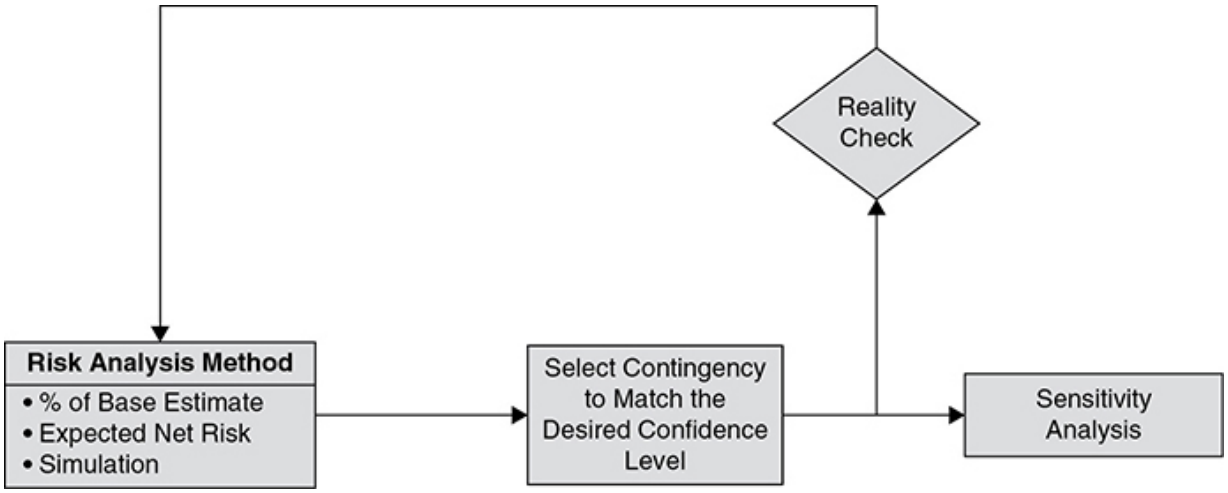


FIGURE 6-11 Risk assessment process.

Percentage of Base Estimate

For some situations, contingency may be assigned based on personal past experience. A percentage is applied to the base estimate to derive the total contingency. Although this is a simple method, the success depends on extensive experience of the estimator and historical cost information from similar projects. It is less accurate than other more structured methods.

Some organizations use standard percentages for contingencies based on the class of estimate. This method is governed by company policy rather than by a numerical analysis. Typically, the percentage used is based on the level of scope definition or on the stage of project development.

In some situations, contingency is determined as a percentage of major cost items rather than as a percentage of the total base estimate. This method typically relies on the personal experience and judgment of the estimator, but the percentage can also be from established standard percentages based on historical data. This method has the advantage of considering risk and uncertainty at a lower level than that used when contingency is based on a percentage of the total base estimate.

The personal experience and judgment of the estimators and engineers should not be overlooked in the process of assigning contingency. Even the most advanced computers are not a substitute for the knowledge and experience of the human mind. Estimators with many years of experience with a particular type of facility can often be quite accurate in assigning contingency based on how they “feel” about the level of uncertainty and risk associated with a project, the degree of scope definition, the cost data used in preparing the estimate, and the thoroughness of the effort in preparing the base estimate.

Expected Net Risk

The estimator may determine contingency based on expected maximum risk and likelihood. After the evaluation of normal contingency of each estimate element, an individual element may also be evaluated for any specific unknowns or potential problems that might occur. The first step involves determining the maximum possible risk for

each element, recognizing that it is unlikely that all the risk will occur for all elements.

The next step involves assessing the percentage probability that this risk will occur. The expected net risk then becomes a product of the maximum risk times the probability. The sum of all the expected net risks provides the total maximum risk contingency required. Table 6-10 illustrates an expected net risk analysis. Refer to Chapter 8 for a detailed discussion.

Estimate Item	Base Estimate	Maximum Cost	Maximum Risk	Percentage Probability	Expected Net Risk
1	$40,000	$50,000	$10,000	20%	$2,000
2	8,000	12,000	4,000	40%	1,600
3	100,000	150,000	50,000	30%	15,000
4	250,000	320,000	70,000	50%	35,000
5	72,000	95,000	23,000	70%	16,100
6	237,000	320,000	83,000	60%	49,800
7	12,000	28,000	16,000	10%	1,600
8	94,000	135,000	41,000	30%	12,300
9	730,000	870,000	140,000	40%	56,000
10	43,000	72,000	29,000	80%	23,200
11	85,000	97,000	12,000	20%	2,400
12	572,000	640,000	68,000	50%	34,000
	$2,243,000	$2,789,000	$546,000		$249,000

TABLE 6-10 Expected Net Risk Analysis

The risk analysis data in Table 6-10 shows a base estimate of $2,243,000 with a maximum anticipated cost of $2,789,000, a difference of $546,000. However, it is unlikely that all the risks will occur for each item in the estimate. Therefore, the expected net risk for each bid item is calculated by multiplying the maximum risk by the probability percentage of each item. The total expected net

risk for the project is $249,000, which is calculated as the sum of the next risk for each item in the estimate. The $249,000 represents a contingency markup of 11.1% on the base estimate of $2,243,000, calculated as [($249,000/$2,243,000) = 11.1%]. For this project, the final estimate is calculated as the base estimate plus the total expected risk, $2,243,000 + $249,000 = $2,492,000.

Simulation

A formal risk analysis for determining contingency is usually based on simulation. A simulation of probabilistic assessment of critical risk elements can be performed to match the desired confidence level. Monte Carlo simulation software packages are useful tools for performing simulation. However, a knowledge of statistical modeling and probability theory is required to use these tools properly.

Range estimating is a powerful tool that embraces Monte Carlo simulation to establish contingency. Critical elements are identified that have a significant impact on the base estimate. For many estimates, there are less than 20 critical elements. The range of each critical element is defined, and probability analysis is used to form the basis of simulation. Using this method, noncritical elements can be combined into one or a few meaningful elements.

Range estimating is probably the most widely used and accepted method of formal risk analysis. In range estimating, the first step requires identification of the critical items in the estimate. The critical items are those cost items that can affect the total cost estimate by a set percentage, for example +/−4%. Thus, a relatively small item with an extremely high degree of uncertainty may be critical whereas a major equipment item for which a firm vendor quote has been obtained would not be considered critical. Typically, no more than 20 critical items are used in the

analysis. If more than 20 critical items are identified, the set percentage can be increased to reduce the number of critical items.

Once the critical items are identified, a range and a target are applied to each item. For example, the range may include a minimum value so there is only a 1% chance that the cost of the item would fall below that minimum. Similarly, an upper value may be established, so there will be only a 1% chance of going over that value. The target value represents the anticipated cost for that item. The target value does not need to be the average of the minimum and maximum values. Usually, the target value is slightly higher than the average.

After the critical items have been identified and ranged, a Monte Carlo simulation is performed. The Monte Carlo analysis simulates the construction of the project numerous times, as many as 1,000 to 10,000, based on the ranges given to the critical items and the estimated values of the noncritical items. The results of the simulation are rank ordered and then presented in a cumulative probability graph, commonly called an S-curve. The cumulative probability graph typically shows the probability of underrun on the horizontal x-axis and either the total project cost or contingency amount on the vertical y-axis. The decision maker can then decide the amount of contingency to add based on the amount of risk.

Caution must be exercised because it is possible to seriously underestimate the cost of a project when using range estimating. There is a risk of understating the true risk of a project due to statistical interdependencies among the critical items in the analysis. Whenever two or more cost items are positively correlated, meaning they increase together or decrease together, the Monte Carlo simulation may cause one to be high and the other low, thus canceling each other out. Thus, the true risk would be understated.

Also, underestimating the ranges on the critical items can have a profound impact on the results, also leading to an understatement of the true risks inherent in the design and construction of the project.

When used properly, formal risk analysis using Monte Carlo simulation range estimating can be an extremely valuable tool because it requires a detailed analysis of the components of the estimate, a process that can identify mistakes and poor assumptions. However, precautions must be used when using simulation methods for early estimates. For many early estimates, there is not enough detailed information or an adequate number of cost items for a valid simulation.

Assessing Estimate Sensitivity

The contingency added to an estimate includes the combined impact of all risk elements. The accuracy of an estimate can be improved by assessing high-cost impact factors, increasing the level of scope definition, or a combination of both. A sensitivity analysis can be performed to illustrate how a specific risk element can impact the total estimate.

The sensitivity analysis evaluates the impact of only one risk element at a time. It is frequently used in conjunction with an economic analysis. During the process of determining contingency, risk elements that have the maximum impact on the total installed cost are prime candidates for sensitivity analysis. Figures 6-12 and 6-13 show a sample sensitivity analysis for a $3 million base estimate.

Equipment cost	$1.20M		
Material cost	$0.60M		
Labor cost	$1.00M	←	(=$50/WH × 20K WH)
Subcontractor cost	$0.20M		
Total base estimate	$3.00M		

FIGURE 6-12 Base Estimate Summary. (M = 1 million, K = 1 thousand, WH = work-hours).

Risk element	% Change from base estimate	New base estimate ($M)	Overall impact to base estimate
Labor rate ($50/WH)	0	$3.00	
Labor rate	+10%	3.10	3.30%
Labor rate	–5%	2.95	1.70%
Total work hours (20K WH)	0	$3.00	
Total work hours	+15%	3.15	5%
Total work hours	–7%	2.93	2.30%
Equipment ($1.20M)	0	$3.00	
Equipment	+5%	3.06	2%
Equipment	–5%	2.94	2%

FIGURE 6-13 Sensitivity analysis. (M = 1 million, K = 1 thousand, WH = work-hours).

From Figure 6-12, equipment costs and labor costs comprise the largest share of the base estimate. Changes in equipment costs, the labor rate, or the labor work-hours will have a sizable impact on the estimate. The results of a simple sensitivity analysis are shown in Figure 6-13.

The sensitivity analysis for the example project shows the impacts of changes to key estimate items on the overall estimate. A large increase in the work-hours for labor has the largest percentage increase to the budget.

For any estimate, it is necessary to add a contingency to the base estimate. The method used for assigning contingency will vary depending on analysis of risk and other factors that can impact the cost of a project. This

section has presented traditional methods used for assigning contingency. Chapter 8 provides a detailed discussion of Monte Carlo analysis and establishing project contingency.

Estimate Feedback for Continuous Improvement

It is unfortunate, but many people have the perception that the estimator's involvement with a project is over when the estimate is finished. In reality, it is an advantage to the management of a project, and in the best interest of the customer, for the estimator to remain connected to the project during execution.

The estimator can be an important asset to project management during the execution phase of a project. Involvement of the estimator during project execution allows the estimator to stay in touch with the project and provide an early warning for any potential cost overruns. Including the estimator in the distribution list of monthly project reports can provide input to the project management team members to enable them to make good decisions related to costs.

During project execution the estimator can also be a valuable resource for recasting the cost estimate into work/bid packages and for analyzing actual bids with the recast estimate. The estimator can also assist in management of changes during project execution, by assessing the impact of changes on cost.

No estimating process is complete without the continuous feedback loops shown in Figure 6-7. Feedback from project execution provides lessons learned to the estimator that allows the estimating team to modify estimating standards and practices. Feedback from project completion also allows the estimating team to update the database for improving

the accuracy of future estimates. Terminating the estimator's involvement when the estimate is finished prevents continuous improvement of the estimating process.

To provide meaningful feedback, the estimator must explore how the cost will be tracked during project execution. An estimate should be prepared with cost breakdowns in a format that allows easy future cost tracking. A standard code of accounts enables an organization to simplify the estimating process, update the database, and facilitate cost control. This benefits both the estimating team and the project management team.

A final project cost report is an extremely valuable document for improving estimates because it provides real feedback in the form of hard data to compare with the original cost estimate. Pitfalls for future estimates can be eliminated or minimized. Both the original estimate and the final project cost reports should be maintained at a central location. A cost reference with reports sorted by project location, type, size, etc., can be used to update the cost database for future estimates.

The best source of data for estimators to develop and enhance the estimating tools and techniques is their own organization. There is an abundance of largely unused project data that are available from completed projects and definitive estimates. The key to success is the establishment of a formal and coordinated mechanism to capture and retrieve this information in a format that can be useful in developing statistical relationships, such as percentage of breakdowns of total installed cost by cost category, total installed cost to equipment cost ratios, and construction indirect costs to direct labor cost ratios. When a project is completed, the actual total installed costs can be added to the database. Estimate feedback is an integral part of the estimating process. It is not an add-on feature. A process for

providing feedback loops is necessary for improving the accuracy of early estimates.

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CHAPTER 7
Project Budgeting

Project Budgets

The discussion of budgeting in this chapter is an extension of Chapter 6 on preparing early estimates. It is also closely related to Chapter 9 on design proposals, which presents the process of determining the cost of engineering design services for projects.

The budget for a project is the maximum amount of money the owner is willing to spend for design and construction to economically justify the project. The budget establishes the basis for cost control for the project. Estimating is a prerequisite to project budgeting. Chapter 6 presented the process of preparing early estimates of projects. As presented in that chapter, after the base estimate is completed, a risk assessment must be performed. The purpose of the risk assessment is to determine an appropriate amount of contingency funds that should be added to the base estimate in order to reasonably predict the final cost of the project considering specific events. Contingency also covers uncertainty in scope definition, in other words, contingency for assumptions. A third component of contingency is for uncertainty in cost estimating. Thus, the budget can be considered to be the base estimate plus contingency for risk events and estimate uncertainties.

Management reserve, as defined by AACE International, is an amount of money that may be identified in the estimate but held for discretionary management purposes outside the defined scope of the project. Management reserve differs from contingency in that this estimated amount is not expected to be spent unless management so decides and is not included in the project budget.

The budget includes allowances (known unknowns) that were included in the estimate and must also document assumptions, exclusions, and exceptions identified in the estimate. These items are extracted from the estimate and held at the top of the budget. Chapter 13 on Monitoring and Reporting will discuss how these items are "earned" or used during project execution.

Another aspect of budgeting includes the phase budget. As discussed in Chapter 2, as the project progresses through the lifecycle phases, additional information and clarity are added to the project's definition prior to project approval and funds authorization. The work to research, collect, and incorporate all of the details of the project requires expenditure of time and money. These amounts are the phase budget and phase schedule. The project manager leads the team through the early phases adhering to budgeted amounts for cost and time. Their focus should be on developing the project in sufficient detail to support a project authorization decision knowing that such a decision is made with imperfect and incomplete data.

After the project has received funds authorization and approval to move forward, the budget is created; this is the baseline budget. Each component of the cost estimate is allocated to a budget item based on the Work Breakdown Structure (WBS). Chapter 3 discusses WBS and the essential role it plays in monitoring and controlling project cost and time. The baseline budget is used to monitor and control project cost expenditures to stay within the overall plan.

Once the project budget is established and approved, formal and rigorous change control processes must be followed to modify it. Changes to the budget arise from many causes such as operability changes, design changes, field changes, and scope changes. Using a formal change control process ensures adequate description, justification, and impact analysis of changes. It separates necessary changes in order to meet project objectives from “nice to have” changes that are not justifiable within the project objectives. “Nice to have” changes lead to scope growth with associated cost and schedule overruns. Change control is discussed in Chapter 13.

Economic Feasibility Study

Regardless of its size or type, a project must be economically feasible. There are at least two ways to determine economic feasibility, depending on whether the owner is in the private sector or public sector. For a private project, the economic feasibility can be determined by an economic analysis of the monetary return on the investment to build the project. For a public or agency project, the economic feasibility is usually determined by a benefit/cost ratio.

Three methods are commonly used by the private sector to evaluate the monetary return on a potential investment: capital recovery, payback period, and rate of return. Each method uses the fundamental equations of time value of money. Numerous books have been published that describe the development and use of these equations for economic analysis. Below is a brief review of the equations.

Money can earn value when invested over time. For example, $100 invested today at 7% interest will be worth $107 one year from now. Thus, the time value of money means that equal dollar amounts at different points in time

do not have equal value. For example, the present worth of $100 today is equivalent to $107 one year from now provided the interest is 7%. Engineering economic analysis is the process of evaluating alternatives. The basic variables used in a time value analysis for economic feasibility are as follows:

P = present-worth amount (the value of money today)
F = compound amount (the future value of money after n periods of time at i interest)
i = interest rate per interest period (usually one year)
n = number of periods of time (usually in years)

Single Payments

The following calculations are provided to illustrate the relationship between P and F for a given i and n.

End of year	Interest earned during the year	Compound amount at end of year (F = future value of money)
0		$= P$
1	Pi	$P + Pi = P(1 + i)$
2	$P(1 + i)i$	$P(1 + i) + P(1 + i)i = P(1 + i)^2$
3	$P(1 + i)^2 i$	$P(1 + i)^2 + P(1 + i)^2 i = P(1 + i)^3$
n	$P(1 + i)^3 i$	$P(1 + i)^3 + P(1 + i)^3 i = P(1 + i)^n$

Thus, $F = P(1 + i)^n$. Note that F is related to P by a factor that depends only on i and n. This factor, $(1 + i)^n$, is called the single-payment compound-amount factor, which makes F equivalent to P. Rearranging terms, $P = F/(1 + i)^n$. The factor $1/(1 + i)^n$ is known as the present-worth compound-amount factor, which makes P equivalent to F. These two equations provide equivalent single payments, now and in

the future. There are four parameters: *P, F, i,* and *n.* Given any three parameters, the fourth can easily be calculated.

Uniform Payment Series

Instead of a single amount of money of *P* today and *F* in the future, as illustrated previously, a series of equal payments may occur at the end of succeeding annual interest periods. The sum of the compound amounts of the series of equal payments may be calculated by using the single-payment compound-amount factor. If *A* represents a series of *n* equal payments, then the sum of these payments after *n* years at *i* interest can be calculated using the following equation:

$$F = A(1) + A(1+i) + \cdots + A(1+i)^{n-2} + A(1+i)^{n-1}$$

Multiplying both sides of the equation by (1 + *i*) gives the following equation:

$$F(1+i) = A(1+i) + A(1+i)^2 + \cdots + A(1+i)^{n-1} + A(1+i)^n$$

Subtracting the first equation from the second gives the compound amount of the uniform series of payments as follows:

$$F(1+i) - F = -A + A(1+i)^n$$

$$F = A\left[\frac{(1+i)^n - 1}{i}\right]$$

Note that *F* is related to *A* by a factor that depends only on *i* and *n.* This factor, $[(1 + i)^n - 1]/i$, is called the uniform-series compound-amount factor, which makes the series of *A* payments equivalent to *F.* Rearranging terms, $A = F\{[i/(1 + i)^n] - 1\}$. The factor $[i/(1 + i)^n] - 1$ is known as the uniform-series sinking-fund factor. It represents the amount

of money *A* that must be invested over the uniform series of payments to equate to the future amount *F.*

Substituting $P(1 + i)^n$ for *F* in the uniform-series sinking-fund equation gives the following equation:

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

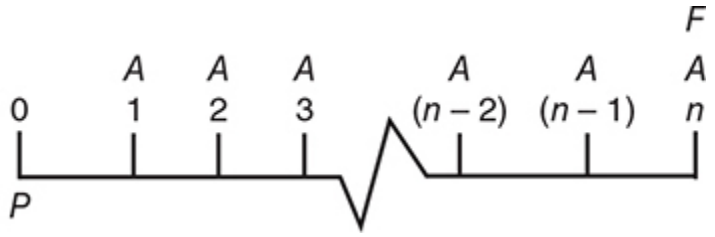
$$= P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

The equation $A = P\{[i(1 + i)^n]/[(1 + i)^n - 1]\}$ gives a uniform series of payments *A* that is equivalent to the present worth of *P.* Again, note that *A* is related to *P* by a factor that depends only on *i* and *n.* This factor, $[i(1 + i)^n]/[(1 + i)^n - 1]$, is called the uniform-series capital recovery factor. Rearranging terms, $P = A\{[(1 + i)^n - 1]/[i(1 + i)^n]\}$. This gives the present worth *P* of the uniform series of *A* payments. The factor, $[(1 + i)^n - 1]/[i(1 + i)^n]$, is called the uniform-series present-worth factor.

For convenience, each of the six basic equations for economic analysis are shown in Equations (7-1) to (7-6).

Fundamental Equations of the Time Value of Money

P = Present Worth
F = Future Sum
A = Equal Payment Series
i = Annual Interest Rate
n = Study Period (years)



Single Payment Series				
		Equation	Factor form	Equation number
Compound Amount	$F =$	$P[(1+i)^n]$	$P(F/P,i,n)$	(7-1)
Present Worth	$P =$	$F\left[\frac{1}{(1+i)^n}\right]$	$F(P/F,i,n)$	(7-2)
Equal Payment Series				
		Equation	Factor form	Equation number
Compound Amount	$F =$	$A\left[\frac{(1+i)^n-1}{i}\right]$	$A(F/A,i,n)$	(7-3)
Sinking Fund	$A =$	$F\left[\frac{i}{(1+i)^n-1}\right]$	$F(A/F,i,n)$	(7-4)
Present Worth	$P =$	$A\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]$	$A(P/A,i,n)$	(7-5)
Capital Recovery	$A =$	$P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$	$P(A/P,i,n)$	(7-6)

The factor form designation represents an abbreviated form of the equation when using factor tables and is illustrated as:

($F/P,i,n$) means find the Future Sum, F, from a known Present Worth, P, and Interest Rate, i, during a Study Period of n.

In general, an economic analysis involves the process of solving for one of the variables. For example, capital recovery solves for A, payback period solves for n, and rate of return solves for i. A more complex analysis using one or more of the basic six equations is required when multiple sums of money are distributed over the study period, or when tax advantages are included. The file 04.07.ProjBudgeting_Engineering_Economics.pdf provides a

useful reference to the basic equations and tables of factors for various interest rates.

The capital recovery method evaluates the amount of annual money, *A,* that must be obtained throughout the study life, *n*, of a project in order to obtain a recovery on the original capital investment, *P*. A simple illustration is given in Example 7-1. There may be other considerations that should be evaluated, such as tax advantages, nonuniform generation of revenue, and the disposal of the facility after its useful life. The payback period method evaluates the number of years, *n,* that a project must be operated in order to obtain an interest rate, *i*, for a given investment, *P*, with an annual generated income, *A.* This method is illustrated in Example 7-2. A rate-of-return analysis evaluates the interest rate, *i*, that equates the initial investment, *P*, to the yearly net cash flow as illustrated in Example 7-3. A trial-and-error solution is required in this example because the annual payments are not uniform. All these examples are simple illustrations of the methods that can be used to determine the economic feasibility of a project.

Example 7-1 This example illustrates the capital recovery method for determining economic feasibility. Suppose the feasibility estimate for a project is $14.0M with an expected operating life of 15 years. Annual maintenance and operating expenses are forecast as $750K per year. Using a 5% interest rate, what net annual income must be received to recover the capital investment of the project?

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] + \$0.75\text{M}$$

$$= \$14.0\text{M}\left[\frac{0.05(1+0.05)^{15}}{(1+0.05)^{15} - 1}\right] + \$0.75\text{M}$$

$$= \$2.10\text{M per year}$$

If the project can be built for $14.0M, operated for $750K per year, and earn $2.1M per year, the project is economically feasible, neglecting any tax advantages. If the project can be built for less than $14.0M, or can be built to

operate more efficiently than $750K per year, it is even more economically attractive.

Example 7-2 This example illustrates the payback period method for determining the economic feasibility of a project. The initial investment for a project is $24.0M. A net annual profit of $5.0M is anticipated. Using a 12% desired rate-of-return on the investment, what is the payback period for the project?

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

$$\$24\text{M} = \$5.0\text{M}\left[\frac{(1+0.12)^n - 1}{0.12(1+.12)^n}\right]$$

$$n = 7.58 \text{ years}$$

Example 7-3 This example illustrates the rate-of-return method for determining the economic feasibility of a project. An initial project investment of $3.0M is being considered for a 4-year analysis period. It is anticipated the project will be sold after the 4-year period for $1.6M. Determine the rate-of-return with the anticipated net profit shown below.

End of year	Net profit ($1,000)
0	0
1	−200
2	−100
3	+500
4	+1,600

Use Eq. (7-2) to transfer the costs from each year to an equivalent present worth. The table below provides an analysis.

End of year	Net profit ($1,000)	$i = 8\%$ $(P/F, i, n)$	Present value	$i = 6\%$ $(P/F, i, n)$	Present value
0	0				
1	−200	0.9259	−$185	0.9434	−$189
2	−100	0.8573	−$86	0.8900	−$89
3	+750	0.7938	+$595	0.8396	+$630
4	+1,600	0.7350	+$1,176	0.7921	+$1,267
		Sum	= +$1,500	Sum	= +$1,619

For an interest rate of 8%, the total of the future amounts is equivalent to $1.5M, which is less than the $1.6M selling price at the end of the 4-year analysis period. Testing the lower interest rate of 6% yields a total equivalent value of $1.62M. The rate-of-return for this study is 6%. This rate-of-return should be evaluated against the owner's minimum required rate-of-return.

It is important for the project manager and his or her team to realize that an owner's economic study, similar to one of those illustrated, is used by the owner to approve the project budget, which is the capital investment, *P.* When a project exceeds its budget, then the economic justification that was used by the owner to proceed with the project is impaired.

A popular method for deciding on the economic justification of a public project is to compute the benefit/cost ratio, which is simply the ratio of the benefits to the public divided by the cost to the government. If the ratio is 1, the equivalent benefits and equivalent costs are equal. This represents the minimum justification for an expenditure by a public agency. Generally, the first step is to determine the benefits that can be derived from a project. This is in contrast to the consideration of profitability as a first step in evaluating the merits of a private enterprise. The second step in evaluating a public project involves an analysis of

cost to the governmental agency. When a public project is being considered, the question is: Will this project result in the greatest possible enhancement of the general welfare in terms of economic, social, environmental, or other factors that serve the needs of the general public? The measurement of benefits is sometimes difficult because they cannot always be expressed in dollars. Many government agencies have a list of projects that are waiting for approval, but for which funds are not yet available. The decision as to which project to approve may be based on the amount of money that is allocated in a fiscal year, rather than economic feasibility.

Design Budgets

The design organization has a difficult task of estimating the cost of providing design services and/or producing contract documents for the project before the design and construction phases begin. For many projects the magnitude of work that is required by the designer cannot be fully anticipated, because design is a creative process that involves the evaluation of numerous alternatives. The evaluation of design alternatives is a necessary part of the design process required to select the best design that satisfies the owner’s need for the project.

Compensation for design services is usually by one of the following methods: lump-sum, salary cost times a multiplier, cost plus a fixed payment, or percent of construction. The method that is used depends on the accuracy of the scope definition that is provided to the design organization.

For projects that have a well-defined scope with no unusual features, and are similar to projects that a designer has handled in the past, a lump-sum design contract is commonly used. Preparation of the design budget can be developed by defining tasks and grouping of tasks in a work

breakdown structure. The development of a project work breakdown structure and design work packages is discussed in Chapter 3. A design work package, shown in Figure 3-4, can then be prepared for each task. Based on the past experience of the designer with similar projects, the estimated labor-hours of design calculations, number of drawings, labor-hours per drawing, travel, and other expenses can be estimated for each task. The total cost for design can be calculated by adding the cost of all design work packages. The final design budget is usually broken down by discipline with the labor-hours based on the number of drawings to be produced. Figure 7-1 illustrates the summary of a design engineering budget. Figure 7-2 shows an example of time distribution for design calculations as well as the development of drawings and specifications for a project. Chapter 9 presents the process of developing design proposals and design budgets. Reference Figures 9-6 and 9-7 for gathering the information necessary to prepare the budget forms shown in Figures 7-1 and 7-2.

Project Budget Form

Date _____ **Project Name** _____

Project ID _____

Dept. #	Department	HOURS							DOLLARS
		ADMIN	MTGS	SCHED	SPECS	CALCS	DWGS	TOTAL	
100	Project Management							12,000	$1,050,000
	Sr. Project Manager	3,000	2,400	900				6,300	
	Project Coordinator	1,500	1,200	3,000				5,700	
200	Architecture		350	100	350	250	800	1,850	$138,800
300	Mechanical		350		480	360	1,760	2,950	$221,300
400	Electrical		350		2,100	3,200	7,450	13,100	$1,179,000
500	Structural							26,360	$1,978,000
	Project Engineer	2,500	750					3,250	
	CADD Coord.		160				2,800	2,960	
	Department		550		1,300	6,700	11,600	20,150	
600	Environmental	1,500	500		650		500	3,150	$330,750
700	Civil							7,140	$642,600

	Turb./Gen. Spec. Department		190	100	340 1,310	2,000	3,200	340 6,800	
800	CADD		100	100			1,000	1,200	$80,000
900	Document Control	2,000			500		1,000	3,500	$131,250
1000	Project Control	1,500	500	500				2,500	$187,500
1100	Clerical	5,000	500		600			6,100	$250,000
1200	Reproduction				350		600	950	$28,000
1300	Management	800						800	$50,000
1400	Consultant A	250	250		90	115	250	955	$75,000
1500	Consultant B	85	165		65		350	665	$48,000
1700	Record Drawings					1,200	3,400	4,600	$240,000
Work-Hour Subtotal		18,135	8,315	4,700	8,135	13,825	34,710	87,820	$6,630,200
Task #	**Description**								
1800	Contingency								$650,000
1900	General Expenses								$57,000
2000	Travel								$215,000
2100	Office Budget								$75,000
	Expenses Subtotal								$997,000
	Total								$7,627,200

FIGURE 7-1 Illustrative design engineering budget.

Calculations

	70% Drawings	20% Drawing Review	10% Drawing Submittals		Total
Architecture	175	50	25		250
Mechanical	252	72	36		360
Electrical	2,240	640	320		3,200
Structural	4,690	1,340	670		6,700
Environmental	0	0	0		0
Civil	1,400	400	200		2,000
Consultants	80	23	12		115
TOTAL	8,837	2,525	1,263		12,625

Drawings

	50% Drawings	20% Drawing Review	20% Drawing Submittals	10% Final Record	Total
Architecture	400	160	160	80	800
Mechanical	880	352	352	176	1,760
Electrical	3,725	1,490	1,490	745	7,450
Structural	7,200	2,880	2,880	1,440	14,400
Environmental	250	100	100	50	500
Civil	1,600	640	640	320	3,200
Consultants	300	120	120	60	600
TOTAL	14,355	5,742	5,742	2,871	28,710

Specifications

	80% Specs	20% Review			Total
Architecture	280	70			350
Mechanical	384	96			480
Electrical	1,680	420			2,100
Structural	1,040	260			1,300
Environmental	520	130			650
Civil	1,048	262			1,310
Turbine/Gen.	272	68			340
Consultants	124	31			155
Clerical	480	120			600
TOTAL	5,828	1,457			7,285

Drawings

	25% Drawings	25% Drawing Review	25% Drawing Submittals	25% Final Record	Total
Reproduction	150	150	150	150	600
Document Control	250	250	250	250	1,000
TOTAL	400	400	400	400	1,600

Specifications

	50% Specs	50% Review			Total
Reproduction	175	175			350
Clerical	300	300			600
Document Control	250	250			500
TOTAL	725	725			1,450

FIGURE 7-2 Example of time distribution for design calculations, drawings, and specifications.

The salary cost times a multiplier method is used for projects when it is difficult to accurately define the scope of work at the time the designer is retained for the project. For these types of projects, preliminary services, such as process studies, development of alternate layout plans, or other services are required to establish information that is needed for the final design. The designer provides a fee schedule to the owner that lists the classification and salary costs of all personnel, and a rate schedule for all other costs that are directly chargeable to the project. Work is then performed based on actual time expended in the design effort. A multiplier, usually within a range from 2.0 to 3.0, is applied to direct salary costs that compensate the design organization for overhead, plus a reasonable margin for contingencies and profit. A larger multiplier may be used for unusual projects that require special expertise, or for projects of short duration or small size. Travel, subsistence, supplies, and other direct non-salary expenses are generally reimbursed at actual costs, plus a 10% to 15% service charge.

The cost plus a fixed payment method is used for projects that have a general description or statement of the scope of contemplated work, such as the number, size, and character of buildings or other facilities and the extent of utilities. The design organization is reimbursed for the actual cost of all salaries, services, and supplies plus a fixed fee that is agreed on between the designer and owner. The fixed fee usually varies from 10% for large projects to 25% for small projects that are short in duration.

Design work may also be compensated based on a percentage of the construction costs of a project, although this method is not as common today as it was in the past. Generally, the percentage is on a sliding scale that

decreases as the construction cost increases. The percentage also varies depending on the level of design services that are provided, such as design only, design and preparation of drawings, or full design services which include design, preparation of drawings, and observation during construction. The percentage generally will range from 5% to 12% of the anticipated construction cost.

The percentage data given in the above paragraphs are not fixed, nor should the ranges be considered as absolute maximums or minimums. Instead, they are presented as a guide to establish the approximate costs that may be incurred for the design of a project.

Contractor’s Bid

Most of the cost of a project is expended during the construction phase when the contractor must supervise large work forces who operate equipment, procure materials, and physically build the project. The cost of construction is determined by the contractor’s bid that has been accepted by the owner before starting the construction process. Depending on the completeness of the design and the amount of risk that is shared between the owner and contractor, there are many methods that have been developed to compensate the construction contractor.

The pricing format for providing construction services can be divided into two general categories: fixed price and cost reimbursable. Fixed price contracts usually are classified as lump-sum, unit-price, or a combination of lump-sum and unit-price. Cost-reimbursable contracts can be classified as cost plus a fixed fee or cost plus a percentage. An incentive is often built into cost-reimbursable contracts to control the total cost of a project. Examples of incentives are “target price” and “guaranteed maximum price.”

For projects with a complete set of plans and specifications that have been prepared prior to construction, the contractor can prepare a detailed estimate for the purpose of submitting a lump-sum bid on the project. Only one total-cost figure is quoted to the owner, and this figure represents the amount the owner will pay to the contractor for the completed project, unless there are revisions in the plans or specifications. The contractor's bid is prepared from a detailed estimate of the cost of providing materials, labor, equipment, subcontract work, overhead, and profit.

The preparation of lump-sum detailed cost estimates generally follows a systematic procedure that has been developed by the contractor for his or her unique construction operations. Building construction contractors usually organize their estimates in a format that closely follows the Construction Specifications Institute (CSI) numbering system, which divides work into major divisions. Each major division is subdivided into smaller items of work referred to as either broad scope, medium scope, and narrow scope. For example, the work required for division 2, site work, is subdivided into clearing, excavation, compaction, etc.. The numbering system is developed for architects writing specifications that are unique to each project. However, contractors typically use CSI numbering system as a checklist and guide for quantity takeoff, price extensions, and summary of costs for the final lump-sum bid.

For years, constructors used the CSI 16 division numbering system, which now has been expanded into a 50 division number system. It does not matter which numbering system is used as long as the information that is needed to assist in the bidding process is included and can be found easily.

An illustrative example of the cost summary for a building construction project is shown in Figure 7-3, which follows the

CSI 16 division numbering system. This table shows the summary costs of material, labor, and subcontract for the 16 divisions from general requirements to electrical. Item 2, site work, has a total cost of $181,389. Figure 7-4 shows a breakdown of the $181,389 site work cost, which includes clearing, excavation, compaction, handwork, termite control, drilled piers, foundation drains, landscape, and paving. Preparation of the estimate would involve further breakdown of the items in Figure 7-4. For example, the cost of excavation work would be broken down into labor and equipment costs for the crew performing excavation work.

Item	Division		Material	Labor	Subcontract	Total
1	General requirements		$16,435	$36,355	$4,882	$57,672
2	Site work		15,070	20,123	146,196	181,389
3	Concrete		97,176	51,524	0	148,700
4	Masonry		0	0	212,724	212,724
5	Metals		212,724	59,321	0	272,045
6	Woods and plastics		38,753	10,496	4,908	54,157
7	Thermal and moisture		0	0	138,072	138,072
8	Doors and windows		36,821	32,115	0	68,936
9	Finishes		172,587	187,922	0	360,509
10	Specialties		15,748	11,104	9,525	36,377
11	Equipment		0	0	45,729	45,729
12	Furnishings		0	0	0	0
13	Special construction		0	0	0	0
14	Conveying systems		0	0	0	0
15	Mechanical		0	0	641,673	641,673
16	Electrical		0	0	354,661	354,661
	Total direct costs		$605,314	$408,960	$1,558,370	$2,572,644
	Material tax	5%	30,266			2,602,910
	Labor tax	18%		73,613		2,676,523
	Contingency	2%			53,530	2,730,053
	Bonds/Insurance				34,091	2,764,144
	Profit	10%			276,414	3,040,558
					Bid Price =	**$3,040,558**

FIGURE 7-3 Building project bid summary using CSI 16 division organization of work.

Cost Code	Description	Quantity	Unit	Material	Labor	Subcontract	Total
2110	Clearing	1	LS	$0	$0	$3,694	$3,694
2220	Excavation	8,800	CY	0	11,880	9,416	21,296
2250	Compaction	950	CY	0	2,223	722	2,945
2294	Handwork	500	SY	0	1,750	0	1,750
2281	Termite control	1	LS	0	0	3,475	3,475
2372	Drilled piers	1,632	LF	14,580	2,800	14,534	31,914
2411	Foundation drains	14	EA	490	1,470	0	1,960
2480	Landscape	1	LS	0	0	8,722	8,722
2515	Paving	4,850	SY	0	0	105,633	105,633
		Div 2 Total		$15,070	$20,123	$146,196	**$181,389**

FIGURE 7-4 Division 2 estimate for site work.

Heavy engineering construction projects generally are organized in a WBS that is unique to the project to be constructed. A WBS organizes costs into major divisions of work. Each division is divided into subdivisions, and each subdivision is organized into more detailed components.

An example of a WBS for an electrical power construction project is illustrated in Figures 7-5 to 7-7. Figure 7-5 is the top division level in the WBS, which shows the summary of costs for each major facility in the project. For example, No. 2100 is the major facility of Transmission Line A. The subdivision of costs for Transmission Line A is shown in Figure 7-6. Cost Item 2130 in Figure 7-6 shows the summary of costs for tower foundations. A more detailed breakdown of the tower foundation costs is shown in Figure 7-7.

Group-level report					
No	Group	Material	Labor and equipment	Subcontract	Total
1100	Switch station	$1,257,295	$323,521	$3,548,343	$5,129,159
2100	Transmission line A	$3,381,625	$1,259,837	$0	$4,641,462
2300	Transmission line B	$1,744,395	$0	$614,740	$2,359,135
3100	Substation at Spring Creek	$572,874	$116,403	$1,860,355	$2,549,632
4200	Distribution Line A	$403,297	$54,273	$215,040	$672,610
4400	Distribution Line B	$227,599	$8,675	$102,387	$338,661
4500	Distribution Line C	$398,463	$21,498	$113,547	$533,508
Total		$7,985,548	$1,784,207	$6,454,412	$16,224,167
For large projects the costs are sometimes rounded to the nearest $100 or $1,000. Figures 7-5 to 7-7 show full dollars to illustrate the transfer of costs among the component, division, and group levels of an estimate.					

FIGURE 7-5 Example of electric power construction bid summary using the WBS organization of work.

DIVISION-LEVEL REPORT FOR TRANSMISSION LINE A					
Cost Item	Description	Material	Labor	Equipment	Total
2100	TRANSMISSION LINE A				
2120	Fabrication of steel towers	$692,775	$0	$0	$692,775
2130	Tower foundations	$83,262	$62,126	$71,210	$216,598
2140	Erection of steel towers	$0	$144,141	$382,998	$527,139
2150	Insulators and conductors	$2,605,588	$183,163	$274,744	$3,063,495
2160	Shield wire installation	$0	$78,164	$63,291	$141,455
Total for 2100		$3,381,625	$467,594	$792,243	$4,641,462

FIGURE 7-6 Example of electric power construction estimate using the WBS organization of work.

COMPONENT-LEVEL REPORT FOR TOWER FOUNDATIONS							
Cost Item	Description	Quantity	Unit	Material	Labor	Equipment	Total
2130	TOWER FOUNDATIONS						
2131	Drilling foundations	4196	LF	$0	$25,428	$44,897	$70,325
2132	Reinforcing steel	37.5	tons	$28,951	$22,050	$15,376	$66,377
2133	Foundation concrete	870	CY	$53,306	$13,831	$10,143	$77,280
2134	Stub angles	3142	LB	$1,005	$817	$794	$2,616
Total for 2130				$83,262	$62,126	$71,210	$216,598

FIGURE 7-7 Example of electric power construction estimate using the WBS organization of work.

The unit-price bid is similar to the lump-sum bid, except that the contractor submits a cost per unit of work in place, such as a cost per cubic yard of concrete. The contract documents define the units the owner will pay the contractor. The final cost is determined by multiplying the bid cost per unit by the actual quantity of work that is installed by the contractor. Thus, the price that the owner will pay to the contractor is not determined until the project has been completed, when the actual quantities are known.

Cost-reimbursable contracts for construction may be used for several reasons; to start construction at the earliest possible date, to allow the owner to make changes in the scope of work without substantial modifications in the contract, or because the project is unique with features that prevent a reasonable approximation of the actual cost of construction. The estimate for this type of project is usually prepared by the contractor as an approximate estimate. The owner and contractor agree on a cost rate for all labor, equipment, and other services that may be charged to the project by the contractor. The contractor is reimbursed for all costs that are accrued during the construction phase of the project plus a percentage of the costs or a fixed fee.

To maintain some degree of control over the total cost of a project, an incentive is often placed on cost-reimbursable contracts. For example, the contract may be awarded on a cost plus basis with a guaranteed maximum price, commonly called a guaranteed maximum price (GMP) contract. For a GMP contract, the owner and contractor agree on a guaranteed maximum price prior to the start of construction. They also agree on the distribution of costs that each will incur if the final cost is above or below the guaranteed maximum price. Then, during construction, the contractor is reimbursed for actual costs plus a fixed fee or

percentage of actual costs. If the actual final cost is above or below the guaranteed maximum price, then the predetermined distribution of the difference of costs is distributed between the owner and contractor. To illustrate, if the cost exceeds the guaranteed maximum price, the contractor may pay 70% of the cost and the owner pays 30% of the cost. If the cost is less than the guaranteed maximum price, the contractor receives 60% of the reduced costs and the owner receives 40%.

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CHAPTER 8
Risk Management

Introduction

Management of a project involves decisions and actions that are intended to move a project toward completion. However, sometimes decisions, actions, and events can result in consequences that adversely affect the forward momentum of a project, impacting the project budget and scheduled completion. These decisions, actions, and events (risks) are inherent in the course a of project and make risk management an essential component of project management.

Risk should not be ignored but should be recognized and managed so any adverse effects can be predicted, reduced, avoided, or exploited. It is important to realize that risk is a part of doing business, especially in the engineering and construction professions. Risks should be identified, analyzed, and managed just like other parts of a project. Risk can impact a project as either a threat or an opportunity and can impact cost, schedule, quality, and safety. Because they are much more likely to occur, this chapter will focus on threats rather than opportunities.

Threats can be defined as any external or internal events or circumstances that can cause a deviation from the plan for project delivery. There are many possible risks in the execution of any project, regardless of size, type, or complexity. Many things can go wrong in all phases of a

project, including feasibility, design, procurement, construction, commissioning, and start-up. Table 8-1 shows examples of risks during design, procurement, and construction of a project. Risks generally take three forms, occurring as risk events, cost uncertainty, and schedule uncertainty all of which may impact costs, durations, and resource availability. Risks can occur with high or low probabilities and impacts, and projects can also experience extremely rare events which carry exceptionally large impacts but with low probabilities. The ultimate result of risk evaluation is to determine the amount of contingency required to overcome project risks and provide for a realistic cost of the project for feasibility assessment and project go-no-go decisions.

Design	Procurement	Construction
Miscommunication of design criteria (basis of design) with the client	Issuing timely orders for purchase of material and equipment	Unacceptable quality of work at the jobsite, requiring rework
Miscommunication of design criteria within the design team	Vendor/Supplier delays in delivery of material/equipment	Misinterpretation, conflicts, or errors in drawings and specs
Incomplete description of the scope of work	Misinterpretation of purchase contract terms and conditions	Misinterpretation of construction contract terms and conditions
Errors or omissions in developing the design drawings and specs	Inadequate methods of handling materials and equipment	Conflicts in schedules, schedule slippage, or cost overruns
Conflicting interests between client and permitting agencies, or regulatory agencies	Availability of adequate inventory or capacity to fulfill orders	Inadequate attention to safe work practices
Availability of experienced labor resources or access to technology	Proper storage and handling of delivered materials or equipment	Problems in start-up and testing of equipment and processes

TABLE 8-1 Risks during Design, Procurement, and Construction

Risks of the Owner, Designer, and Contractor

The principal parties in a project are the owner, designer, and contractor. Each party plays an important role in delivering a successful project. When problems arise in a project, the fault often can be attributed to a combination of the owner, designer, and contractor. When something goes wrong for one party, it usually affects other parties in the project. Therefore, it is important for each party to work together to share risks, rather than trying to assign risk to another party. Communications play an important role in risk management. Information that is misunderstood, inadequate, or received too late can cause many things to go wrong in a project.

The first consideration in risk management is the type of contract, its terms and conditions. Negotiations between parties to a contract should involve identifying potential risks. One of the primary purposes of the contract, regardless of the type, is to bind the parties together and allocate known risks. It is best to share risks equitably by apportioning and assigning risks to the party that is best capable of controlling the risk. Whether a project is defined by one contract or many, the owner, designer, and contractor must recognize that teamwork is essential to risk management.

The principal components of a project with a defined scope are cost, schedule, and quality of work. Jointly and individually the owner, designer, and contractor have important roles that expose them to risks related to cost, schedule, and quality. Owners are responsible for risks associated with setting performance expectations of the completed work, which subsequently establishes the cost, schedule, and quality of a project. Designers and contractors have risks in meeting the owner’s expectations.

Designers are in the best position to control risks related to quality, although owners and contractors have quality-related risks. Typically, contractors are in the best position to control risks related to cost and schedule on a project, although owners and designers are also exposed to risks related to costs and schedules.

All parties are exposed to risks related to costs. Owners in the private sector develop cost budgets based on economic feasibility of the project and consideration of available funds or sources of financing. Owners in the public sector develop cost budgets for their projects based on benefit/cost ratios to the public and consideration of available funds. Any deviation of design or construction costs from the owner's budget presents a risk to the owner. Contractors prepare cost estimates for bid purposes. Any underestimate of costs presents a risk to the contractor. Designers have responsibilities to meet the expectations of the owner and protect the health and safety of the public. Overruns in the design budget typically pose less significant risk than overruns of construction costs. However, overruns in design budgets impact the funds available to build the project and can erode the business outcomes of the project.

The owner, designer, and contractor are also exposed to risks related to schedule. The time to complete a project is a major concern of all parties. The length of time to finish a project should be long enough for the designer and contractor to do their respective work in accordance with the contract documents, but short enough for the owner to have possession of the project so it can be used for its intended beneficial purpose. The time allowed for design and construction will dramatically affect costs and quality of the completed work. For private sector owners, the intended use is typically to make a profit with the use of the project, whereas for public sector owners, the intended use is to make the project available for the public benefit. The

expected return on investment or benefits are significant drivers for risk planning.

The owner defines the level of quality that is expected in the project. It is the responsibility of the designer to prepare drawings and specifications in conformance to appropriate standards, codes, and regulations. The outputs from the designer are design documents that will achieve the performance requirements of the owner. The contractor is responsible for implementing the specified quality in accordance with the contract documents during construction through start-up. Inspection of the work during construction is necessary to ensure this quality. The inspection may be done by the owner, but more often is performed by the designer's organization or an independent third party. Thus, all parties have a responsibility and are exposed to risk to ensure quality in the finished project.

Precautions for Owners

Owners play an important role in the success of any project. They are the only participant that is involved from the start to the end of the project. There are at least four issues where owners need to exercise caution:

1. Project changes
2. Funding of the project
3. Owner-furnished material and equipment
4. Public and regulatory environment

The owner is ultimately responsible for defining the scope of a project and the level of quality. During the conceptual phase and early design, the scope of a project will likely change many times. The changes may be due to the owner's desire to modify the project based on available funds or constraints of time, results from design reviews, safety and constructability issues, or concerns from the

owner’s operations and maintenance staff that will use the project after it is completed. Frequent changes during early design of a project generally have the least negative impact on cost and schedule. However, changes that occur after detailed design, and especially during construction, can have a significant impact on the cost and schedule of the project (reference Figure 2-4). Therefore, the owner plays a key role in managing change.

Essentially, the owner pays for everything in a project. Accordingly, owners have the burden of securing financing for their projects. Failure to have adequate funding available throughout the project places all parties at risk, especially the contractor because the contractor’s cost is typically much larger than the designer’s cost. The owner needs adequate funding to make progress payments to the contractor for completed work because a common cause of failure of construction companies is their inability to meet short-term obligations, such as payments to material suppliers, laborers, and for rental equipment. Failure of the owner to make timely progress payments places the contractor at risk and threatens the timely completion of the project.

For some projects, the owner procures and furnishes bulk material or special equipment for installation by the contractor at the jobsite. For example, an electric utility company may procure steel poles and conductor wire for an electric transmission line construction project. An oil and gas company may procure special equipment, such as a pump, compressor, or heat exchanger for delivery to the job-site for installation by the contractor. Owner supplied material and equipment can be a significant risk factor for the contractor. Extensive coordination is necessary between the owner, designer, and contractor to ensure that engineering data and owner procured items are delivered in a timely manner. Owner-furnished material and equipment

must be engineered and designed in a timely manner so the project designer can incorporate the information into the project design and the procured items can be on the jobsite when the contractor needs them. Most contractors have an installation schedule for storage and installation of equipment at the job. Late delivery of owner-furnished equipment is a common cause of delays of construction work and late completion dates of projects. Also, late designs by manufacturers can cause delays in foundation design and the purchase of ancillary materials such as anchor bolts.

Public perceptions of a project, or extensive regulatory requirements, can create an adverse and complex environment for projects, which can pose risks for owners. Sometimes there is resistance to construction of a project because of the type and/or location of the project. For example, there may be resistance from an environmental group to build a nuclear power plant, or people in a residential neighborhood may resist construction of a commercial business that is located adjacent to their houses. Other factors that can pose risks to the owner include site security, traffic control for safety, and dust suppression at the job-site. These competing interests pose risks that may also affect the owner's ability to attract the best designers and contractors to work on the project and require owners to take precautions to manage these risks.

Precaution for Designers

The designer serves in a key role between the owner who needs the project and the contractor who is responsible for building the project. The designer must convert the needs of the owner into a set of plans and specifications that are constructible by the contractor, that are within the cost and completion date that is acceptable by the owner and that meets the owner's business objectives.

Design work involves collecting site information, performing many calculations, using computer applications, developing design drawings with details, and writing numerous pages of technical specifications. The chance of missing critical information and creating errors is enormous. There are at least six issues where designers need to exercise caution:

1. Control of scope growth
2. Quality and completeness of plans and specifications
3. Approval of shop drawings and materials
4. Response to change orders
5. Inspection during construction
6. Managing the budget and schedule for design

Designers must continually monitor and control scope growth during the design process. The designer should only produce drawings and specifications that pertain to the needs and requirements of the owner. The designer should carefully document all criteria that define appearance, function, and performance requirements that are identified by the owner. It is especially important to also document any items that deviate or enhance the project performance. The designer should help the owner separate “needs” from “wants” because changes in the project’s performance criteria and functionality frequently lead to scope growth. Potentially all changes in a project will lead to scope growth. Over-designing, over-drafting, and over-writing specifications also lead to scope growth, which increases costs and schedule. These risks not only affect the budget and schedule of the designer but can also impact construction costs and schedule.

The quality and completeness of plans and specifications have a tremendous impact on the cost, schedule, and quality of a project. Plans and specifications should be

thoroughly reviewed and checked for errors and omissions before they are released for construction. Defects in the design documents, whether perceived or real, are a common cause of construction claims and disputes. It is prudent to have persons with extensive construction experience to check drawings to ensure constructability and review specifications for clarity.

Early in a project the construction contractor issues submittals for review of shop drawings and approval of materials. The shop drawings are produced from the design documents. The designer is responsible for the review and approval of the shop drawings for compliance with the contract documents before the contractor can begin work. Any delay in the time allowed for review and approval of shop drawings can cause a delay in the contractor's operations, which may cause a delay claim from the contractor. Delays in the contractor's schedule caused by the designer, or owner, usually lead to contractor claims for additional time and associated cost. Thus, it is important for the designer to respond to review of shop drawings in a timely manner.

Change requests during construction may be issued by the owner, designer, or contractor. The owner may want to add to the project, the designer may want to correct an error in the drawings or clarify a specification. The contractor may request a change for additional time and money to handle a differing site condition or cleanup after a severe weather event. Change requests typically increase the time and cost of construction. Prior to approving or denying change requests, the owner usually asks the designer to review and evaluate the scope, cost, and schedule of the change requests. Failure to respond to change requests in a timely manner is a common cause of claims from the contractor for additional time and money.

Inspection of construction work is required to ensure quality of materials and workmanship. Usually, the designer is responsible for inspection at the request of the owner. The contractor is obligated to perform the work in accordance with the contract documents, no more and no less. Performing inspections introduces risks. The inspector also needs to be responsive to the contractor's request for inspection of their work. Lack of timely responsiveness of inspection can lead to delay claims from the contractor. However, defective work, regardless of how or when it is discovered, is a risk to the contractor who is responsible for the means and methods of construction.

The cost of design work is often measured in work-hours and bar charts are commonly used for design schedules. Managing design budgets usually involves comparing actual hours worked to budgeted hours for the project. For small projects, many designers work on multiple projects at the same time, which makes the process of managing design budgets more difficult. A cost control system that accurately charges design hours to each project is necessary, otherwise there is a risk of cost overruns or misallocation of costs. Most designers are more interested in designing the work than keeping track of the cost or schedule. To prevent schedule slippage, periodic design meetings need to be conducted to compare accomplished work to the scheduled work for key milestone dates in the design effort.

Precaution for Contractors

During construction the contractor is in control of the project, which exposes the contractor to risks. The amount of control is defined in the contract documents. Contractors estimate costs, prepare schedules, purchase materials, and manage labor and equipment. There are at least four issues where contractors need to exercise caution:

1. Underestimated quantities or costs
2. Unrealistic schedules
3. Ineffective control of subcontractors
4. Overestimating labor productivity

Most contractors do a relatively good job of preparing cost estimates. However, there is always the possibility of underestimating a job. Low or inaccurate estimates lead to low bids. If the bid is low enough, the contractor is awarded a contract that will not sustain its business. An underfunded job places the contractor in the risky situation of continually having to find ways to recover money through change requests, claims, or temptations to consider questionable business practices.

Prior to construction, the only scheduling information usually given to contractors is the approved start date and the required end date for a project. For some projects, the contractor may be given some critical intermediate milestones dates. Contractors are responsible for preparing a comprehensive master schedule to direct and control all aspects of their operations. The schedule should be detailed enough to serve as a guide to workers at the jobsite and to ensure timely delivery of materials. The contractor’s schedule must be periodically updated based on events that occur on the job, to show actual work progress compared to planned progress.

Project control systems are crucial in construction. Control systems include costs, schedules, quality, safety, and materials management. To be effective, a project control system must be simple to administer and easily understood by all participants in a project. An efficient control system must be developed so information can be routinely collected, verified, evaluated, and communicated to the persons responsible for managing the work. It should be recognized that project control systems are most valuable

when there is a good plan and schedule for the job. A good control system provides a mechanism to identify and mitigate risks.

Construction workers at the jobsite are the most important resource of the contractor. They operate equipment, install materials, detect problems, solve problems, and get the work accomplished despite the many obstacles that may arise. The contractor needs to make a special effort to give proper instructions for work assignments, provide adequate training, ensure a safe working environment, and create a sense of teamwork. When the contractor takes care of the workers, the workers will take care of the contractor. Well-managed workers are more productive and have better safety records, which reduces other risks of the contractor.

Contract Considerations for Risk

The construction industry is one of the few industries that quote prices, promise schedules, and make commitments to perform high-risk work before work is started. Few contracts allow repricing of the work in the middle of construction. The designer and contractor are bound to perform their work in accordance with the contract price, scope, and schedule that were agreed upon at the time the contract was signed. Additional time or cost to complete a project beyond what is specified in the contract documents is typically permitted only by changed conditions from the original scope, time, and quality requirements.

Project owners can try to mitigate risk by various methods including reduce, avoid, transfer, etc. But the ultimate risk-taker on the project is the owner. Shifting responsibility for risk through contracting strategies can result in increased cost and delayed schedules, and the risk may not be fully transferred.

Table 8-2 shows some of the risks that can be experienced by a project even after the owner uses contracting methods to transfer risk to other parties.

Cost Uncertainty	Risk Events	Schedule	Other
Quantity variances	Delivery delays	Duration uncertainties	Indemnities
Market variances	Availability of skills	Unexpected delays	Customs/duties
Escalation	Errors and omissions	Work sequence issues	Force majeure
Poor work coordination	Quantity takeoffs	Poor workmanship	Governing laws
Currency exchange	Vandalism/theft	Owner-caused delays	Environmental issues
Audit risks	Nonconformance	Schedule inefficiencies	Performance guarantees
Incentives	Worse than planned weather	Poor productivity	Intellectual property disputes
Scope changes	Poor subcontractor performance	Insufficient staff	Constructive acceleration

TABLE 8-2 Potential Project Risks

Deciding which type of contract to use for Engineering, Procurement, and Construction (EPC) projects can be influenced by risk allocation concerns. It is often assumed by project owners that project risks are mitigated by assigning the risk to the construction contractor through contract terms such as lump-sum contracts. This assumption is far from valid and can lead a project team to a false sense of cost and schedule security. The project owner is still subject to change orders, scope changes, force majeure, owner-caused delays, and a host of other risks. The project owner needs to write the contract to allocate risk properly to the contractor and assign owner-controlled threats to the owner's team who will then monitor the project carefully for these threats. Under a lump-sum contract, the contractor is exposed to a number of anticipated threats that will be included in their bid as contractor risk contingency. The contractor will also be exposed to unanticipated threats, which they may not have included in their bid, which may lead to them trying to

transfer these threats back to the owner. A well-constructed contract will provide the owner the mechanism to defend against these transfer attempts and give the owner's team a clear understanding of their risk responsibility. With this knowledge, the owner's team can then allocate sufficient contingency to cover their possible threat exposure.

Project contract risks for the owner generally fall into two categories, risks transferred to the contractor and the risks that remain with the owner. The risks transferred to the contractor consist of three types: pure cost-related risks, pure schedule-related risks, and integrated cost and schedule risks. Even well-written contracts that contain detailed risk transfer clauses leave risk exposure for the project owner that require monitoring by the owner. The contractor will have reserved some funds and time for his or her identified risk exposure; however, if the contractor neglects to adequately account for this risk exposure, the risks may transfer back to the project owner (i.e., if a contractor completely fails and the owner is left with an unfinished project).

Figure 8-1 represents the project sequence of work for an EPC contract and the risks to which projects are exposed. The P90 and the P?? values for project cost and project time are discussed later in this chapter. The dark gray contractor's risk box at the lower left of the figure represents the responsibility of the EPC contractor. The risks inside this box surrounded by the bold dashed lines have been contractually assigned to the contactor. The risks outside the dark gray box represent the owner's residual risk, which may have not been addressed in the contract. The goal of the owner's contract language and the owner's risk coordination are to keep those risks in the dark gray box from migrating back to the owner via change orders, incentive bonuses, scope changes, owner-caused delays, force majeure, and other forms. The contract needs to be

administrated such that the risk allocated to the contractor through contract language does not shift back to the owner.

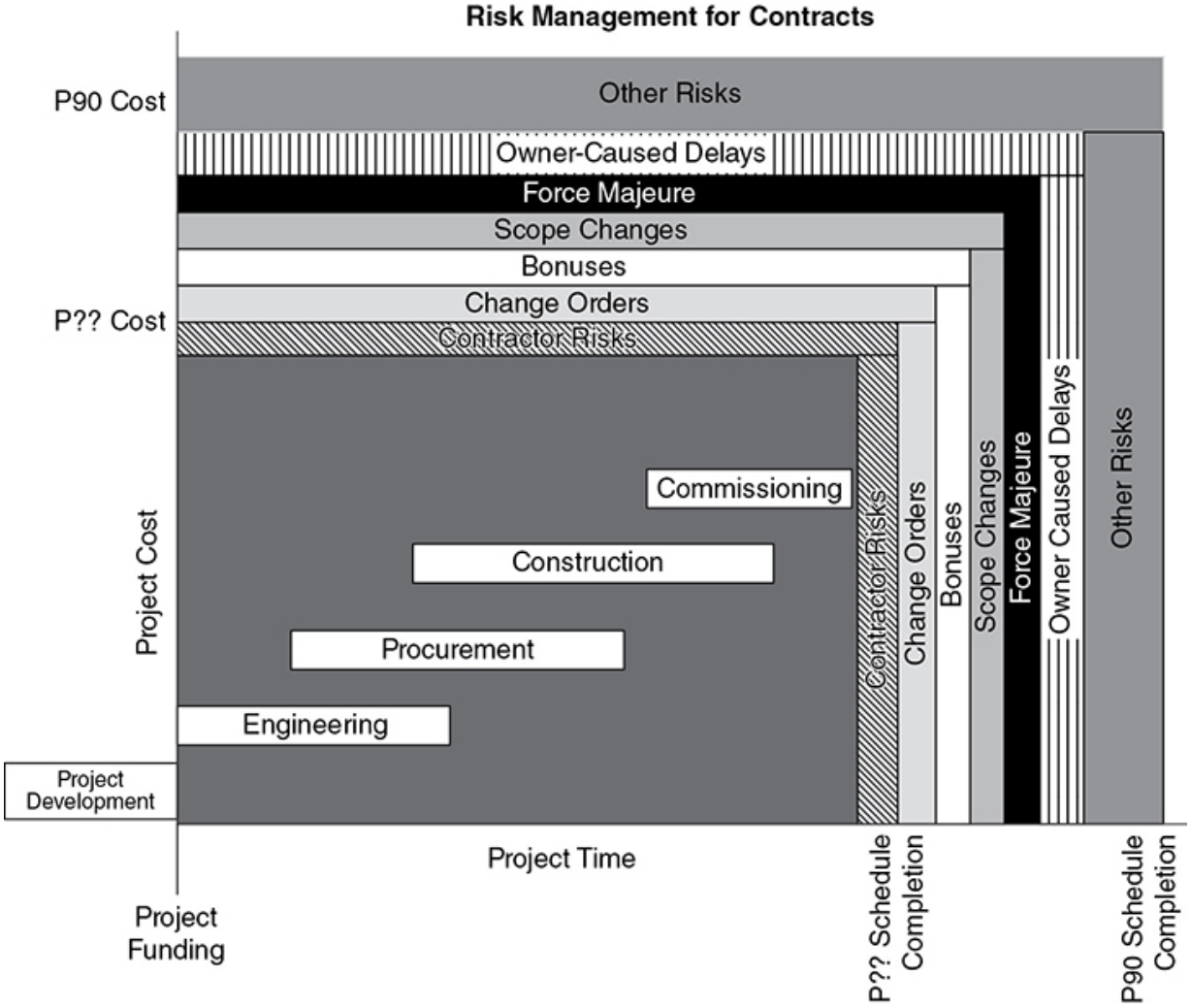


FIGURE 8-1 Risk management for contracts.

The strategy for assigning risk to the contractor is to identify risks that are under the contractor's control and use contract language to allocate these risks to them. The risks usually assigned to the contractor and priced in the dark gray box are the following:

- Labor productivity
- Equipment productivity

- Sequence of work
- Material logistics
- Craft interference
- Quality issues and rework

Although the contractor will assume responsibility for most primary risks, the project owner usually chooses to keep some risks under their control. The following list contains some risks the owner may choose to retain:

Owner Project Risks

- Competitive economic environment
- Project complexity
  - New technologies
  - Organizational relationships
  - Multi-business partners
  - Additional regulation
  - Project governance
- Government intervention
- Product liability
- Uncertain market
- Escalation

The realization or occurrence of contractor-allocated risks can result in negative outcomes to the project, which will inevitably be borne by the project owner. Some of these negative outcomes are as follows:

Outcomes

- Unforeseen cost
- Schedule delays
- Poor quality

- Safety issues
- Operational failures
- Regulatory noncompliance
- Penalties and fines
- Owner–customer dissatisfaction
- Loss of competitive advantage
- Loss of market share
- Damage to reputation
- Lost profitability

Each of these negative outcomes can make a demand on the contingency and management reserve identified for the project. If reallocation of these funds is used to offset budget overruns from negative outcomes, the project can have a false sense of security and confidence in project objectives. By reallocating funds, cost overrun trends can be masked, and the impact of these trends are not visible until it is too late to effect any positive changes to the inevitable outcome.

Given the probability that contracting strategy will not entirely mitigate all the risks an owner is exposed to on any given project, owners need to monitor contracts carefully to prevent the allocated risks from migrating back to the owner's responsibility. Owners also need to allocate some contingency and management reserve to cover the possibility that these allocated risks fail to stay within the contractor's responsibility or actively manage risks to keep the dark gray box in Figure 8-1 from growing.

Types of Risk and Impacts

The environment in which projects exist is full of uncertainty —changing market conditions, scope vagueness,

productivity losses, and inclement weather. The Project Management Institute (PMI) categorizes these risks as known-knowns, known-unknowns, and unknown-unknowns. The known-knowns are risks that can be identified, their occurrence is known, and their impact can be quantified. The known-unknowns are risks that can be identified, their occurrence is most likely known, but their impact cannot be uniquely quantified. The unknown-unknown risks may or may not be known, their occurrence is likely unknown, and the extent of their impact is completely unknown.

The known-known risks can be assimilated into project estimates and incorporated into the requirement of the project. The known-unknowns are added to a list and their range of impact is documented. To determine the unknown-unknowns in this environment, the project team must use their past experience to look into the future, identify unknown events, determine their probability of occurring, and quantify the impact they may have on the project.

To make this effort more manageable, it is useful for project teams to define the risks as uncertain events, conditions, or circumstances that, if they occur, may have a range of positive or negative effects on the project objectives. The project team will need to group these risks into three main types: risk events, estimate uncertainty, and schedule uncertainty. These risk types can be handled in an integrated fashion or managed separately. The integrated approach will require software dedicated to this purpose; the separate approach will only require generalized software. Each risk type will need to be developed independently and then refined to eliminate redundancies, gaps, and overlaps.

Risk from Events

Risk events can impact both cost and schedule and should be identified, assessed, analyzed, and mitigated by the

project team using a risk register and risk management process described later in this chapter. The magnitude of impacts can vary greatly and can change during the life span of the project requiring continuous monitoring throughout the project. Risk events affect the cost, time, quality, and safety of the project both independently and in association with budget and schedule uncertainties. Risk events are usually managed through a risk register. The risk register consists of a description of the risk, a qualitative and quantitative value of the impact, a probability of occurrence, and possible mitigation plans. The project team will identify and develop the elements of the risk register through individual interviews with project participants, or by using risk workshops with the entire project management team or a combination of the two. Creating the risk register will be discussed in more detail in the risk management process section.

Risk of Estimate (Cost) Uncertainty

The uncertainties contained within the project cost estimate include scope variations, quantity variations, and price fluctuations. Cost estimates also include imprecise data usually delt with in the form of allowances, which would fall into the known-unknown category, and are known to the estimator but are not detailed in the estimate. Cost uncertainty is usually addressed at the summary level of the cost estimate to prevent the offsetting contributions from excessive detail. The project team will assess the variability of various estimated items accounting for the uncertainty contained in the estimate. The estimator may provide some insight into these uncertainties as part of preparing the estimate and documenting these uncertainties in the Basis of Estimate.

Risk of Schedule Uncertainty

Schedule uncertainty includes variations in planned resources, variations in activity duration, and conditional sequencing among activities. The schedule can be analyzed independently of the cost elements or can be analyzed as an integrated cost-schedule risk analysis. By using a cost and/or resource loaded schedule, the influence of the schedule uncertainty can be integrated with the cost risk model providing a more accurate earned value assessment.

Risk Management Process

The owner, designer, and contractor are all exposed to risk from the start of a project through its completion, and sometimes beyond. The risks may involve cost, schedule, quality, environmental, health, safety, or customer satisfaction. Each party must identify the risks, evaluate their probability of occurrence, analyze their severity and impact, and then develop a plan to prevent or avoid each risk and uncover mitigations to rectify the impacts of each risk if it occurs. Risks in the project need to be recognized and managed using a systematic approach following the six basic steps outlined in Figure 8-2.

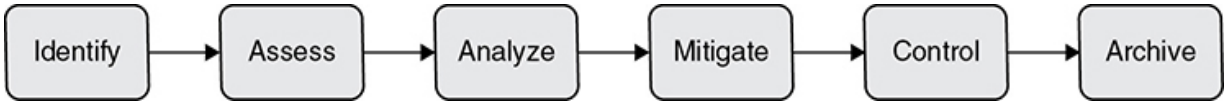


FIGURE 8-2 Risk management process.

Step 1—Risk Identification

Identify risks type (threat or opportunity).
Identify risk parameters (description, cause, effects/consequences).
Identify risk responsibility (project area, risk owner).
Identify risk sources (internal, external).

Step 2—Risk Assessment

- Determine probability of occurrence (likelihood) of the risk.
- Evaluate severity (impact) of the risk to cost, schedule, scope, and quality.

Step 3—Risk Analysis

- Use the premitigation score to rank and prioritize the risks.
- Use probabilistic methods to determine the range of exposure and total impact to the project.

Step 4—Mitigation

- Develop plans to prevent, avoid, reduce, or transfer the risk.
- Develop strategies to minimize the risk if it occurs.

Step 5—Control

- Implement mitigations to reduce impacts from triggered risks.
- Monitor the activity of the project to assess the remaining risk exposure.

Step 6—Archive

- Document the causes, effects, and mitigations for use on future projects.

Assessment of risk involves identifying the risk (what can go wrong), determining the root cause, and identifying what parts of the project could be impacted if the risk occurs. Risks are also sorted into categories, such as health, safety, environmental, quality, financial, or delay, and responsibly assigned to the project participant best suited to deal with the risk. It should be noted that some risks may fall into several categories and require multiple monitoring parties. After each risk is identified and assessed, an analysis can be made to determine the probability of occurrence (likelihood it may occur) and the severity (impact of the risk) if the risk occurs. After the probability and severity of the risk are

determined, a mitigation strategy can be established to prevent the risk (risk prevention) and/or develop a plan to resolve the risk impact (how to fix or reduce the problem) if it occurs. Thus, risk management involves risk assessment, analysis, and mitigation.

It is important to identify and manage risks early in a project, rather than later. Attempting to deal with risks late in a project puts pressure on people, which can lead to frustration and poor decision making.

Table 8-3 shows activities and deliverables in a risk management process. Methods of identifying, analyzing, and mitigating risks are obvious parts of the risk management process. However, it is also important to capture and document lessons learned from executing a risk management process. In particular, it is important to document issues related to risk mitigation strategies that were effective and therefore should be used on future projects. Also, methods that were not effective should be documented with recommendations to modify or discard. Lessons learned from previous projects are extremely useful for effectively managing future projects.

Process	Activities	Method	Deliverables
Risk identification	Identify and document risks Document causes and effects	Interviews/risk workshop	Risk register
Risk assessment	Perform qualitative analysis	Interviews/risk workshop	Risk register
Risk analysis	Perform quantitative analysis	Monte Carlo	Risk analysis report
Risk mitigation	Select risk response strategies Develop risk mitigation plans Identify addition costs associated with the mitigation	Risk owner interview	Risk mitigation plan
Control	Monitor work for risk triggers	Team reviews	Updated risk register
Lessons learned	Document lessons learned Conduct post project review	Record impacts and mitigations	Lessons learned log

TABLE 8-3 Activities and Deliverables of Risk Management Process

Guidelines for Risk Management Process

There are at least seven guiding principles that should be followed by every project team member involved in the risk management process.

1. The project team should determine and agree on the level of severity for each risk.
2. A single person should be assigned responsibility for each risk, even if there are several people working to mitigate that risk.
3. The most severe risks should receive the highest priority and be tracked closely.
4. Realistic due dates should be established, and the team should then work to meet those dates.
5. After decisions are made, they should not be revisited unless substantively new facts become available.
6. Risks should be mitigated at the appropriate level, such as owner, project team, subcontractor, vendor, etc.
7. There should be documentation of the planned and actual mitigation of each risk, to serve as input into lessons learned for future projects.

Risk Assessment

Risk assessment involves identifying potential risks. In simple terms, a list of risks is the answer to the question of "What can go wrong?" Members in functions from all areas of the project team should assess the work for which they are responsible and develop a list of risks. It is especially important to identify the most critical risks, which are the

risks that are most likely to occur and the risks that could have the greatest impact on the project, and then document those risks.

Members of the project team should participate in identifying potential risks for the project. A variety of techniques can be used for risk identification, including brainstorming, interviews, checklists, and review of project risk registers from previous projects. Usually, early in the life of a project a risk workshop will be conducted to identify risks based on lessons learned and experience from previous projects. Typically, participants include the project manager, risk specialists, and people from project controls, scheduling, contracts, designers, and other subject matter experts. Participants in the workshop may also include risk management consultants from outside the company.

Table 8-4 is a sample list of common risk factors that may occur during the design, procurement, and construction phases of a project. Table 8-5 is an example of a checklist of risks for construction of an electrical transmission line project.

Design
Changes (owner design changes, scope growth, cost growth, schedule slippage)
Design errors or omissions (calculations, spreadsheets, software)
Compliance (owner's standards, regulatory codes, and requirements)
Drawing errors (conflicts in dimensions, plans, elevations, sections, details)
Specifications (conflicts in writings of related specs and/or omissions)
Conflicts in documents (between drawings and specs, and reports and studies)
Underestimating construction costs of design alternatives
Working relationships with owner and contractor
Procurement
Prequalification of suppliers and vendors
Late issue of requisitions for long lead time equipment
Delayed vendor engineering and design
Partial shipment of materials and/or equipment to jobsite
Failure of factory acceptance tests (FATs)
Damaged shipment of special materials/equipment
Failure to meet specification requirements
Construction
Physical risks (site access/storage, subsurface conditions, weather)
Contractual (approval process, subcontractor failure, supplier defaults)
Costs (underestimated costs, cash flows, cost overruns, liquidated damages)
Schedule (unrealistic schedules, delays in work, weather, subcontractor schedule conflicts)
Labor (availability, productivity, strikes, safety, accidents, defective work, disputes)
Delivery of material/equipment (late/partial/damaged delivery to job-site)
Drawings and specifications (errors in drawings, conflicts in specs)
Working relationships with owner, designer, vendors, and other contractors
Coordination with owner's staff and staff of other contractor's working on project
Construction traffic, proximity to public thoroughfares
Construction equipment availability and maintenance
Interference by protesters or regulatory agencies

TABLE 8-4 Risk Factors during Design, Procurement, and Construction

Material delivery delays
Steel poles
Conductor wire
Shield wire
Foundation problems
Encountering rock instead of clay in drilling foundations
Moving underground utilities
Right-of-ways
Delays in securing right-of-way
Condemnation hearings to secure right-of-ways
Energizing line
Schedule slippage due to adverse weather conditions
Loss of tax advantage if line is not energized by the end of calendar year

TABLE 8-5 Checklist of Risks for Construction of an Electrical Transmission Line Project

Most companies establish policies and develop standards that are used to guide the risk management team in risk assessment. Typically, risk assessment is made using qualitative methods in accordance with the risk standard of a company. After a risk is defined, a subjective evaluation of the risk is made based on the judgment and collective thoughts of the risk management team. For example, a company standard for evaluating the level of occurrence of a risk may be classified by a scale, such as very low, low, medium, high, or very high. A low level of occurrence designates a small chance the risk will occur, while a high level of occurrence designates a high chance the identified risk will occur. A similar initial evaluation of the impact or severity of a risk is often made on a qualitative scale from very low to very high. Typically, a company risk management standard defines guidelines for converting qualitative evaluations to quantitative numerical values as illustrated in Table 8-6. The project team may also set the levels appropriate for the project location, type of operation, complexity, and market environment.

Scale	Probability	Schedule Impact	Cost Impact
Very high	> 65%	> 40%	> 20%
High	30%–65%	20%–40%	10%–20%
Medium	10%–30%	10%–20%	5%–10%
Low	1%–10%	1%–10%	1%–5%
Very low	1%	> 1%	> 1%

TABLE 8-6 Converting Qualitative to Quantitative Values

Risk Analysis

Risk analysis involves analyzing the probability of occurrence and the degree of severity of each risk. Although statistical models, simulations, and other numerical methods can be used in risk analysis, the judgment and wisdom of competent people who have extensive experience in project work should be included. Numerical analysis of risk is not a stand-alone substitute for common sense and judgment of experienced people. There are also usually company standards for evaluating and ranking the risks using a Boston Square matrix to score each risk as illustrated in Figure 8-3. Risk scores are shaded to indicate the level of severity. A risk register can be sorted by these scores to establish the risks which deserve the greatest attention.

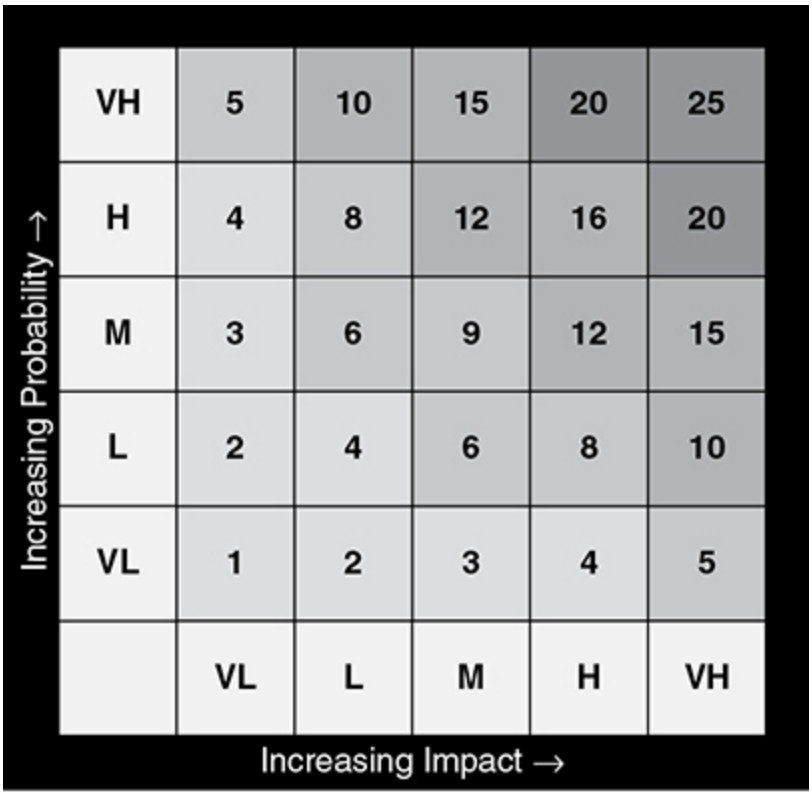


FIGURE 8-3 Boston Square risk assessment matrix.

Table 8-7 shows an expected value risk analysis of the checklist of items for the electrical transmission line project shown in Table 8-5. A probability of occurrence and a level of severity is given to each item in the checklist. The risk score is calculated by multiplying the probability times the severity factor. A legend of the criteria for the analysis of severity is shown at the bottom of the table. The risk score for the project is calculated as the sum of the risk score for each item in the checklist. Results of the analysis shows the highest risk is delivery of material, in particular, delivery of conductor wire to the jobsite. Therefore, special attention should be devoted to ensuring delivery of conductor wire. Actions that can be taken to ensure timely delivery of conductor wire include verifying availability from the supplier, issuing an early purchase order, securing a

confirmation delivery date in the purchase order, and follow-up by contacting the vendor on shipping dates.

Risk Item	Probability (Likelihood)	Severity (Impact)	Risk Score
Delivery of materials			
Steel poles	70%	Low (3)	2.1
Conductor wire	50%	High (9)	4.5
Shield wire	25%	Medium (6)	1.5
		Material Delivery Subtotal =	**8.1**
Foundation problems			
Encountered rock	40%	High (8)	3.2
Underground utilities	10%	Low (2)	0.2
		Foundation Problems Subtotal =	**3.4**
Right-of-way easements			
Delays in securing	50%	Medium (7)	3.5
Condemnation	15%	Medium (6)	4.4
		Easements Subtotal =	**7.9**
Energizing Line			
Schedule slippage	30%	Low (3)	0.9
Lost tax advantage	30%	High (9)	2.7
		Energizing Line Subtotal =	**3.6**
		Total Project Risk Score =	**23.0**
Company established criteria for severity:			
	Severity	***Cost***	***Schedule***
	Low (1–4)	*Reduced profit*	*No penalties*
	Medium (5–7)	*Lost profit*	*Minimal penalties*
	High (8–10)	*Catastrophic loss*	*Severe penalties*

TABLE 8-7 Expected Value Risk Analysis of Electrical Transmission Line Project

Risk Analysis of Costs

There are many risks in preparing a cost estimate for a project. There are risks in calculating the quantities of materials, extension of prices, and variations in quotes from subcontractors and suppliers of materials and equipment. There are also risks in assumed production rates of laborers and construction equipment.

Typically, the basis of the cost estimate consists of the estimated cost plus a contingency amount that is applied to each bid item. After an estimate is prepared, a thorough review of bid items in the estimate should be conducted to identify potential risks. Then each bid item in the list can be evaluated for gaps or overlaps in scope, budget, quality, or other potential risks that might occur. The first step in risk analysis involves determining the maximum possible risk for each bid item, recognizing that it is unlikely that all the bid items will incur risk. The next step involves determining the probability of occurrence of each risk. The maximum possible risk multiplied by the probability of occurrence percentage gives the expected net risk for each bid item, reference Table 8-8.

Estimate Item	Base Estimate	Maximum Cost	Maximum Risk	Probability Percentage	Expected Net Risk
1	$40,000	$50,000	$10,000	20%	$2,000
2	100,000	150,000	50,000	30%	15,000
3	250,000	320,000	70,000	50%	35,000
4	237,000	320,000	83,000	60%	49,800
5	94,000	135,000	41,000	30%	12,300
6	730,000	870,000	140,000	40%	56,000
7	572,000	640,000	68,000	50%	34,000
8	85,000	97,000	12,000	20%	2,400
Totals	$2,108,000	$2,582,000	$474,000		$206,500

TABLE 8-8 Risk Analysis of Cost Using Expected Value

The risk analysis data in Table 8-8 shows a base estimate of $2,108,000 with a maximum anticipated cost of $2,582,000, a difference of $474,000. However, it is unlikely that all of the risks will occur for each item in the estimate. Therefore, the expected net risk for each bid item is calculated by multiplying the maximum risk by the probability percentage of each item. The total expected net risk for the project is $206,500, which is calculated as the sum of the net risk for each item in the estimate. The $206,500 represents a contingency markup of 9.8% on the base cost of $2,108,000, which is calculated as ($206,500/$2,108,000) × 100 = 9.8%. For this project the final estimate can be calculated as the base estimate plus the total expected net risk, $2,108,000 + $206,500 = $2,314,500. The project team must remember that just because some risks do not materialize, the money calculated for those individual risks cannot be reallocated. The expected value for the project is a “bucket” of money to cover the expected cost of the risks that do materialize. For example, if risk 6 occurs, the cost of that risk will probably not be $56,000, it could be as high as $140,000 or more. Therefore, the project manager cannot reduce the total expected value for the project. For example, if risk 7 does not materialize, risk 7’s expected value ($34,000), should not be deducted from the project’s total expected value amount because that money could be required to cover the costs of other risks should they occur.

Risk Analysis Using Simulation

Monte Carlo simulation is a statistical method for interactively evaluating a deterministic model using sets of random numbers as inputs. It can be used as a tool for risk analysis of schedules, cost estimates, and/or risk events.

Monte Carlo analysis begins with a deterministic model, such as a baseline schedule or base cost estimate.

Computer software programs are available to mathematically compute and track many different possible risk scenarios and the probabilities of occurrence associated with each risk. Analysis of risks can be made for cost estimates, project schedules, labor productivity, or resource allocations. Software packages are available to analyze models created in spreadsheets, defining variable inputs in terms of realistic ranges of possible values and probable outcomes. The analysis assists in making decisions on which risks to accept and which risks that should be mitigated or avoided.

Monte Carlo simulations are typically applied and most helpful in the process of front-end planning by owners for high-risk projects, prior to actual work. The Monte Carlo simulation is used to define a contingency amount to allocate for the project. The larger the project, the more need for sophisticated risk analysis tools like Monte Carlo simulation to analyze a range of risk probabilities.

It is important to note that the credibility of Monte Carlo simulations is only as effective as the cumulative experience of those who develop the variables that are used in the simulation. The reliability of a project schedule simulation is highly dependent on the quality of the baseline schedule for the project. For example, the project schedule must have appropriate sequencing of activities and realistic durations before attempting to run a simulation analysis. Likewise, the reliability of a simulation analysis of a cost estimate is highly dependent on the quality of the baseline estimate. Attempting to run a simulation analysis on a baseline cost estimate that is full of errors results in unreliable results.

Risk Analysis of Schedules Using Simulation

Simulation allows much greater flexibility than The Program Evaluation Review Technique (PERT) analysis for risk analysis of schedules. A Critical Path Method (CPM) schedule is a deterministic model that consists of relationship of activities and their durations. Simulation is a technique that uses a computer to evaluate the model numerically. Monte Carlo is a simulation technique that requires a computer to perform thousands of calculations to evaluate activity durations and sequences in a CPM network. Many of the computer scheduling software packages have the capability to perform a Monte Carlo simulation.

Monte Carlo simulation of a project schedule involves developing multiple schedules based on durations that are randomly selected from a set range for each activity. First, a duration range is defined, and a duration distribution is established for each activity. The distributions may be linear or nonlinear, such as uniform, triangular, or exponential. Figure 8-4 shows examples of duration distributions that are typically used for simulations of costs and schedules for engineering and construction projects. The minimum duration is (**a**) and the maximum is (**b**) and the most likely is (**m**).

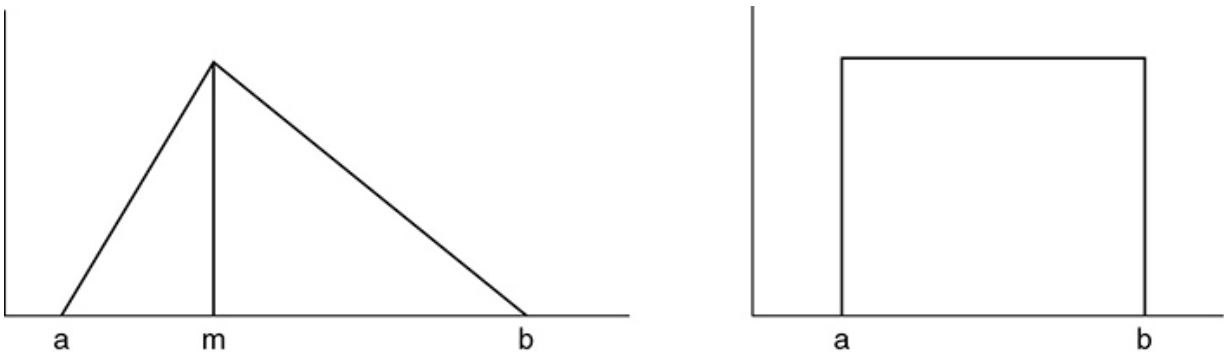


FIGURE 8-4 Examples of duration distribution.

After the range and duration distribution is defined for each activity, the software creates a schedule for the project by assigning a duration for each activity that is randomly

selected from the duration distribution of each activity. For example, the first CPM calculation for a schedule may calculate a project duration of 380 days. Then, a second schedule is developed by assigning a duration for each activity that is again randomly selected from the duration distribution of each activity. The second CPM calculation of this schedule may calculate a project duration of 420 days. This process is repeated thousands of times by the computer to develop a profile of the project duration. The end result may be a range of durations from 360 days to 450 days. Then the mean and standard deviation of the project durations can be calculated, and a probability curve can be developed.

Figure 8-5 is an example of using simulation for risk analysis of a project schedule. The left-hand ordinate shows the number of calculated durations in the simulation process, and the right-hand ordinate shows the cumulative frequency and range of working days. The abscissa shows the range of working days from a minimum of 162 to a maximum of 237 days. The simulation analysis shows there is a 10% probability the project will be completed in 182 days and a 90% probability it will finish in 221 days. There is a 50% probability the project will be completed in 206 days. The probability of completing the project in 190 days is 17%. Risk analysis by simulation allows the project team and upper management to make decisions using the probability of achieving different durations, rather than reporting a single duration for the project.

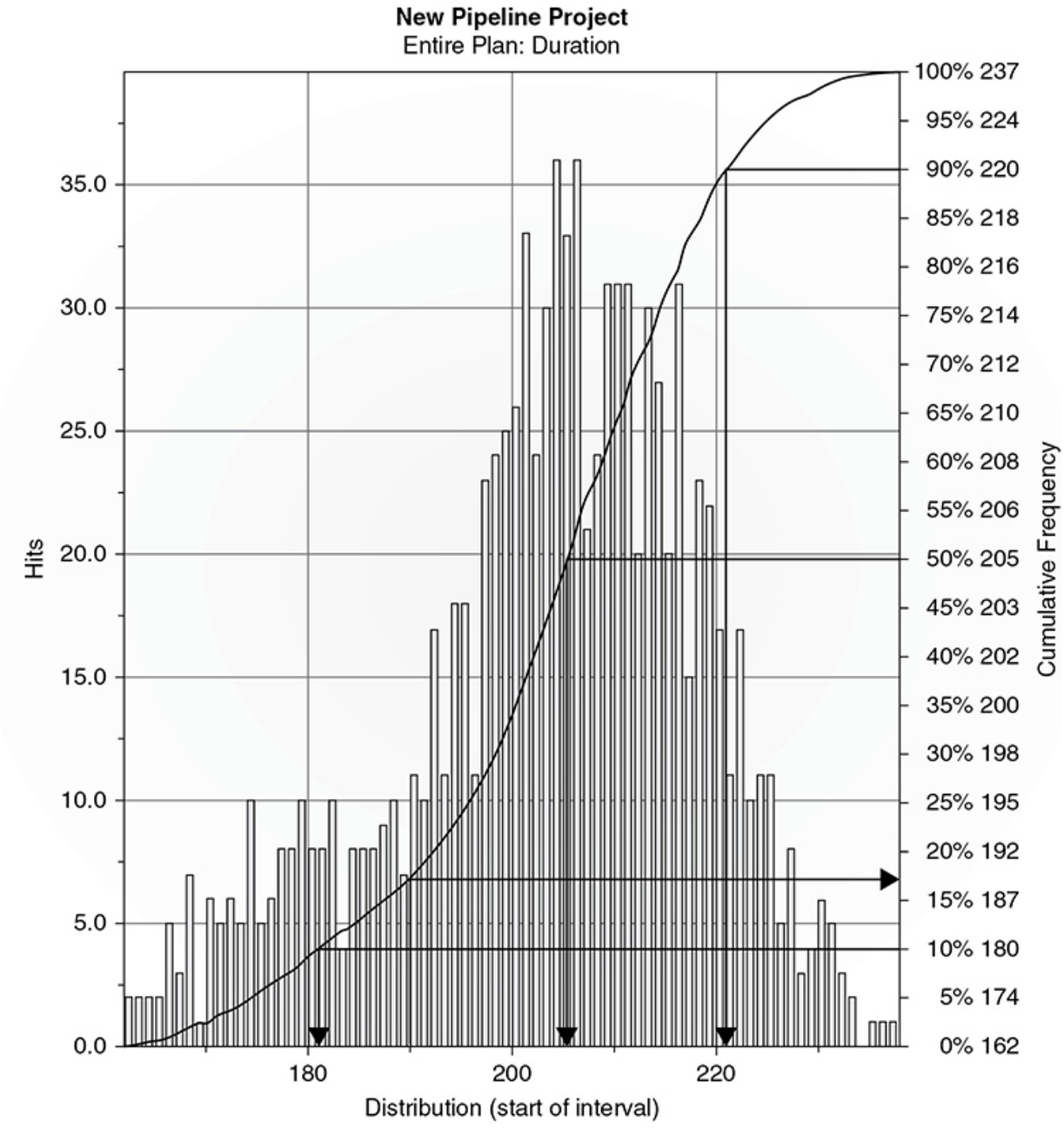


FIGURE 8-5 Risk analysis of project schedule using simulation.

Risk Analysis of Costs Using Simulation

Monte Carlo simulation of costs begins with the deterministic cost estimate, which is commonly called the base cost estimate. The base cost estimate is calculated

using the most likely cost of items in the estimate. A range of costs for each item in the estimate varies from an optimistic minimum value (a) to a pessimistic maximum value (b). A cost distribution is established for each cost item in the estimate. Using a computational algorithm, the Monte Carlo simulation program runs thousands of simulations, each time using a different set of values that are randomly selected from the cost distributions. The thousands of simulations calculated by the computer are used to develop a profile of the cost estimate of the project. The end result is a range of estimates with a corresponding probability percentage. Then the mean and standard deviation of the project cost estimates can be calculated, and a probability curve can be developed.

Similar to Figure 8-5 for schedules, Figure 8-6 is an example of using simulation for risk analysis of a cost estimate. The left-hand ordinate shows the number of calculations in the simulation process, and the right-hand ordinate shows the cumulative frequency and range of costs. The abscissa shows the range of cost estimates from a minimum of $11,595,500 to a maximum of $16,103,607. The simulation analysis shows there is a 10% probability for a cost estimate of $12,656,786 and a 90% probability for a cost estimate of $14,329,143. There is a 50% probability for a cost estimate of $13,413,536. Risk analysis of a cost estimate by simulation allows upper management to make decisions based on a range of costs with associated probabilities, rather than reporting a single number for the cost estimate.

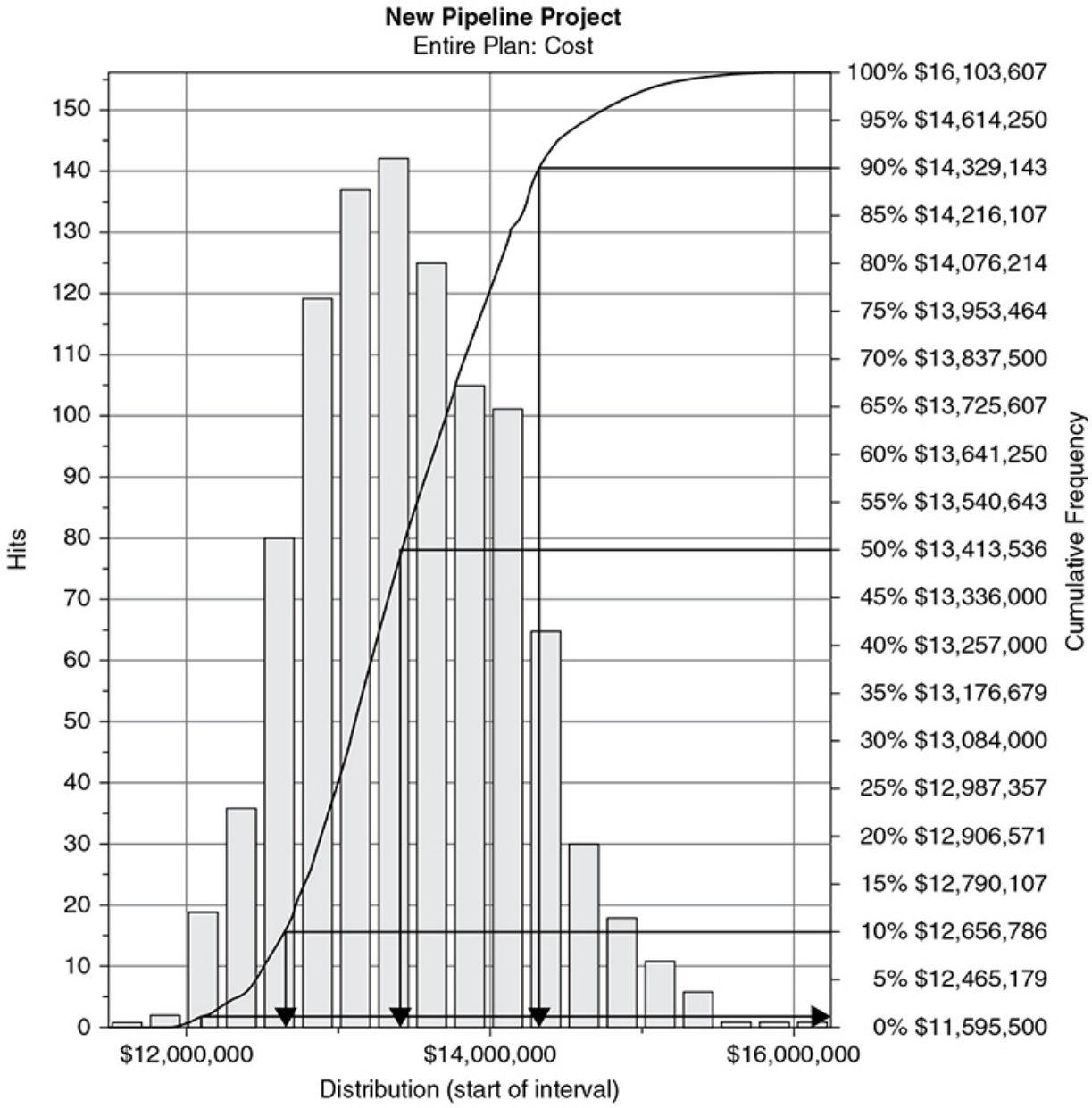


FIGURE 8-6 Risk analysis of cost estimate using simulation.

As a comparison to the expected value method, a Monte Carlo simulation of Table 8-8 provides a range of possible outcomes shown in Figure 8-7. Company standards usually provide the project team with guidance for selecting the certainty (P-number) that the project should use for risk contingency. In this case, the expected value of $206,500

provides a P-value of 93%, or the project team can be 93% certain that the project cost will not exceed $206,500.

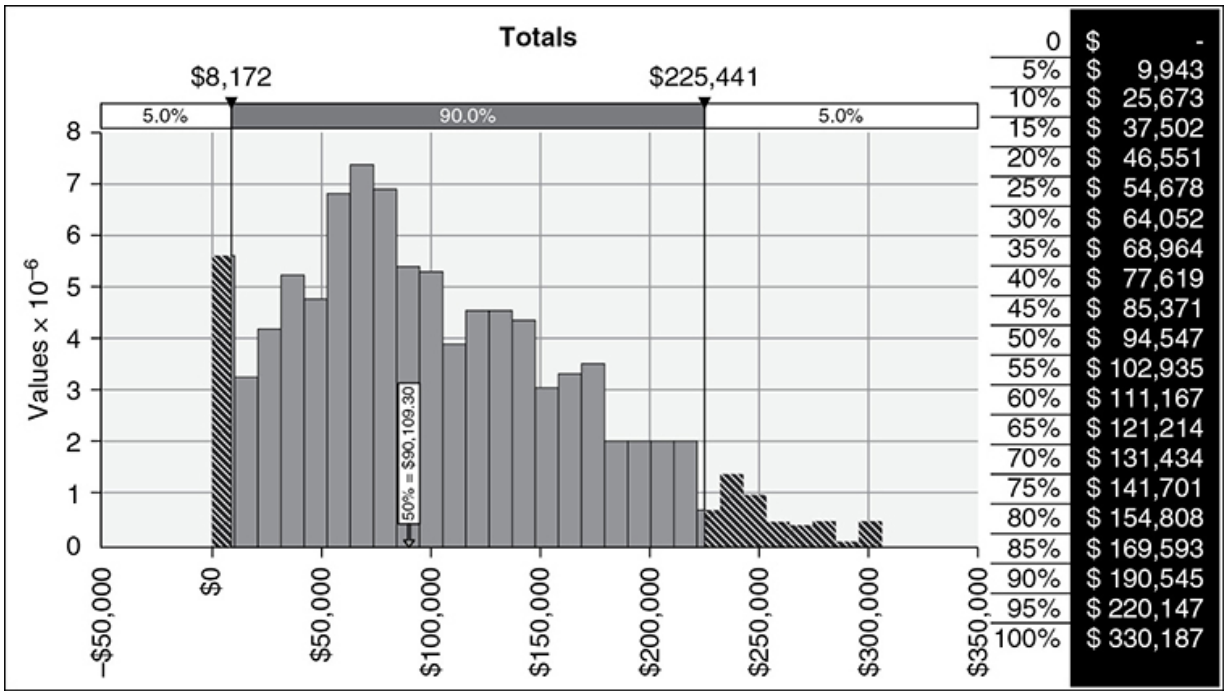


FIGURE 8-7 Monte Carlo simulation.

Mitigation of Risk

A key attribute of experienced and successful project managers is their ability to identify and manage risk. Successful project managers are always looking for what can go wrong, and they have a plan to rectify the problem. A project manager should be proactive in managing risk, rather than responding to risks after they occur.

It is always much easier to prevent a risk from happening than it is to fix problems that occur after the risk is realized. In simple analogous terms, an ounce of prevention is worth a pound of cure. Many risks can be easily prevented by effective communications and instructions. For, example, a simple call to a supplier to confirm delivery dates, performing certified welds in the shop instead of field welds

at the jobsite, etc. Fixing problems from the occurrence of a risk can be challenging and costly with respect to time, money, and quality.

Experienced project managers generally have good ideas of what can go wrong in projects. Their knowledge and wisdom are gained from “lessons learned” while working on previous projects. Capturing the experience gained in handling risk issues on previous projects and bringing those “lessons learned” to risk management of new projects is a tremendous advantage in mitigating future risks.

The contract for a project plays a major role in risk management. Contracts govern the process of design and construction. The contract is a legal document that defines the roles and responsibilities of the parties and the requirements for performance of the work. Thus, the contract assigns risk to participants in the project. There is detailed information that is written in the contract, but too often the contract is not read. Understanding the terms and conditions of the contract that is signed by both parties is important to identifying, assessing, and mitigating risks.

There are multiple risks for any project. Therefore, the risks in a project should be considered collectively, rather than individually. To effectively manage and mitigate risks, a project risk register should be developed prior to the start of a project. A project risk register is a tool for collecting information about each risk and tracking the risk management process throughout the lifecycle of a project. The project risk register should be regularly evaluated at team meetings and updated when new risks are identified as a project moves through the project lifecycle.

Project Risk Register

A project risk register is a document that contains information about each risk event. An example risk register

is shown in Figure 8-8. The information should include a description of the risk, level of risk assessment, probability of occurrence, impact of the risk (in schedule and costs), and a risk management action plan. The following information should be contained in a project risk register:

Description of Identified Risk	Area of Risk	Probability of Occurrence	Estimated Value of Risk	Potential Impact of Risk	Status of Risk	Risk Mitigation Action Item
Design completion schedule (4 week slippage due to changed process)	Schedule	60%	$250,000	$150,000	Open	Dependent on extent of client comments
New equipment for revised process is manufactured overseas	Quality	33%	$48,000	$16,000	Open	Arrange for factory acceptance test at origin by expert witness
Schedule reduction (25 mo. vs. 24 mo.) to reduce insurance	Schedule	55%	$20,000	$11,000	Open	Start construction as soon as possible (<5 months from notice to proceed)
Estimated labor rates are $1/hr. above local average (consider using local labor?)	Cost	40%	$170,000	$68,000	Closed	Accounted for in estimate
What is the owner's timeframe to provide approval of submittals?	Contract	40%	$39,000	$15,600	New	Need 8 days, not 28, approval of shop drawings (collaborate with submitter & reviewer)
Expedite procurement of long lead-time material & equipment (piping & compressors)	Cost and Schedule	10%	$750,000	$75,000	Open	Obtain commitment letter from owner & check cancelation costs
Significant dewatering requirements to install piping along river alignment	Cost and Schedule	60%	$500,000	$300,000	Open	Designate hydrogeologist to create dewater plan with dewatering subcontractor
Power lines cross the work area where cranes will be working	Safety	100%	$58,000	$58,000	Closed	Coordinate with power company to relocate line (buy and install line guards)
Weather: construction will be in adverse winter conditions	Schedule	25%	$120,000	$30,000	Mitigating	Check local area history for typical severe weather days & prepare accordingly
Obtaining right-of-way easements are taking longer than expected	Schedule	40%	$90,000	$36,000	Open	Employ additional land agents and/or consider alternate routes
Original land acquisition plan was based on know 45.3 mile route, but now find that state does not allow eminent domain	Scope	90%	$1,894,000	$1,704,600	New	Rerouting of pipeline is expected, which may result in 48.8 mi. of pipe rather than planned 45.3 mi.
Client expects first system in service not later than 180 days after award of contract	Schedule	80%	$350,000	$280,000	Open	Coordinate sufficient resources for multiple shifts or extended work-hours

FIGURE 8-8 Illustration of project risk register.

- Description of identified risk—a description that uniquely describes the risk including cause and effect
- Risk manager—(sometimes called risk coordinator or risk owner) the person responsible for maintaining and implementing the risk mitigation plan
- Risk category—primary area of the project to which the risk pertains; risks are generally organized in categories associated with the risk breakdown structure or the Work Breakdown Structure

- Status—indicates the risk's standing in the risk management process; status may be defined as new, open, canceled, mitigating, and completed
- Risk assessment score—a qualitative assessment of the impact of the risk ranked for very low to very high
- Risk probability—indicates the probability of the risk occurring on a percentage basis
- Estimated value of risk—estimated value of remediating the realized risk based on an estimated, or known, project cost impact and remedial measure
- Potential risk impact—calculated value by multiplying the risk probability times the estimated risk value
- Allocation—identifies that element of the project team that is best able to control the risk mitigation
- Risk mitigation plan—summary narrative of the actions, schedule, and assigned resources required to mitigate the risk

Any member of the project team can, and should, identify potential risks in a project, and each risk should be entered in a project risk register. Each risk is identified in a risk area, such as financial, legal, work performance, technology, design, procurement, safety, quality, or labor resources. Persons that identify the risk are responsible for an initial assessment of the risk based on their judgment, or the collective thoughts of the project team. Subsequent analysis of each risk is performed that includes the probability of occurrence, level of severity, and impact of the risk. The person that defines the risk is sometimes called the risk originator.

The risk is then assigned to a risk manager (most often doubling as the project manager) who is empowered to ensure the risk is mitigated. The assignment is based on the type of risk and expertise of the risk manager responsible

for mitigating the risk. The risk manager is responsible for successfully mitigating the risk to a target (lower) risk severity level. The target severity level is determined by the risk manager, and it represents the expected result of implementing the plan to mitigate the risk. The risk manager is also responsible for providing the progress of mitigation to the project team. It should be noted that often the effect of mitigating a risk is not to eliminate the possibility that a risk could occur, but instead to reduce the likelihood and/or impact of the risk to an acceptable level.

In the process of identifying risks in a project it is helpful to ask "What If" questions. For example, in Figure 8-8 the last risk would be identified by the question "*What if the owner wants the first system to be in service not later than 180 days after award of the contract*." For this risk the 80% probability of occurrence is based on the current late finish date and the estimated schedule delays included in the risk register to-date. The estimated value of the risk is calculated as (cost of liquidated damages) × (potential days past in the in-service date.). The potential impact of the risk is calculated as (probability of occurrence) × (estimated value of the risk), (80% × $350,000 = $280,000). A unique analysis is made of each item in the project risk register.

Development of the Initial Project Risk Register

Generally, the initial development of the project risk register is performed in a brainstorming workshop. Those who participate in the identification of project risks will include staff from all parties who are involved in the project. For example, for a Design-Build project, the participants should include the project manager from each organization, lead design engineers, construction manager, lead cost estimator and scheduler, procurement manager, start-up and commissioning people, and the owner's operations and maintenance personnel. These key staff people fulfill a

broader role on the project as members of the risk management team.

Team members selected to participate in the risk identification process are provided background information in the form of proposal documents, the designer's scope of work, pre-design studies, design development deliverables, geotechnical reports, and cost estimates. This information is used by each participant to become familiar with the project and its requirements as well as the owner's goals and objectives.

After the brainstorming session, the identified risks are placed in the project risk register. Thus, the project risk register becomes a project management tool that should be regularly evaluated at project team meetings. Additionally, as the project delivery cycle moves forward, the project risk register is updated with newly identified risks as the project progresses through design milestones into construction execution and the start-up and commissioning phases of the project. Risks will also be closed as the potential for the risks is passed or the risks are realized and mitigated.

Strategies to Mitigate Risks

The first step in developing a risk mitigation plan is selection of a strategy to mitigate the risk. The strategy selected depends on the level of impact of the risk and the potential to successfully apply the strategy to mitigate the risk. Strategies for risk mitigation include the following:

- Accept the risk
- Avoid the risk
- Control the risk
- Investigate the risk
- Reduce the risk

- Transfer the risk

Acceptance of a risk is normally used for risks that have low probabilities of occurrence and minimal impacts. This technique may also apply to risks that are difficult to control. It is a passive technique that focuses on allowing the outcome of the risk to occur without trying to prevent that outcome.

Avoidance is a technique that prevents the occurrence of the risk. The risk is circumvented by changing the contract parameters that were established between the owner and contractor. Examples include reduction in scope of work, changing the requirements in the specifications, changing the statement of work, and submitting waivers and deviations.

Controlling the risk involves taking actions to reduce the likelihood of occurrence or impact of the risk. The control-based actions can occur at all phases of the project's lifecycle. The actions selected to control the risk are monitored and reported as part of the regular performance analysis of the project.

Investigation is a technique that defers all actions until more work is done and/or more facts become known. This technique does not define any mitigation for reducing an individual risk. It is applied to risks where no clear solution is identified, and further research is required.

Reduction is a technique to actively lower the risk by a planned series of activities. The method of reduction is unique for each risk.

Transferring a risk is a process of moving the risk to another party in the project. Typically, the risk is transferred to subcontractors or suppliers who are more able to reduce the overall risk exposure. This technique is mostly used during the proposal process of a project. The transfer of risk

can also include the use of third-party guaranties, such as insurance or performance bonds.

Methods to Prevent or Mitigate Risks

Methods of risk prevention or mitigation depend on the type of project and type of risk. Engineering and construction projects are generally categorized into three sectors: buildings, infrastructure, or process industry. The building sector may be subdivided into divisions, such as residential, commercial, or industrial buildings. Examples of infrastructure industry projects include highways and bridges, water and sewer systems, electrical transmission and distribution systems, etc. The type of projects in the process industry includes oil and gas, chemical plants, manufacturing, pharmaceutical, etc. Figure 8-9 gives examples of methods of preventing or mitigating risks for a project in the infrastructure sector.

Risk Description	Method to Prevention/Mitigation
Potential safety risks in constructing underground intake shaft	Manage the project safety plan closely, ensure all personnel are well-trained, and adhere to regulations.
Public interest group opposition to project	Develop public relations plan and establish effective communications to address issues
Distraction of client representatives from core project roles	Transparent analysis of alternatives; effort to hear and address concerns
Schedule delay	Weekly short-interval schedules; design and construction milestones; early start on construction before full design completion; stacking trades; multiple shifts; overtime
Accidental damage to environment	Conduct environmental compliance training; set up a full-time environmental monitoring system
Access shaft proximity to pump station construction & trucks cuttings across site	Employ a conveyor system to transport spoils to common loading point adjacent to site entrance
Evaluation and classification of geotechnical conditions	Contingency plan developed to shift crews to an alternate location.
Misalignment impacts performance and schedule of tunneling operation	Bore the intake shaft first and then bring the tunnel to it.
Risks to diving personnel due to depth and visibility conditions at underwater intake assembly and installation	Maintain the allowable bottom time per dive plus decompression time. Preassemble as many components as possible. Use remotely operated vehicles (ROVs) for inspection task (when visibility allows) to reduce diving requirement. Formulate means and methods (templates, stabbing guides, remotely activated equipment, etc., to minimize diving requirements)
Water source for testing tunnel pipelines	Develop flushing and testing plan; coordinate the connection of pipelines with large basin construction as a potential reservoir to flush
Risks to ongoing plant operations	Develop a plan to maintain plant operations during construction; construct bypass systems; install temporary systems
Average of 60 in. of snowfall per year; the average winter temperature is below 40°F	Site-specific safety procedures; training requirements, administrative controls, engineering controls, personal protective equipment; protection of the ongoing and completed work from extreme weather

FIGURE 8-9 Methods to prevent/mitigate risks.

Development of a Risk Mitigation Plan

After a risk mitigation strategy is selected, a risk mitigation plan can be developed by the risk manager. The risk mitigation plan is essentially a response to the risk. It

contains a series of action items in a sequential order that will successfully mitigate the risk to the target severity level and due date for mitigation of the risk. Each action item should have a defined start and finish date.

Each action item should also have a target severity level, which is the severity level that will be obtained when the action item is completed. It should also identify persons who will be responsible for performing the action items. The risk manager may contact the project manager or any member of the project team for assistance in developing and implementing the action plan. The project team should be contacted immediately if the risk manager is not able to mitigate the risk. There may be situations when it may be necessary to reassign the risk to another risk manager who is capable of resolving the risk.

After the risk mitigation plan is developed, it should be presented to the project team for their review and final approval. Upon approval of the risk management plan, the project risk register is updated and the risk manager can commence the risk mitigation. During implementation of the risk mitigation plan, the risk manager provides status updates as they occur through the risk register and prior to each project team meeting.

When the risk is mitigated, the risk manager updates the action items and provides adequate detail that describes the final status in the project risk register. If the project team agrees that mitigation is completed, the risk status is shown as “completed” or “closed” in the risk register.

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CHAPTER 9
Design Proposals

Evolution of Projects

As introduced in Chapter 1 and discussed in Chapter 2, a project progresses through a lifecycle of feasibility, conceptualization, detailed scope development, detailed engineering, and construction. As it pertains to developing a project, an owner may engage a design firm for three basic efforts. In Feasibility and Conceptualization phases, the design firm conducts studies for the owner to determine if the project objective will satisfy the primary business objective and performs alternative analysis which may also include identifying project alternatives for the owner. As a project makes it through approval decisions and enters Detailed Scope Development, the owner utilizes a design firm to develop preliminary designs, detailed scopes of work, estimates, schedules, and risk assessments. These work products are presented to decision-makers in the owner organization for project funding authorization. The third effort for which design firms are engaged is detailed engineering and design, the subject of this chapter.

This chapter is written from the perspective of the project manager who is responsible for managing the design effort —detailed engineering and design. Therefore, the use of project manager in this chapter refers to the design project manager. The material presented and discussed in this chapter on engineering design is an illustrative example of

applying the principles and techniques of project management presented in Chapter 3. For example, *scope* refers to the scope of work required for the design effort, *budget* refers to the cost for providing design services, and *schedule* refers to the schedule for performing the design work.

A project is in a continual state of evolution as it develops from conception to completion. Because of this project evolution, the design project manager should be involved at the beginning of the project and remain with the project until final completion. In all instances, the project manager is the prime contact with the owner of the project (owner's representative or owner's project manager). Various names are given to the owner, including owner, business unit, operating group, client, customer, and end user. Essentially, the owner is the organization that requests the work and will use the work when it is completed. Any change in a project is a major issue for the design team. Changes occur as a project progresses through the project phases as shown in Figure 9-1.



FIGURE 9-1 Project phases.

The owner's development phase (project approval and funds authorization) usually ends in a Request for Proposal (RFP) to further develop the project. At this time in the development of a project, there must be a clear understanding of the proposal request and the owner's goals. Continuity of the design project manager through early development and continuing through detailed design is crucial to a successful project. It is important for the design team to have a clear understanding of the desired outcome of the project and the reasons the project is being

undertaken by the owner. The design project manager serves as the binding thread for the team to ensure the team's clear understanding of the objectives and to remind the team along the way.

Project Initiation

Upon receipt of an RFP for design services, the design project manager must thoroughly review the RFP with the firm's management to determine if the design firm wants to undertake the project. Once the design firm decides to accept the RFP, the project manager should prepare a project charter. A thorough dissection of the RFP should establish a clear scope of work, key milestones, cost limitations, and special conditions. Has the owner provided a project objective statement that details why the project is being undertaken? Has the owner provided a feasibility threshold that the project must deliver? Has the owner clearly listed the deliverables needed?

Documenting the fundamental elements of the project from the RFP is the first step for the design firm to develop the project. Too often, RFPs have vaguely defined scopes of work that will later cause unforeseen additional work, which adversely impacts the budget and schedule. The effort to write a charter will reveal missing information needed to properly respond to the request, ambiguous requirements contained in the request, and conflicting requirements. Working with the client to solidify the project's purpose and key requirements in a charter establishes a clear project objective to guide the design team's efforts.

Once the charter is approved, the next step in developing a design proposal is development of the project execution plan to manage the design process. The focus of this project execution plan is the project that consists of performing the design work and delivering the design as specified in the

RFP and captured in the charter. The plan must include the scope of work covered in the RFP and interfaces with others who will be involved in the project, including both in-house and contract personnel. Table 3-4 provides a general outline for a project execution plan which can be modified to be specific for preparing a design proposal.

The plan must address the three fundamentals of the project: scope, time, and cost. Time spent decomposing the scope into discrete deliverables enables better scheduling of work efforts and improved estimating of work efforts. The plan at a minimum should include a milestone schedule that shows major phases and areas of work, including critical due dates. An overall preliminary budget must be developed to guide the project to ensure there are no unexpected surprises as the project develops. The budget should be supported with an estimate which is documented in the basis of estimate as described in Chapter 6.

Project Definition

Although project definition is primarily the responsibility of the owner's organization, often the design organization is involved in assisting project definition. Early questions of the design team include: What do we know about the project? What are we trying to do? What work do we need to do? The answers to these questions depend on a good definition of the project. It is not possible to define the scope of design work without a good definition of the project. Project definition is a prerequisite to engineering design.

Poor project scope definition is the source of project changes, rework, schedule delays, and cost overruns. The preproject planning research team of the Construction Industry Institute developed the Project Definition Rating Index (PDRI) as a tool to measure the level of definition of a project (see Figure 9-2). It allows a project team to quantify,

rate, and assess the level of scope development on projects prior to authorization for detailed design or construction. The central premise of the research team effort was that teams must be working on the right project in a collaborative manner (alignment) and performing the right work (scope definition) during preproject planning.

PDRI for Industrial Projects

I Basis of Project Decision

A Manufacturing Objectives Criteria
- A.1 Reliability Philosophy
- A.2 Maintenance Philosophy
- A.3 Operating Philosophy

B Business Objectives
- B.1 Products
- B.2 Market Strategy
- B.3 Project Strategy
- B.4 Affordability/Feasibility
- B.5 Capacities
- B.6 Future Expansion Considerations
- B.7 Expected Project Life Cycle
- B.8 Social Issues

C Basic Data Research & Development
- C.1 Technololgy
- C.2 Processes

D Project Scope
- D.1 Project Objectives Statement
- D.2 Project Design Criteria
- D.3 Site Characteristics Available vs. Required
- D.4 Dismantling & Demolition Requirements
- D.5 Lead/Discipline Scope of Work
- D.6 Project Schedule

E Value Engineering
- E.1 Process Simplification
- E.2 Design & Material Alternatives Considered/Rejected
- E.3 Design for Constructability Analysis

II Front End Definition

F Site Information
- F.1 Site Location
- F.2 Surveys & Soil Tests
- F.3 Environmental Assessment
- F.4 Permit Requirements
- F.5 Utility Sources with Supply Conds.
- F.6 Fire Protection & Safety Considerations

G Process/Mechanical

H Equipment Scope
- H.1 Equipment Status
- H.2 Equipment Location Drawing
- H.3 Equipment Utility Requirements

I Civil, Structural, Architectural
- I.1 Civil/Structural Requirements
- I.2 Architectual Requirements

J Infrastructure
- J.1 Water Treatment Requirements
- J.2 Loading/Unloading/Storage Facilities Requirements
- J.3 Transportation Requirements

K Instrument & Electrical
- K.1 Control Philosophy
- K.2 Logic Diagrams
- K.3 Electrical Area Classifications
- K.4 Substation Requirements/Power Sources Identified
- K.5 Electric Single Line Diagrams
- K.6 Instrument & Electrical Specifications

III Execution Approach

L Procurement Strategy
- L.1 Procurement Strategy Equipment & Materials
- L.2 Procurement Procedures & Plans
- L.3 Procurement Responsibility Matrix

M Deliverables
- M.1 CADD/Model Requirements
- M.2 Deliverable Defined
- M.3 Distribution Matrix

N Project Control
- N.1 Project Control Requirements
- N.2 Project Accounting Requirements
- N.3 Risk Analysis

P Project Execution Plan

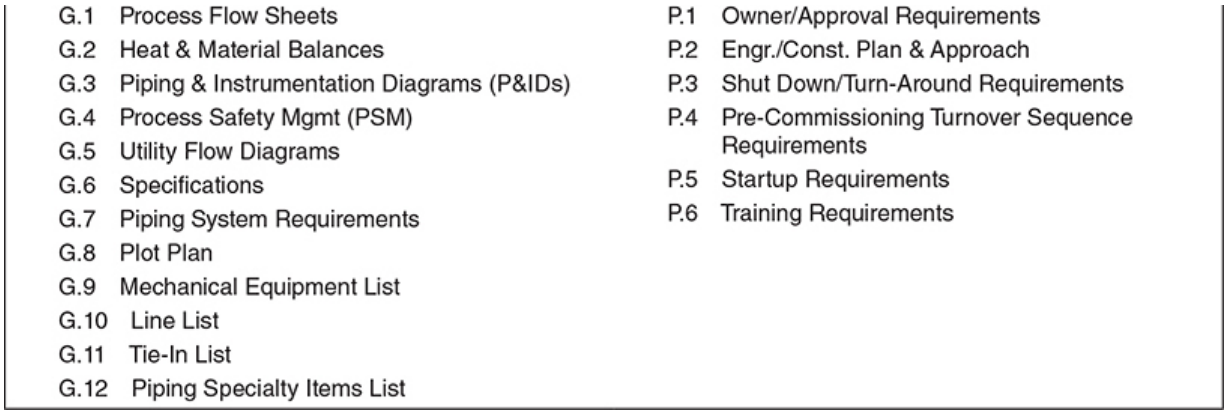


FIGURE 9-2 Project definition rating index (PDRI) for industrial projects—sections, categories, and elements. (*Source:* Construction Industry Institute.)

Figure 9-2 is the PDRI for industrial projects, which applies primarily to process industry work. There is also a PDRI for infrastructure projects and a PDRI for building projects. NASA's Pre-Project Planning Team has utilized PDRI for building projects. NASA also identified that the use of PDRI for industrial projects was suited for power plants, manufacturing facilities, and other similar projects. Figure 9-3 shows the PDRI sections, categories, and elements for building projects as used by NASA.

PDRI for NASA Building Projects

I Basis of Project Decision

A Business Strategy
- A.1 Building Use Requirement
- A.2 Business Justification
- A.3 Business Plan
- A.4 Economic Analysis
- A.5 Facility Requirements
- A.6 Future Expansion/Alteration
- A.7 Site Selection Considerations
- A.8 Project Objectives Statement

B Owner Philosophies
- B.1 Reliability Philosophy
- B.2 Maintenance Philosophy
- B.3 Operating Philosophy
- B.4 Design Philosophy

C Project Requirements
- C.1 Value-Analysis Process
- C.2 Project Design Criteria
- C.3 Evaluation of Existing Facilities
- C.4 Scope of Work Overview
- C.5 Project Schedule
- C.6 Project Cost Estimate

II Front End Definition

D Site Information
- D.1 Site Layout
- D.2 Site Surveys
- D.3 Civil/Geotechnical Information
- D.4 Governing Regulatory Requirements
- D.5 Environmental Assessment
- D.6 Utility Sources with Supply Conds.
- D.7 Site Life Safety Considerations
- D.8 Special Water & Waste Treatment Requirements

E Building Programming
- E.1 Program Statement
- E.2 Building Summary Space List
- E.3 Overall Adjacency Diagrams
- E.4 Stacking Diagrams
- E.5 Growth & Phased Development
- E.6 Circulation & Open Space Requirements
- E.7 Functional Relationship Diagrams/Room by Room
- E.8 Loading/Unloading/Storage Facilities Requirements
- E.9 Transportation Requirements
- E.10 Building Finishes
- E.11 Room Data Sheets
- E.12 Furnishings, Equipment, & Built-Ins
- E.13 Window Treatment Considerations

F Building/Project Design Parameters
- F.1 Civil/Site Design
- F.2 Architectural Design
- F.3 Sturctural Design
- F.4 Mechanical Design
- F.5 Electrical Design
- F.6 Building Life Safety Requirements
- F.7 Constructability Analysis
- F.8 Technological Sophistication

G Equipment
- G.1 Equipment List
- G.2 Equipment Location Drawings
- G.3 Equipment Utility Requirements

III Execution Approach

H Procurement Strategy
- H.1 Identify Long Lead/Critical Equipment & Materials
- H.2 Procurement Procedures & Plans

J Deliverables
- J.1 CADD/Model Requirements
- J.2 Documentation/Deliverables

K Project Control
- K.1 Project Quality Assurance & Control
- K.2 Project Cost Control
- K.3 Project Schedule Control Requirements
- K.4 Risk Management
- K.5 Safety Procedures

L Project Execution Plan
- L.1 Project Organization
- L.2 Owner Approval Requirements
- L.3 Project Delivery Method
- L.4 Design/Construction Plan & Approach
- L.5 Substantial Completion Requirements

FIGURE 9-3 Project definition rating index (PDRI) for NASA building projects—sections, categories, and elements. (*Source:* NASA Pre-Project Planning Team.)

The PDRI for industrial projects consist of 70 elements, grouped into 15 categories, which are further grouped into 3 broad sections (see Figure 9-2). To determine the PDRI, each of the elements is rated on a scale from 1 to 5. An element rating of 1 represents complete definition, whereas a rating of 5 represents incomplete or poor definition of the element. The sum of the element weights is the composite weighted score of a project, which can range up to 1,000 points, with lower points as a better score and higher points as a worse score. Based on an analysis of 40 projects, the research team found that projects scoring less than 200, out of 1,000 total points, were significantly more successful than those that scored greater than 200.

The PDRI can be used in many ways for improving project definition. At the most basic level, it can be used as a checklist. At a very mature level, PDRI facilitators can be used to objectively score projects and eventually compare the results to project performance measures.

An important part of the design project, beginning during early discussions with the owner, should include incorporating value improving practices (VIPs). These were introduced in Chapter 3. The process of project development attempts to balance trade-offs between project cost, project schedule, and facility operability to meet the business objectives stated in the project charter. VIPs, when applied systematically and consistently during project development, provide an owner with measurable project performance parameters. This project performance data can prove useful to owners with large capital project portfolios by allowing them to improve overall capital project performance. As discussed in Chapter 3, VIPs aim to improve the lifecycle performance of the asset being considered, meaning from

first operation through the asset’s life, to retirement or decommissioning. Value engineering is a well-known VIP as is constructability assessments. A partial list of VIPs includes the following list. More information can be found in the references at the end of this chapter.

- Setting business priorities
- Customized standards and specifications
- Waste minimization and management
- Design to capacity
- Technology selection
- Value engineering
- Process simplification
- Constructability

Problems in Developing Project Definition

Too often, insufficient time is devoted to defining the requirements of projects. Project definition is usually performed by people outside engineering and construction. These individuals generally have job responsibilities involving finances, marketing, or managing a business unit in the owner’s organization. Their job responsibilities and expertise are often not related to defining requirements of a project in terms that can be converted to engineering design and construction. Therefore, it is vitally important that members of the current operating group that will use the project when it is completed should be involved in confirming that the established project definition will meet their goals and objectives. The goals and objectives must be adequately quantified and documented. This requires

coordination between the owner’s organization and the project team.

Sometimes the only fixed known information about the project is the amount of money the owner has to spend. This is accompanied by only a vague idea of what the owner would like from the expenditure of money. The owner may have a wish list of what he or she would like, but the only firm information is the total amount of available funds. For this type of situation, the designer must work closely with the owner to identify the desired operational criteria of the project: what the owner must do with the project when it is completed in order to satisfy the business objective driving the project. The designer must assist the owner in separating what the owner needs from what they want. The designer must convert the owner’s needs into an engineering scope of work and the associated construction costs to produce the final project. A cost for each element in the project must be determined to ensure the project will not exceed the owner’s available funds. The design project manager should be prepared to modify the owner’s expectations of what can be achieved with the reality of what can be afforded with the budget.

High turnover of people is another problem for project definition. Many owner organizations frequently promote and reassign personnel. This often occurs during the length of time required to develop a project. Twenty-first century workers do not display company or project loyalty as in the past and will leave for perceived better opportunities regardless of project needs. Turnover of people can lead to changed project priorities and confusion. By the time a project reaches the funds’ approval stage, often the people who established the initial project definition may no longer be involved. This very real risk to the project is best managed by a well-documented project charter, project execution plan, and other key documents.

A thorough and detailed definition of the project is a prerequisite to planning the work because the team members must know what the project is before they can plan it. Too often, there is a rush into the implementation phase even before the team has a good understanding and agreement of project definition. Getting early team agreement on definition prevents the project scope from creeping out of control.

Engineering Organization

Starting with the technical or discipline managers, members of the design team should be involved in the project at the earliest possible date, preferably during the proposal preparation phase. The design engineers that will actually be doing the work can be extremely valuable for defining scope, identifying potential problems, and preparing realistic budgets and schedules for performing the work. Too often, the designers are not a part of the proposal preparation or do not become involved until the proposal is presented to and approved by the owner. By then, the scope, budget, and schedule may be fixed, but it may not represent the actual work that is necessary to complete the project the way the owner expects from the proposal. Getting input and early involvement of the design team is crucial to a successful project.

To effectively manage the design effort, an organizational chart should be developed for each project. The organizational chart is effective for defining the roles and responsibilities of the engineering manager and his or her team members during design. There must be a clear understanding of the reporting relationships of all members of the engineering team. If external consultants are involved, there must be a clear description of their reporting relationships as well as their roles and responsibilities. There

must be a list of key members of the engineering team, including consultants where applicable, along with their telephone numbers, fax numbers, and e-mail addresses.

Figure 9-4 is an example of a list of technical expertise that may be needed for engineering design. For the list of particular technical expertise that is unique for each project, the project manager should develop an organizational chart that shows the interrelationships, roles, and responsibilities of each member on the project team.

Project Manager

- A Project Engineer
- B Project Controls
  1. Contract Administrator
  2. Planning and Scheduling Engineer
  3. Estimating Engineer
  4. Cost Control Engineer
  5. Risk Engineer
- C Drafting Coordinator
- D Disciplines
  1. Architecture
     a. Lead Architect
     b. Architects
     c. Draftsmen/CADD
  2. Civil
     a. Lead Civil Engineer
     b. Civil Engineers
     c. Civil Technicians
     d. Surveyor
     e. Draftsmen/CADD
  3. Electrical
     a. Lead Electrical Engineer
     b. Electrical Engineers
     c. Electrical Technicians
     d. Draftsmen/CADD

4. Mechanical
   a. Lead Mechanical Engineer
   b. Mechanical Engineers
   c. Mechanical Technicians
   d. Draftsmen/CADD
5. Structural
   a. Lead Structural Engineer
   b. Structural Engineers
   c. Structural Technicians
   d. Draftsmen/CADD

E Document Control Personnel

F Clerical Personnel

FIGURE 9-4 Illustrative example of expertise required for design.

Design Proposals

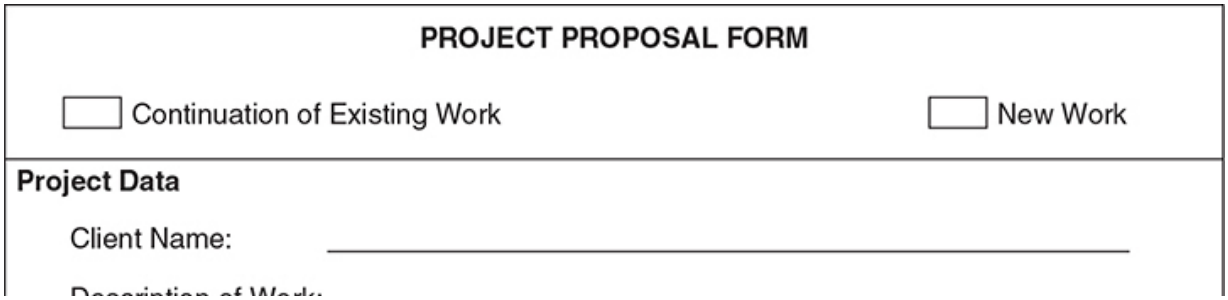
The purpose of the proposal is to identify the scope and develop the budget and schedule for preparing the design. The project proposal may be as formal as a request for qualification for a new owner or as informal as a brief outline of scope for expansion of existing work.

After developing the project charter for the design project, the design project manager should use it and the RFP to become familiar with the global issues related to environmental aspects, community relations, hazardous waste, bidding strategy, required permits and regulations (federal, state, and local), expectations, and goals of the customer. Although these issues will be developed in more detail at a later date, the project manager must be aware of all aspects of the project.

During this early stage in project development, the design engineer must convert the owner's project definition into an engineering scope of work. However, the design engineer

may feel the owner's definition is inadequate or may feel there is missing information. The owner should be contacted for clarifications. However, sometimes the owner is unable to fully clarify or respond to rectify the discrepancies. For these situations, the design engineer must define the scope of engineering work to the best of his or her ability and then develop a budget and schedule based on the designer's assumed scope of work. The design engineer must create a basis of design to document and communicate to the owner the assumptions made and the impact of the work on the total project. This essentially locks in the scope of work at this time in the project. Then, at a later date when additional information is known, the assumed scope, budget, and schedule for that portion of the work can be adjusted appropriately.

Figure 9-5 is an illustrative example of a project proposal form. Project data should include a brief description of the work. If needed, the space under "Comments" may be used to relay information important to the proposal. All disciplines that will be involved in the project should be identified, including architectural, civil, electrical, mechanical, and structural, or other special expertise. If the budget or estimated fee for design is not known, then the magnitude of the project or estimated construction cost should be listed. After the top portion of the form is completed, it is submitted to management for review and approval. Analysis of the completed project proposal form will allow management to make decisions based on fundamental project information.



PROJECT PROPOSAL FORM

☐ Continuation of Existing Work ☐ New Work

Project Data

Client Name: _____

Description of Work: _____

Location of Work: _____

Prepared by: _____ Date: _____

Disciplines Involved

Architect $_____ Electrical $_____

Civil $_____ Mechanical $_____

Structural $_____ Geotech $_____

Environmental $_____ Other $_____

Estimate

Fee $_____ Work-Hours: _____

Start Date _____ Completion Date _____

Proposal Required ☐ No ☐ Yes, Due Date _____

Comments, Key Points

Approval Date: _____

☐ No Further Action Required ☐ Further Discussion Required ☐ Proceed

Distribution

President _____

Principal in Charge _____

Project Manager _____

Marketing Rep _____

Document Control _____

FIGURE 9-5 Project proposal form for design.

The design project manager is responsible for managing the overall coordination of the proposal effort. Specific duties include the following:

- Defining the scope of work for the project
- Establishing a work plan, including budget and schedule, for the proposal effort
- Monitoring the work plan to ensure effective communication among team members
- Communicating with discipline managers to identify key personnel
- Assist in preparation of the proposal documents
- Attend the owner's interview
- Participate in establishing a rate schedule
- Assimilating the list of project deliverables

To accomplish these duties, the design project manager and his or her team need to address the following questions and subtopics:

Why?	Why are we doing this project—project objectives? • Expectations for the project—identify and document • Operating parameters—products to be produced or services to be provided • Business requirements—cost/schedule limitations and functional requirements
What?	What is needed to accomplish the end objective of the project? • Description of major systems required—plot plans, flow sheets, etc.

	• Identify applicable environmental and safety regulations—federal, state, and local • Confirm standards to be used—company standards and owner's standards
How much?	What is the cost to complete the project? • Identify costs—dollars, work-hours, or both • Description of the cost estimate method—historical records, vendor quotes • Organize estimate—develop estimate worksheets by disciplines
When?	How much time is required to complete the project? • Describe key milestone dates—design, procurement, construction, and closeout • Identify required advanced purchases—major equipment and special materials • Identify potential schedule risks—provide contingency options
Who?	Who will be doing the work? • Identify required expertise—technical and nontechnical • Determine availability of personnel—internal personnel and external personnel • Assign duties and roles—defined authority and responsibility
What can go wrong?	What are potential risks in the project? • Assess risks—identify risks for cost, schedule, quality, and scope • Analyze risks—probability of occurrence and impact of each risk

- Develop action plan—for prevention and/or mitigation of the risk

The discipline managers are responsible for providing technical support for the proposal. This support may include assigning personnel, establishing preliminary designs, reviewing owner information, and performing quality-control review of proposal documents. The discipline managers are also responsible for establishing the total work-hours needed for the project, to ensure that adequate technical expertise will be available when necessary to meet the project schedule.

Figure 9-6 illustrates a project proposal checklist. The project data can be the same as listed on the project proposal form. Prior to the owner's interview, the project manager should compile a list of proposed attendees, an agenda, and a list of materials that will be used for the presentation: boards, photographs, slides, or electronic media presentations.

PROJECT PROPOSAL CHECKLIST

Project Manager _____ Marketing Representative _____

Project Data

Client Name: _____

Description of Work: _____

Location of Work: _____

Estimated Work-Hours _____

Estimated Cost to Prepare Proposal: _____

Proposal Support Documentation

☐ Organization Chart ☐ List of Special Graphics

☐ Rate Schedule ☐ List of Travel Expenses

☐ List of Projects to Include ☐ Proposal Sheets

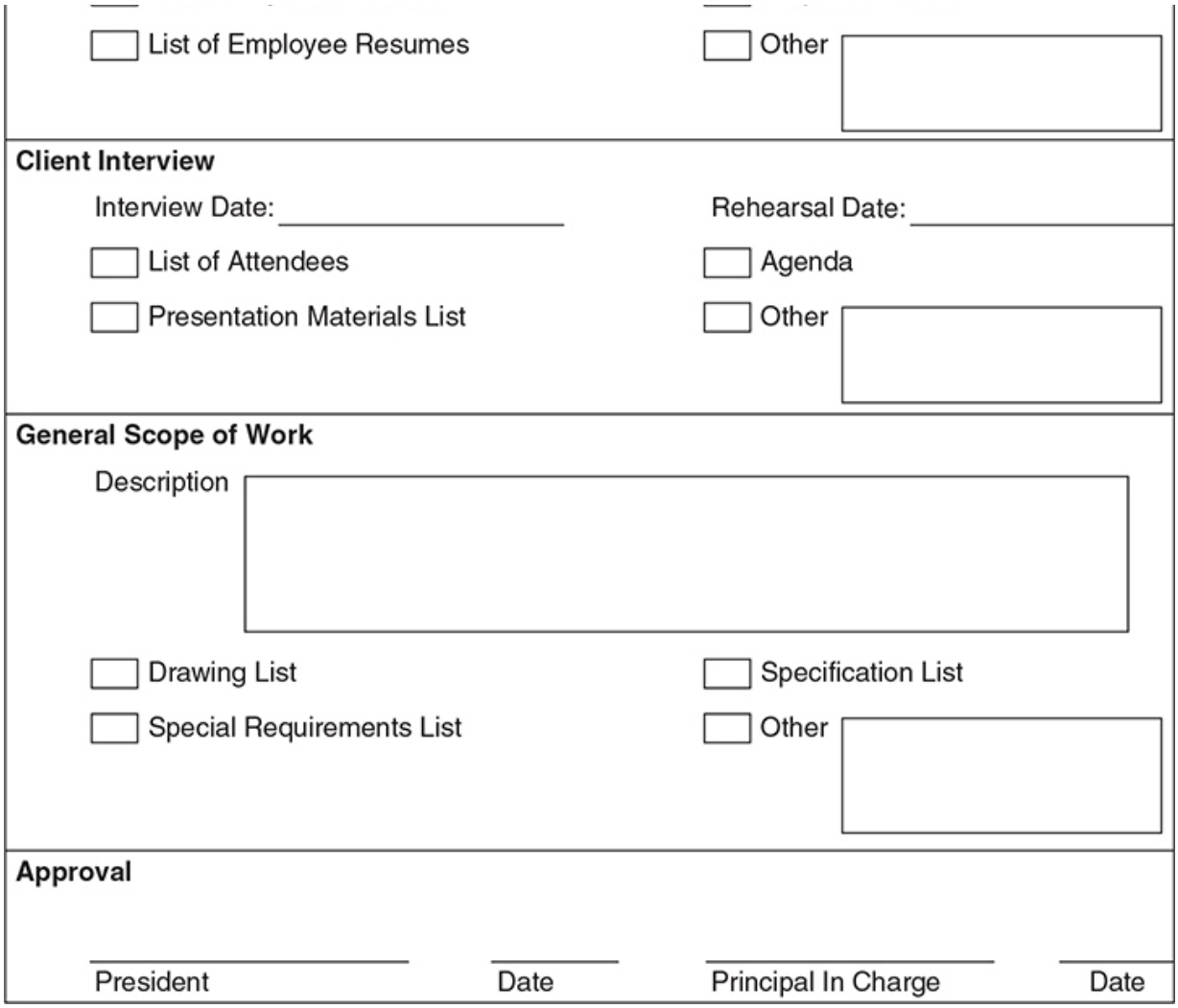


FIGURE 9-6 Proposal checklist for design.

As a minimum, the general scope of work for the project is included in the space provided. Additional information, such as drawing lists, equipment lists, specification lists, or special owner requirements, can be attached to the form. The completed form, plus attachments, is submitted to management prior to preparation of the proposal.

Scope Baseline for Budget

Project proposal detail sheets as illustrated in Figure 9-7 help formulate a budget for estimated design services.

These forms also assist in developing the final Work Breakdown Structure (WBS) and Organizational Breakdown Structure (OBS) for the project. Thus, the project proposal detail sheet forms the basis for setting up and managing the project.

PROJECT PROPOSAL DETAIL SHEET

Discipline_____

Project Data

Project Manager_____ Marketing Rep _____

Proposal Number_____ Client Name _____

Description of Work _____

Location of Work: _____

Estimated Dept Budget $_____ Work-Hours _____

Scope Definition

Client Reference Documents & Attachments

Personnel Categories Required with Work-Hours

	Admin.	Specs	Engr.	Dwgs
Dept. Manager				
Lead Engineer				
Senior Engineer				
Junior Engineer				
CADD/Drafting Coord.				
Total				

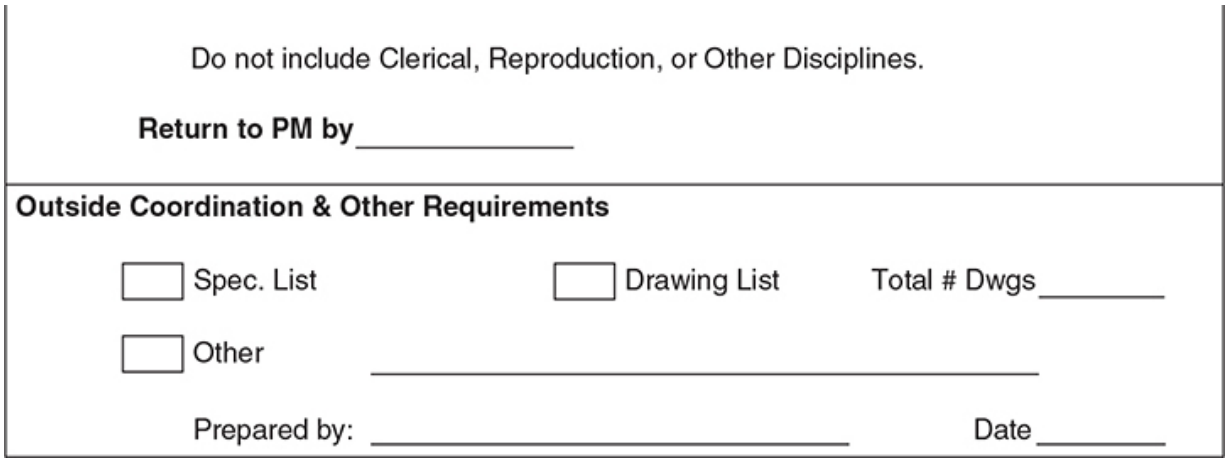


FIGURE 9-7 Detail sheet for design proposal.

The design project manager initiates one of these forms for each design discipline involved in the project. The scope definition and estimated budgets should be as complete and accurate as possible. It is the responsibility of each design discipline to thoroughly examine the project definition from the owner's organization and convert project definition into engineering scope definition. A scope of work for the discipline must be defined in sufficient detail to enable a reasonable estimate of the work-hours required to complete the design work.

After the project data shown on the top of Figure 9-7 is completed, each form and any supporting documentation should be reviewed with the appropriate discipline manager and the lead discipline representative. These two individuals should estimate the required design work-hours for each personnel category required to complete the scope of work requested. This estimate will require preparation of a detailed scope outline, a list of required specifications, and a preliminary drawing list. Preparation of mini-drawings, as discussed later in this chapter, is an effective method of preparing the drawing list. The number of drawings to be produced provides a basis for the number of required design work-hours.

The discipline manager should complete the project proposal detail sheet by summarizing the estimated design work-hours on the sheet. The personnel categories with design work-hours should be completed by the design manager. It is a summary of the hours required for each classification of work, including administration, specifications, engineering, and drawings. Depending on the uniqueness of the project, it may be necessary to add to or delete some of the classifications shown in Figure 9-4. The completed form, plus all supporting documentation, is returned to the project manager.

After the design project manager has collected and reviewed the project proposal detail sheets from the design disciplines, the project budget form shown in Figure 9-8 can be completed. This form compiles all the information received from the discipline managers plus information supplied by the design project manager. The resource-hours for clerical, reproduction, project support, and project management are added to complete the design budget. An example of this completed form is given in Figure 7-1.

Project Budget Form

Date _____ **Project Name** _____

Project ID _____

Dept. #	Department	HOURS							DOLLARS
		ADMIN	MTGS	SCHED	SPECS	CALCS	DWGS	TOTAL	
100	Project Management								
200	Architecture								
300	Mechanical								
400	Electrical								
500	Structural								
600	Environmental								
700	Civil								
800	CADD								

900	Document Control								
1000	Project Control								
1100	Clerical								
1200	Reproduction								
1300	Management								
1400	Subcontractor A								
1500	Subcontractor B								
1600	Subcontractor C								
1700	Record Drawings								
Work-Hour Subtotal									
Task #	**Description**								
1800	Contingency								
1900	General Expenses								
2000	Travel								
2100	Office Budget								
	Expenses Subtotal								
	Total								

FIGURE 9-8 Budget form for design proposal.

A dollar budget can be computed using one of several methods. For smaller projects, or projects without well-defined scopes, an average unit cost per resource-hour can be applied to all the identified hours. For larger projects, or projects with well-defined scopes, a more detailed dollar budget can be obtained by breaking down the hours by each personnel classification so the hourly rate can be applied more accurately and competitively, rather than using an average hourly rate. The total budget for resource-hours (labor costs and expenses) forms the basis for establishing the project cost control system for the project during design.

During the budgeting process, checks should be made to reduce the possibility of major oversights in the budget and to ensure the design effort can be completed within the budget. Examples of checks may include number of expected drawings per building, anticipated number of design work-hours per drawing, expected time duration anticipated by design discipline, percent of design costs per total cost of project, and number of design hours per major piece of equipment. Simple checks of these ratios based on data from past projects can be made to identify and prevent significant errors in the design budget.

The design project manager must also communicate with the various discipline design managers to ensure that the resources shown in the budget will be available when needed. A simple check of the average number of resources needed over the expected time duration of the design effort is an indication of the future expected workload for the design team. The discipline managers can compare this demand for resources with their normal availability of designers. Too often, a budget is established for a design effort and then later it is found the project cannot be completed in time or within budget because the resources are not available. Simple checks can reduce these types of problems in engineering design.

Design Work Package

After the design proposal is accepted by the owner, the project manager for the design firm can develop a complete Work Breakdown Structure (WBS) for the design effort. As shown in Figure 3-1, the work package is the lowest level of the WBS. The work package links the WBS to the OBS of the design team.

Figure 9-9 is an example work package for design of foundations for an electrical transmission steel pole line

project. The work package is divided into three categories: scope, budget, and schedule. The scope describes the required work and services to be provided. It should be described in sufficient detail, so other team members, who will be providing related work, can interface their work accordingly. This is important because a common problem in project management is coordinating related design work. There is a risk of the same work being done by two persons, or work not being done at all, because two people are each thinking the other person is providing the work. Clarification of who does what is shown in the scope of Figure 9-9.

WORK PACKAGE

Title Foundation Design

WBS Code 7-5-42-A10

1. Scope

Required scope of work

Provide engineering analysis and design services for 31 foundations of the Spring Creek to Valley View steel pole transmission line project

Serices to be provided

Review background material for project. Coordinate with structural engineer of steel pole manufacturer to obtain foundation ground line reactions without overload factors. Write soil investigation specification. Analyze soil report and borings, size diameter and depth of foundations, size vertical and horizontal reinforcing steel. Prepare drawings and write specification for construction

Services excluded from this work package but included in another work package

Clearing of right-of-way in Site Work package. Staking of foundation locations for soil investigation firm in Surveying Work Package

Services excluded from this work package but performed by

Preparation of structural details by steel fabricator vendor. Construction inspection services to be provided by XYZ Consulting Services, Inc

2. Budget

Personnel Assigned to Job	Job Title	Work-Hrs	$-Cost	CBS Code
Fred Jones	Geotechnical Engineer	35	1925	8159
Abigail Adams	Foundation Engineer	180	12600	8172
Ralph Smith	CADD Level 2	68	3060	7080
Support	Engineering Intern	20	600	1054

Total Work-Hrs	303
Total Personnel Cost	$18,185

Other personnel costs

Travel Expenses	$3,200
Training Expenses	$0
Overhead loading	$3,637

Total budget = Personnel + Other $25,022

3. Schedule

OBS Code	Work Task	Responsible Person	Start Date	End Date

510	Review backup material	Abigail Adams	02/05/33	07/05/33
510	Obtain ground line reactions	Abigail Adams	06/05/33	13/05/33
530	Write soil investigation spec	Fred Jones	13/05/33	15/05/33
530	Evaluation of soil report	Fred Jones	03/06/33	10/06/33
510	Foundation design	Abigail Adams	10/06/33	17/06/33
520	Development of drawings	Ralph Smith	13/06/33	24/06/33
520	Write construction specs	Abigail Adams	20/06/33	28/06/33
510	Design review	Abigail Adams	01/07/33	03/07/33
		Work Package: Start & End Dates	02/05/33	03/07/33

Additional Comments

Project engineer responsible for site work needs to ensure right-of-way is cleared by May 10 to allow staking of foundations and to allow soil boring truck access to project. Project engineer responsible for surveying needs to ensure foundations are staked by May 15, so soil Investigation company can begin soil borings. Need to notify steel supplier to ensure timely completion of structural steel details before completion of design drawings and writing of specifications.

Prepare by: _____ Date: _____

Approved by: _____ Date: _____

FIGURE 9-9 Work package for design of foundations.

Information from the design proposal shown in Figures 9-6 and 9-7 are useful in preparing the budget for the work package. For example, the work-hours for each person in the design of foundations are shown in the budget of Figure 9-9. Also, the list of work tasks, responsible person, and start and end date of each person involved in the foundation design are shown in the schedule of Figure 9-9. It should be noted that the overall start date and end date for the entire foundation design are shown at the bottom of the schedule.

Design work packages provide the basis of design coordination, which is discussed in Chapter 11 of this book. Work packages establish a benchmark to monitor progress in work to ensure the design effort is completed on time and within approved budget. Work packages also serve to mitigate the risks associated with interfaces between design disciplines.

Mini-Drawings

For design proposals, mini-drawings are an effective and organized method of defining the design deliverables: the

design drawings and specifications. Mini-drawings, sometimes called cartoons or stick drawings, are hand-drawn sketches on 8½ × 11 paper to represent the full-size drawings that will be developed in the design effort. Since they are hand drawn, they can be prepared quickly.

A complete set of mini-drawings for the project includes title page, plan views, elevations, sections, schedules, and details in the order they will appear in the final drawings. Figure 9-10 is an illustrative example of one page from a set of mini-drawings. It shows five plan views for each floor in a building in the top portion of the page and provisions for text on the bottom portion of the sheet. In the full set of mini-drawings, there would be one page for each full-size drawing that is expected to be produced in the design effort. Development of the mini-drawings involves working through each drawing and blocking out to scale each anticipated sheet for size and location.

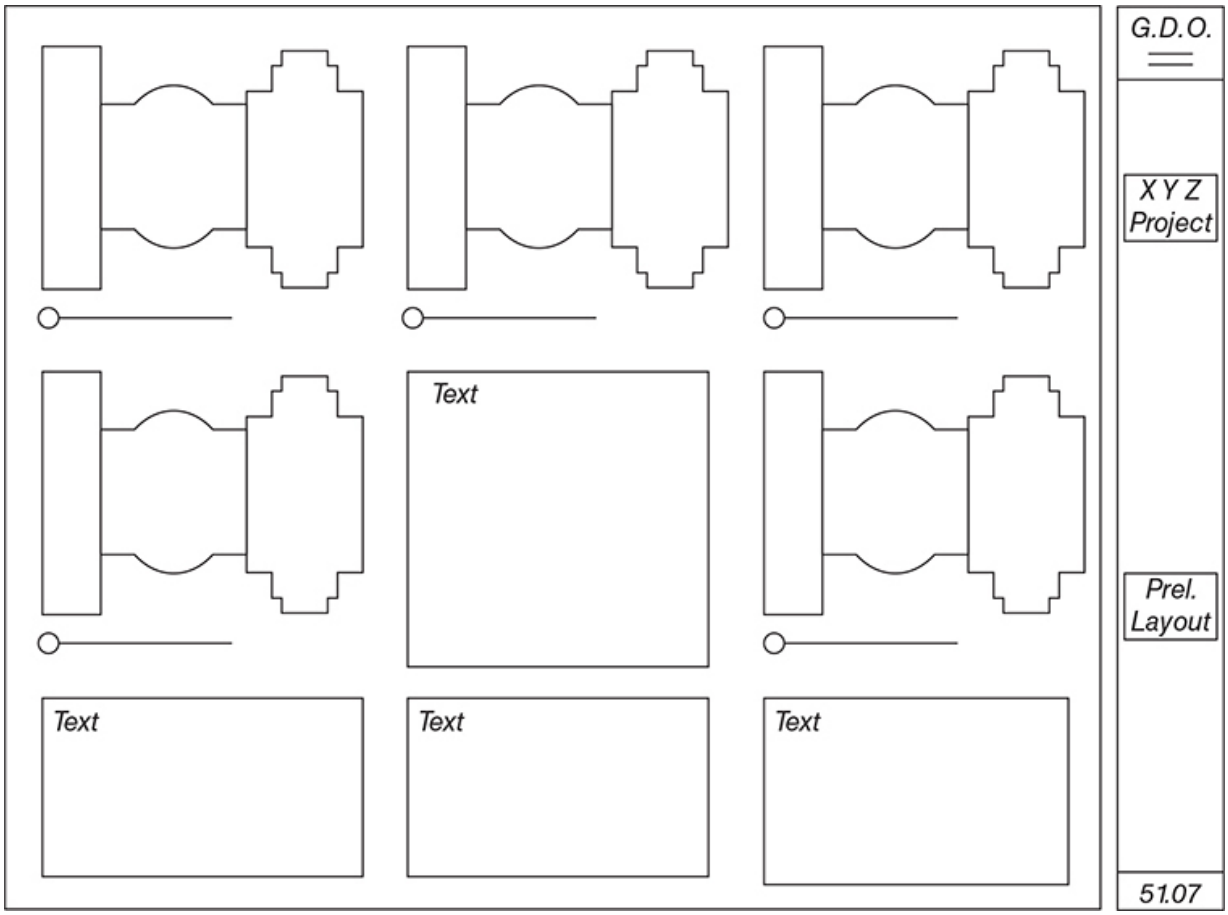


FIGURE 9-10 Illustrative example of mini-drawing.

Design schedules, such as the room finish schedule or door and window schedules, are also identified, and assigned to locations on the drawings. Details can be determined, counted, and assigned locations within the typical detail sheet grid. Copies of the mini-drawings can be given, with instructions, to the draftsperson or CADD operator. As conditions change during design, the mini-drawings can easily be referenced, changed, and reorganized. This provides an effective means of managing the design effort.

The final set of mini-drawings can be submitted to the discipline managers for review and approval prior to starting design. The mini-drawings communicate the manner in which the design team intends to document the design and

produce the design deliverables. Therefore, it is important that the mini-drawings be complete because they become a communications tool to management and the design team, for their reference throughout the design process.

Mini-drawings are living documents that may shift and change during the design process as changes occur. These documents must be kept up-to-date. Mini-drawings provide early establishment of drawing content and assist in defining drawing completeness. In addition, they provide the following benefits:

- Establish an efficient and orderly layout of the drawings
- Determine an early count of the anticipated number of drawings
- Identify the required areas of technical expertise needed for the design effort
- Assist in determining the work-hours required in design
- Provide a system for delegating drafting or CADD assignments
- Enable the department and discipline managers to schedule personnel

After a set of mini-drawings are completed, the number of anticipated drawings is known, which provides a procedure for determining the cost for design. After the list of drawings is completed, a summary sheet can be prepared for each design discipline that shows the number of hours anticipated to produce the drawing. Based on the number of design-hours needed per drawing and the rate schedule for the designers, a design cost and budget can be determined. In addition to planning drawing content, the mini-drawings can be used during actual design for project team communications and for keeping records of hours charged to the job.

Development of the Design Work Plan

Most design organizations work on billable hours. In simple terms, billable hours are hours that can be charged to, and are paid by, the owner's organization. Typical examples include design calculations, writing specifications, preparing drawings, conducting tests, or providing inspection. Many owner organizations do not compensate the designer's organization for developing a design work plan. As a result, there may be little, or no effort placed in developing an overall plan for design. However, this is a critical mistake because even a small amount of planning before starting work can prevent many future problems, including overspending on the design effort and late completion of design work. A good work plan for design also helps to reduce rework that can lead to errors in design. Every design effort should have a written work plan, even if the cost will not be reimbursed by the owner organization.

The level of detail of the work plan depends on the time schedule and the allocated budget for preparing the design and contract documents. Preparation of the schedule should begin during proposal preparation or immediately after the contract award date. A CPM schedule as presented and discussed in Chapter 10 is recommended for larger or more complex projects because this format provides a better level of detail and a clearer definition of the order and interdependency of the work tasks. Using the CPM method of scheduling forces the user to think through and clearly define the interdependency and interrelationships of activities between the various design disciplines. This results in a more detailed design schedule.

For a small design project that must be completed in a short time, a bar chart that shows each task in chronologic order is simple and easy to follow. The bar chart is less

detailed and more useful for small, less complicated design projects. However, it may be advantageous to roll all the individual design bar charts into an overall master CPM diagram to schedule the entire design effort.

Chapter 10 presents a discussion and example of CPM scheduling for engineering design, and Chapter 13 presents integration of the CPM design schedule with procurement and construction. Appendix A also presents an illustrative example of linking the schedule of design, procurement, and construction of a project.

Regardless of the methods used, either CPM or bar charts, the schedule should incorporate all the required tasks, starting with a thorough review of all backup material that was used in preparing the proposal. In particular, the schedule should include review of backup material to identify conditions that can affect the design work, including the owner organization's special requirements, applicable codes, and regulatory agencies. The schedule should also show key progress reviews, value improving process (VIP) evaluations, final checking and corrections, work to be performed by outside consultants, and any particular issue that may impact the successful completion of the design. The design schedule should be construction driven because construction is the costliest component of most projects.

A common mistake in development of design schedules is the failure to include adequate contingency in the project schedule. Too often the design work plan includes everything that is known to be accomplished but fails to include a reasonable allowance to compensate for unforeseen delays that inevitably will arise during the design effort. Examples include delays in acquisition of permits, responses from regulatory agencies, reviews of design by clients, delays in responses from vendors, and requests for information (RFI) from outside organizations that supply information to the design team.

The design budget should be integrated with the design schedule. For design work, it is more beneficial to define the budget in work-hours rather than in dollars of cost because design is driven by hours. Integrating the total staff hours into the schedule provides a systematic method of managing the budget and schedule simultaneously. An integrated schedule also allows monitoring of staffing needs throughout the design effort.

After the work plan is established, a progress schedule can be developed using information in the work plan, including the mini-drawings that forecast the full-scale drawings. Each group of drawings should be allocated hours for completion determined by complexity, reusability from production design, and work-hour data based on past experience on similar projects. The progress schedule should be reviewed and updated on a regular reporting period, usually coinciding with the submittal of timesheets. A review of actual progress, based on an analysis of the degree of completeness of each drawing or group of drawings or tasks, relative to the allocated hours versus estimated hours to complete, provides a projected outcome at the current level of effort. Regular reviews provide a consistent reporting of overall progress. This allows adjustments that may be necessary on a timely basis to ensure completion within the established time schedule and allocated budget. Chapter 13 discusses monitoring and reporting in more detail.

After the work plan is established and mini-drawings are completed, the project manager must establish ground rules for the design team and outside consulting specialists. Standards for drawings and CADD work must be established, documented, and reviewed with the entire team. The American Institute of Architects (AIA) has layering standards that are commonly used for projects in the building sector. Owners or clients in the process industry

sector have drawing standards that are required of engineering firms that perform design work on their projects. Many specify the particular CADD system that must be used for the design of their projects. The management system for handling the project should be reviewed with the team to ensure everyone knows what is expected of him or her. In particular, a system of checking design calculations and a procedure for checking drawings is necessary to ensure minimum errors and reduce impacts to constructability.

The design budget is based on the contract for design services and related to the work plan for producing the contract documents. Careful monitoring of actual costs compared to the approved budget is necessary to ensure profitable completion of the construction documents.

Engineering Project Controls

For any design effort, there must be a process to control changes in scope. The scope change process should ensure that when scope changes occur, the impact of the change on project cost and schedule is fully understood by all members of the project team, in particular, the owner's organization. The adverse impact of late changes in scope must be communicated to the owner. Scope changes must be logged, documented, and resolved in a timely manner. Strict discipline from the project team regarding scope control is essential to deliver a successful design project.

A system must be established for progress measurement and schedule control. The system should include the WBS for engineering, including the roles and responsibilities of the engineering manager and the engineering team with respect to progress measurement and schedule control. The roles and responsibilities of outside consultants should also be included in the system. A system for schedule control

must define the process that will be used for obtaining approval for changes in the engineering schedule. Changes in the baseline schedule must come from an approved change order.

A system must also be established for cost control. The system should describe the roles and responsibilities of the engineering manager and team members, including outside consultants. The system should include the cost breakdown structure (CBS) for engineering. The cost contingency for engineering and how it will be managed is a critical factor in cost control of the design effort. A system for cost control must define the process that will be used for obtaining approval for changes in the engineering budget. As with the schedule, changes in the engineering budget must arise from an approved change order. The cost control system must also include procedures for measuring productivity and reporting cost performance.

Progress Measurement of Engineering Design

The purpose of the project plan is to successfully control the project to ensure the scope of the design effort is completed within budget and schedule constraints. Measuring the progress of a project supports management in establishing a realistic plan for execution of a project and provides the project manager and client with a consistent analysis of project performance. Progress measurement also provides an early warning system to identify deviations from the project plan and scope growth. To control engineering work, a drawing list, specification list, equipment list, and instrument list are used to determine the project status and continued planning.

After completion of the project proposal, the project manager should establish a system of measuring the

progress of engineering design. The deliverables of design include performing calculations, producing drawings, and writing specifications for the project. These deliverables are defined in the scope of work, organized in the WBS, and used in determining the budget for design. Table 9-1 is an illustrative example of a progress measurement system for engineering design. The system is broken down into work packages by disciplines of engineering, including architectural, civil, structural, electrical, instrumentation, and mechanical engineering. The system includes the hours required to produce drawings as well as a breakdown of the percent of time for producing design calculations and drawings for each discipline. The information in this table forms the basis for measuring cost and schedule performance, which are discussed in Chapter 13.

A: Work Breakdown of Architectural Design Work Packages **Architectural design** = 300 design-hours and 180 CADD hours Drawings: 83 hours per drawing	
Design = 40% of design effort	
Design parameters identified	25%
Layout and methods established	20%
Ready to start related drawings	35%
Final drawings issued	20%
	Total = 100%
Drafting = 60% of design effort	
Borders & basic layout established	15%
Review of completed information	10%
Related design work at 80% complete	25%
Quality-control review #1	3%
Drawings complete	39%
Quality-control review #2	3%
Record drawings	5%
	Total = 100%
Specifications: 8 total, 2 hours per specification	
B: Work Breakdown of Civil Engineering Design Work Packages **Civil engineering design** = 171 design-hours and 100 CADD hours Drawings: 135 hours per drawing	
Site grading and drainage = 91 design-hours and 60 CADD hours	
Site work details = 80 design-hours and 40 CADD hours	
Drafting	
Field survey	8%
Site base drawing	35%
Quality-control review #1	3%
Contract engineering	26%
Complete site drawing and details	20%
Quality-control review #2	3%
Record drawings	5%
	Total = 100%
Specifications: 7 total, 1 hour per specification	

C: Progress Measurement of Structural Engineering Design Work Packages **Structural engineering** = 480 design-hours and 240 CADD hours Drawings: 80 hours per drawing	
Engineering design = 40% of design effort	
Design parameters identified	25%
Layout and methods established	20%
Ready to start related drawings	35%
Final drawings issued	20%
	Total = 100%
Drafting = 60% of design effort	
Borders and basic layout established	15%
Review of existing information	10%
Related design work at 80% complete	25%
Quality-control review #1	3%
Drawings complete	39%
Quality-control review #2	3%
Record drawings	5%
	Total = 100%
D: Work Breakdown of Electrical Engineering Design Work Packages **Electrical engineering design** = 72 design-hours and 42 CADD hours Drawings: 18 hours per drawing	
Engineering design = 40% of design effort	
Design parameters identified	25%
Layout and methods established	20%
Ready to start related drawings	35%
Final drawings issued	20%
	Total = 100%
Drafting = 60% of design effort	
Borders and basic layout established	15%
Review of complete information	10%
Related design work at 80% complete	25%
Quality-control review #1	3%
Drawing complete	39%
Quality-control review #2	3%
Record drawings	5%
	Total = 100%
Specifications: 4 total, 1 hour per specification	

E: Progress Measurement of Instrumentation Design Work Packages	
Instrumentation design = 124 design-hours and 84 CADD hours	
Drawings: 121 hours per drawing	
Engineering design = 40% of design effort	
Design parameters identified	25%
Layout and methods established	20%
Ready to start related drawings	35%
Final drawings issued	20%
	Total = 100%
Drafting = 60% of design effort	
Borders and basic layout established	15%
Review of complete information	10%
Related design work at 80% complete	25%
Quality-control review #1	3%
Drawing complete	39%
Quality-control review #2	3%
Record drawings	5%
	Total = 100%

F: Work Breakdown of Mechanical Engineering Design Work Packages	
Mechanical engineering design = 496 design-hours and 235 CADD hours	
Drawings	
P&ID drawing of existing plant	56 design-hours and 20 CADD hours
Mechanical floor plan	60 design-hours and 25 CADD hours
Details—Piping, feed water	120 design-hours and 60 CADD hours
Boiler piping schematic sheet #1	60 design-hours and 30 CADD hours
Boiler piping schematic sheet #2	60 design-hours and 30 CADD hours
Boiler stack details	80 design-hours and 40 CADD hours
Miscellaneous details	20 design-hours and 10 CADD hours
Develop equipment list	40 design-hours and 20 CADD hours
Engineering design = 40% of design effort	
Design parameters identified	25%
Layout and methods established	20%
Ready to start related drawings	35%
Final drawings issued	20%
	Total = 100%

F: Work Breakdown of Mechanical Engineering Design Work Packages **Mechanical engineering design** = 496 design-hours and 235 CADD hours (*Continued*)		
Drafting = 60% of design effort		
Borders and basic layout established		15%
Review of information complete		10%
Related design work at 80% complete		25%
Quality-control review #1		3%
Drawings complete		39%
Quality-control review #2		3%
Record drawings		5%
		Total = 100%
Specification		
Boiler specification = 132 design-hours		
Base specification marked up		25%
Related information reviewed		15%
Typed, ready for review		20%
Issue for client review		20%
Revise per client review		10%
Final issue		10%
		Total = 100%
Other specifications: 19 total, 1 hour per specification		

TABLE 9-1 Example Progress Measurement System for Engineering Design Work Packages

Measuring progress of design is difficult because design is a creative process. Sometimes considerable time may be expended in the design effort without seeing any physical results. For example, numerous computer simulations may be necessary during a design analysis. Significant amounts of work and time may be expended in the simulation effort, but if the simulations are not completed, there will be no produced drawings to show any physical results of the design effort. Similarly, numerous drawings may be near complete, yet none of them completely finished. It is difficult to define a half-finished drawing. Thus, measuring design progress by counting the number of completed

drawings may not fully measure the progress of the design effort.

Most owners request milestones in the design schedule for reviews. For example, there may be a 60% design complete milestone that is designated for review by the owner. There must be agreement between the owner and the design team on how to define and measure the 60% design complete. For example, 60% design complete may be defined as completion of all architectural work and structural work, completion of 50% of the electrical drawings, 25% of the mechanical drawings, and initiation of the specification writing. Chapter 13 presents methods of measuring design progress.

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CHAPTER 10

Project Planning and Scheduling

Project Planning versus Project Scheduling

Project planning is the process of identifying all the activities necessary to successfully complete the project (how) and establishing sequential relationships between them. Project scheduling is the process of determining time requirements (durations) for each activity and relating them to calendar time (when). Thus, project planning is a fundamental step to project scheduling because there is no way to determine the sequence or start and finish dates of activities until they are identified.

However, the terms of project planning and scheduling are often used synonymously to the detriment of planning and the overemphasis of scheduling. A project schedule can be the straightforward result from good planning effort or a collection of milestones with little value in controlling the project. The project manager should focus the team to accomplish forming a comprehensive, cohesive, sequential set of activities (the plan) before focusing on developing a project schedule.

Planning is more difficult to accomplish than scheduling. The real test of the project planner is their ability to facilitate the team in identifying all the work required to

complete the project and putting the work together in a progression to accomplish the objective. The preceding chapters of this book focused on identifying work activities and grouping those activities into meaningful categories. For example, the process of developing a well-defined work breakdown structure (WBS) as presented in Chapter 3 results in a list of activities that must be performed to complete a project. Planning that is well done ensures the following:

- Identification of all activities to be performed
- Identification of methods to be used to accomplish tasks
- Identification of resources to be used
- Assignment of responsibility and accountability for each task
- Establishing an integrated plan to achieve the completion of work

Planning must be done for each phase of the project lifecycle bearing in mind the project objective. During the feasibility and conceptualization phases, little is known regarding the detailed activities required for subsequent phases. The plan for the project evolves as the project progresses with more detail added as more development work is done. Once a project has received approval and funds authorization, detailed planning ensues. A defined master schedule or overall project schedule built from activities for each phase should be prepared as part of project definition. This schedule develops more detail as additional planning is completed during the project lifecycle.

After the activities are identified, it is relatively straightforward to determine the schedule for a project. Many methods and tools have been developed for scheduling. The computer is universally used to perform the

calculations for a project schedule. However, adequate attention must be given to both planning and scheduling. Sometimes a project schedule becomes nonworkable due to too much emphasis on getting a computer-generated schedule. The project manager and project planner/scheduler must give adequate time to project planning before turning to the computer to generate the schedule. In simple terms, it is better to be a good planner than to be proficient in computer applications. The material presented and discussed in the preceding chapters has set the stage for developing a useful project schedule.

This chapter will address planning with a review of basic scheduling mechanics. The project manager and planning professional should focus on identifying all of the work included in the execution plan and connecting that work in a sequence that meets cost requirements, minimizes adverse impacts (risks), and satisfies time requirements.

Desired Results of Planning

Project planning is the heart of good project management because it provides the central communication that coordinates the work of all parties. Planning also establishes the benchmark for the project control system to track the quantity, cost, and timing of work required to successfully complete the project. Although the most common desired result of planning is to finish the project on time, there are other benefits that can be derived from good project planning (see Table 10-1).

1. Finish the project on time
2. Continuous (uninterrupted) flow of work (no delays)
3. Reduced amount of rework (minimal number of changes)
4. Proactive management of risk events with minimal impacts to the project
5. Minimize confusion and misunderstandings
6. Increased knowledge of project status by everyone
7. Meaningful and timely reports to management
8. You run the project instead of the project running you
9. Knowledge of scheduled times of key parts of the project
10. Knowledge of distribution of costs of the project
11. Accountability of people, defined responsibility/authority
12. Clear understanding of who does what, when, and how much
13. Integration of all work to ensure a quality project for the owner

TABLE 10-1 Desired Results of Project Planning and Scheduling

Planning is the first step to project scheduling. Planning is a process and not a discrete activity. As more information is obtained or changes occur, additional planning is required to incorporate the changes into the baseline plan. Incorporating new information or changes requires updates to the project's scope, execution plan, estimate, and schedule. There are many situations or events that can arise and impact a project's plan. Examples are changes in personnel, problems with permits, change in a major piece of equipment, or design problems. Good planning detects changes and adjusts the plan and subsequently the schedule in the most efficient manner.

A common complaint of many design engineers is they cannot efficiently produce their work because of interruptions and delays. The cause of this problem is usually poor planning, and in some instances no planning at all. Planning should clearly identify the work that is required by each individual and the interface of work between

individuals. It should also include a reasonable amount of time for the exchange of information between project participants, including the delay time for reviews and approvals.

A common complaint and a real problem for many designers is the amount of rework they must do because of changes in the project. This also creates confusion and misunderstandings within the design team and between the owner and the design firm that further hinder productive work. Planning should include a clear description of the required work before the work is started, both what is included and what is excluded. As the project evolves, changes are a necessary part of refining the project, especially in the early development phases. The project manager is responsible for managing those changes. If changes in the work are expected, or probable, then project planning should include provisions for a reasonable allowance of the anticipated changes. Too often, people know that changes will occur, but fail to include them in the project planning.

Thorough project planning and scheduling can serve as effective means of preventing and tempering problems. It can prevent delays in work, a major cause of late project completion and cost overrun, which often leads to legal disputes. It can also prevent low worker morale and decline in productivity that is caused by lack of direction.

Benefits of Planning

One of the obvious purposes of project planning is to complete a project on time. However, planning projects provides other benefits. Planning is a centralized tool for communications that coordinates the work of all parties. When the project team is involved in the planning process, it creates commitment to and ownership of the work. The

project plan provides a benchmark of work activities, resource requirements, and commitments that can be used to frame decisions and to measure progress. It keeps the work flowing in a continuous manner, so everyone is better informed. The process of developing the plan requires the project team to identify, in advance, the work that must be performed and the dependencies between work activities. After it is completed, the project plan provides accountability of people, with defined responsibility and authority. Organized work leads to improvement in the quality of the project.

Project planning also prevents problems. A well-developed project plan reduces the number of changes in a project and the amount of rework. A good project plan helps to prevent duplication of work, or overlaps in work. It helps in preventing interruptions and delays in work, which can improve productivity and quality of work. Project planning reduces confusion and misunderstandings between people on the project, which helps prevent low worker morale and declining productivity of workers. A good plan also helps to reduce and manage legal disputes that may arise in a project.

Principles of Planning and Scheduling

There must be an explicit operational plan to guide the entire project. The plan must include and link the three components of the project: scope, budget, and schedule. Too often, planning is focused only on schedule without regard to the important components of scope and budget. Developing a project execution or work plan was previously discussed in Chapter 3.

To develop an integrated total project execution plan, the project must be broken down into well-defined units of work that can be measured, managed, and controlled. This

process starts with the WBS. Once this is completed, the project team members who have the expertise to perform the work can be selected. Team members have the ability to clearly define the magnitude of detail work that is required and dependencies with other work packages in the WBS. They also have the ability to define the time and cost that will be required to produce the work. With this information, a complete project execution plan can be developed. Often a planning meeting held over several days is used to develop the work plan. It may or may not be facilitated, but its sole purpose is to confirm the limits (what is included and what is excluded) for each work package, the dependencies with other work packages, the personnel, equipment, and other costs required, and the risks, if any, related to the work package.

The resulting project plan must clearly define individual responsibilities, schedules, budgets, and anticipated problems. The project manager should prepare formal agreements (change orders) with appropriate parties whenever there is a change in the project. There should be equal concern given to schedule, budget, and risks; all three are linked. Planning, scheduling, and controlling begin at the inception of the project and are continuous throughout the life of the project until completion. Table 10-2 lists key principles for planning and scheduling.

1. Begin planning before starting work, rather than after starting work
2. Involve people who will actually do the work in the planning process
3. The schedule represents the complete logical time-phased project plan
4. Include all aspects of the project: scope, budget, schedule, and quality
5. Build flexibility into the plan, include allowance for changes and time for reviews and approvals
6. The plan is the road map for doing the work; it will never be precisely correct
7. The schedule is the “when” view of the plan
8. Keep the plan simple, eliminate irrelevant details that prevent the plan from being readable
9. Communicate the schedule to all parties; any schedule is worthless unless it is known. Don’t frame it, use it

TABLE 10-2 Key Principles for Planning and Scheduling

Responsibilities of Parties

The principal parties of owner, designer, and contractor all have a responsible role in project planning and scheduling. It is erroneous to assume this role is the responsibility of any one party. Each must develop a schedule for his or her required work and that schedule must be communicated and coordinated with the other two parties, because the work of each affects the work of the others.

The owner establishes the project completion date, which governs the scheduling of work for both the designer and contractor. The purpose of the owner's schedule is to identify and interface overall project activities: design, procurement, and construction. A workable schedule must be developed that integrates the activities of all parties involved in a project. Any change to the project schedule should be approved by all parties and promptly communicated. The owner should also set priorities for the components that make up the project. For example, if the project consists of three buildings, the relative importance of the buildings should be identified. This assists the designer in the process of organizing his or her work and developing the design schedule to produce drawings that are most important to the owner. It also assists in the development of the specifications and contract documents that communicate priorities to the construction contractor.

The design organization must develop a design schedule that meets the owner's schedule. This schedule should include a prioritization of work in accordance with the owner's needs and should be developed with extensive input from all designers who will have principal roles in the design process. Too often, a design schedule is produced by the principal designer, or the project manager of the design

organization, without the involvement of those who will actually do the work.

The construction contractor must develop a schedule for all construction activities in accordance with the contract documents. It should include procurement and delivery of materials to the job, coordination of labor and equipment on the job, and interface the work of all subcontractors. The objective of the construction schedule should be to effectively manage the work to produce the best-quality project for the owner. The purpose of construction scheduling should *not* be to settle disputes related to project work, but to manage the project in the most efficient manner.

For some projects, it may be desirable for one party to maintain the schedule and the other parties to participate in monitoring it. Ultimately each one of the parties will be responsible for his or her portion of the schedule. Maintaining one common schedule as a cooperative effort between parties can reduce problems associated with maintaining three separate schedules.

Planning for Multiple Projects

Many project managers are assigned the responsibility of simultaneously managing several small projects that have short durations. A small project is usually staffed with a few people who perform a limited number of tasks to complete the project. For projects of this type, there is a tendency for the project manager to forgo any formal planning and scheduling because each project is simple and well defined. However, the problem that the project manager has is not the management of any one project at a time; instead, the problem is managing all the projects simultaneously. The task of simultaneously managing multiple small projects can be exceedingly difficult and frustrating. Thus, the need for

good planning and scheduling is just as important for the management of multiple small projects as it is for the management of a single large project.

To manage multiple small projects, the project manager must develop a plan and schedule that includes all projects for which he or she is assigned, even though the projects may be unrelated. This is necessary because the staffing of small projects requires assigning individuals to several projects at the same time so they will have a full-time workload. Thus, their work on any one project affects the work on other projects. For this type of work environment, the project manager must develop a plan and schedule that interfaces the work of each individual that is working on all the projects for which the project manager is responsible. In particular, the plan should clearly show how the work of each person progresses from one project to another.

A large project is commonly assigned to one project manager who has no other responsibilities than management of the single project at one time. It is staffed by persons who provide the diverse technical expertise that is required to accomplish the numerous tasks to complete the project. For projects of this type, the problem of the project manager is identifying and interfacing related tasks to ensure the work is accomplished in a continuous manner. He or she relies on the input of team members to develop the project plan and schedule. Much of the work of the project manager involves extensive communications with team members to ensure that work is progressing in a continuous and uninterrupted manner.

Regardless of the project size, large or small, planning and scheduling must be done. Perhaps the greatest mistake a project manager can make is to assume that planning and scheduling are not required for some reason, such as, he or she is too busy, there will be too many changes, or the project is too small.

Schedule Development

The complexity and size of a project are two of several considerations for developing the project schedule. AACE International defines the schedule as the plan for completion of a project based on a logical arrangement of activities, available resources, imposed dates, or funding budgets. To build a comprehensive schedule requires following an intentional design process.

Building the schedule is a project in itself. The scheduling effort requires a plan or design that is independent of and precedes schedule development. Utilizing the design process creates team buy-in. It provides a consistent process that yields an effective and appropriate schedule for the project. Table 10-3 contains several factors in the schedule design process but does not provide a comprehensive list.

1. Schedule's purpose	How will the schedule be used—financial reporting, design coordination, control and monitoring of resources, forecasts, or costs
2. Report design	What reports are required from the baseline schedule and update schedules
3. Description of schedules	Identify and describe all the schedules that are required and their source
4. Schedule outline	WBS and work packages, milestones, long lead procurement, considerations for site, regulatory constraints, key activities to monitor
5. Level of detail	Sufficient for the nature, size, duration, and complexity of the project
6. Activity code definition	Done after the schedule outline. Used to sort, filter activities
7. Weather planning	How will adverse weather be accommodated, peak runoff periods
8. Risk management plan	Incorporate risk mitigation and contingencies
9. Historical information	Utilize information from past projects to avoid repeating mistakes or problems
10. External influences	Regulatory changes, government administration changes, tariffs, labor negotiations, and others

TABLE 10-3 Factors in Schedule Design

The importance of preparing the Basis of Estimate (BOE) was discussed in Chapter 6. The BOE is a support document and the basis of control changes in the estimate. The Basis of Schedule (BOS) is a similar support document for control of the schedule. It should be developed and available for presentation, review, and future use. The BOS is updated as the project progresses through the project lifecycle, gaining more details as more information is collected. A thoroughly documented schedule forms a baseline for project control, so decisions during project execution can be made with a better awareness of project timing. Using the BOS to document the schedule helps to minimize omissions, overlap in responsibilities, interference between activities and misunderstandings.

A thoroughly prepared basis of schedule includes and addresses the following:

- Documents the project scope
- Identifies any area designations
- Provides a general description of sequencing
- Identifies departures from sequencing mandated in contracts
- Identifies project phasing
- Identifies milestones including those stipulated in contracts
- Risk management results and mitigation measures
- Outstanding risks
- List and explain calendars
- Explain adverse weather planning included in the schedule
- Identify unusual logic relationships between activities, including the use of lags
- Identify constraint dates and regulatory windows

A standard default format or outline should be developed to organize and prepare documentation for the schedules. The process of developing, utilizing, and storing the documentation for future use should be built into the schedule design process. Some of the items that should be documented are shown in Table 10-4. Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the basis of schedule outline.

1. Project description including the project phase and personnel involved
2. Scope of work (WBS, OBS)
3. Execution strategy
4. Key project dates
5. Planning basis—sources or methods for developing the project schedule
6. Critical path
7. Path of execution
8. Start-up and turn over
9. Issues or concerns
10. Risks or opportunities
11. Assumptions, exclusions
12. Changes to baseline including explanations
13. Scheduling software specific details—version, settings, etc.

TABLE 10-4 Sections to Include in a Basis of Schedule

Techniques for Planning and Scheduling

The technique used for project scheduling will vary depending on the project's size, complexity, duration, personnel, and owner requirements. There are two general methods that are commonly used: the bar chart (sometimes

called the *Gantt chart*) and the critical path method [sometimes called Critical Path Method (CPM) or network analysis system].

The bar chart, developed by Henry L. Gantt during World War I, is a graphical timescale of the schedule. It is easy to interpret; but it is difficult to update, does not show interdependences of activities, and does not integrate costs or resources with the schedule. It is an effective technique for overall project scheduling, but has limited application for detailed construction work because the many interrelationships of activities, which are required for construction work, are not defined. Many project managers prefer the bar chart for scheduling engineering design work because of its simplicity, ease of use, and because it does not require extensive interrelationships of activities. However, it can require significant time for updating since the interrelationships of activities are not defined. A change in one activity on the bar chart will not automatically change subsequent activities. Also, the bar chart does not integrate costs with the schedule, nor does it provide resources, such as labor-hours, that are important for management of design.

Some designers argue that they cannot define the interrelationships between the activities that make up a design schedule. They use this argument to support the use of a bar chart. They will also argue that resources change constantly on a design project, resulting in a schedule that is too difficult to maintain. Either of these situations are exceptions and should not be commonplace. Investing the effort to develop a detailed scope reflected in a WBS and decomposed into work packages that are sequenced together will yield a schedule that allows for control and management of the design effort including resources.

CPM was developed in 1956 by the DuPont Company, with Remington Rand as consultants, as a deterministic

approach to scheduling. The CPM is commonly used in the engineering and construction industry. A similar method, Program Evaluation and Review Technique (PERT), was developed in 1957 by the U.S. Navy, with Booz, Allen, & Hamilton Management consultants, as a probabilistic approach to scheduling. It is more commonly used by the manufacturing industry; however, it can be used for risk assessment of highly uncertain projects. Both methods are often referred to as a network analysis system. The CPM provides interrelationships of activities and scheduling of costs and resources. It also is an effective technique for overall project scheduling and detailed scheduling of construction. However, it does have some limitations when applied to detailed engineering design work during the early stages of a project because it requires an extensive description of the interrelationships of activities.

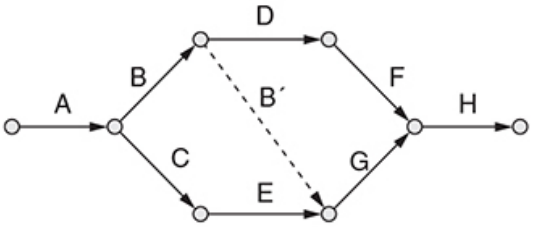
Although the CPM technique requires more effort than the bar chart method, it provides more detailed information that is required for effective project management. Using a network schedule to plan a project forces the project team to break a project down into identifiable tasks and to relate the tasks to each other in a logical sequence in much greater detail than a bar chart. This up-front planning and scheduling help the project team to identify hand-offs and conflicts for resources before they occur. The project manager must use his or her own judgement and select the method of scheduling that is most appropriate for the project. The method should define the work to be done, communicate project requirements, and promote successful accomplishment of the project objective.

Network Analysis Systems

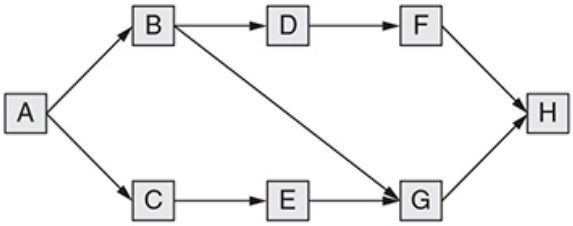
A network analysis system (NAS) provides a comprehensive method for project planning, scheduling, and controlling.

NAS is a general title for the technique of defining and coordinating work by a graphical diagram that shows work activities and the interdependences of activities. Many books and articles have been written that describe the procedures and applications of this technique. It is not the purpose of this book to present the details of network methods because so much material has already been written. The following paragraphs and figures present the basic fundamentals of NAS to guide the project manager in the development of the project plan and schedule. The basic definitions shown in Figure 10-1 are presented to clarify the following paragraphs because there are variations in terminology used in network analyses.

Activity	The performance of a task required to complete the project, such as, design of foundations, review of design, procure steel contracts, or form concrete columns. An activity requires time, cost, or both time and cost. An activity description needs an action to produce a deliverable.
Network	A diagram to represent the relationship of activities to complete the project. The network may be drawn as either an "arrow diagram" or a "precedence diagram."



Arrow Diagram



Precedence Diagram

Duration (D)	The estimated time required to perform an activity. The time should include all resources that are assigned to the activity.
Early Start (ES)	The earliest time an activity can be started.
Early Finish (EF)	The earliest time an activity can be finished and is equal to the early start plus the duration. $EF = ES + D$
Late Finish (LF)	The latest time an activity can be finished.
Late Start (LS)	The latest time an activity can be started without delaying the completion date of the project. $LS = LF - D$
Total Float (TF)	The amount of time an activity may be delayed without delaying the completion date of the project. $TF = LF - EF = LS - ES$
Free Float (FF)	The amount of time an activity may be delayed without delaying the early start time of the immediately following activity. $FF_i = ES_j - EF_i$ where the subscript i represents the preceding activity and the subscript j represents the following activity.
Critical Path	A series of interconnected activities through the network diagram, with each activity having zero free float and zero total float time. The critical path determines the minimum time to complete the project.
Dummy Activity	An activity (represented by a dotted line on the arrow network diagram) that indicates that any activity following the dummy cannot be started until the activity or activities preceding the dummy are completed. The dummy does not require any time.

FIGURE 10-1 Basic definitions for CPM.

For project management, the CPM is the most commonly used NAS method. The concept is simple; the computations only require basic arithmetic. A large number of computer programs are available to automate the work required of CPM scheduling. The most difficult task in the use of CPM is identifying and interfacing the numerous activities that are required to complete a project, that is, development of the CPM network diagram. If a well-defined WBS is developed first, the task of developing a CPM diagram is greatly simplified.

There are two basic methods of drawing CPM diagrams: the arrow diagram (sometimes called activity on arrow) and the precedence diagram (sometimes called activity on node). Although both methods achieve the same results, most project managers prefer the precedence method because it does not require the use of dummy activities. The precedence method can also provide the start-to-start, finish-to-finish, start-to-finish, and finish-to-start relationship of activities, which can significantly reduce the number of activities that are required in a network diagram. However, many individuals prefer to not use these relationships because of potential confusion in the network scheduling.

Figure 10-2 is a simple precedence diagram that is presented to illustrate the time computations for analysis of a project schedule by the CPM. Each activity is described by a single letter. The number at the top of the activity is the assigned activity number, and the number at the bottom of each activity represents the duration in working days. A legend is shown in the lower left-hand corner to define the start and finish days. All calculations for starts and finishes are based on end-of-day. The critical path is indicated by a double line arrow.

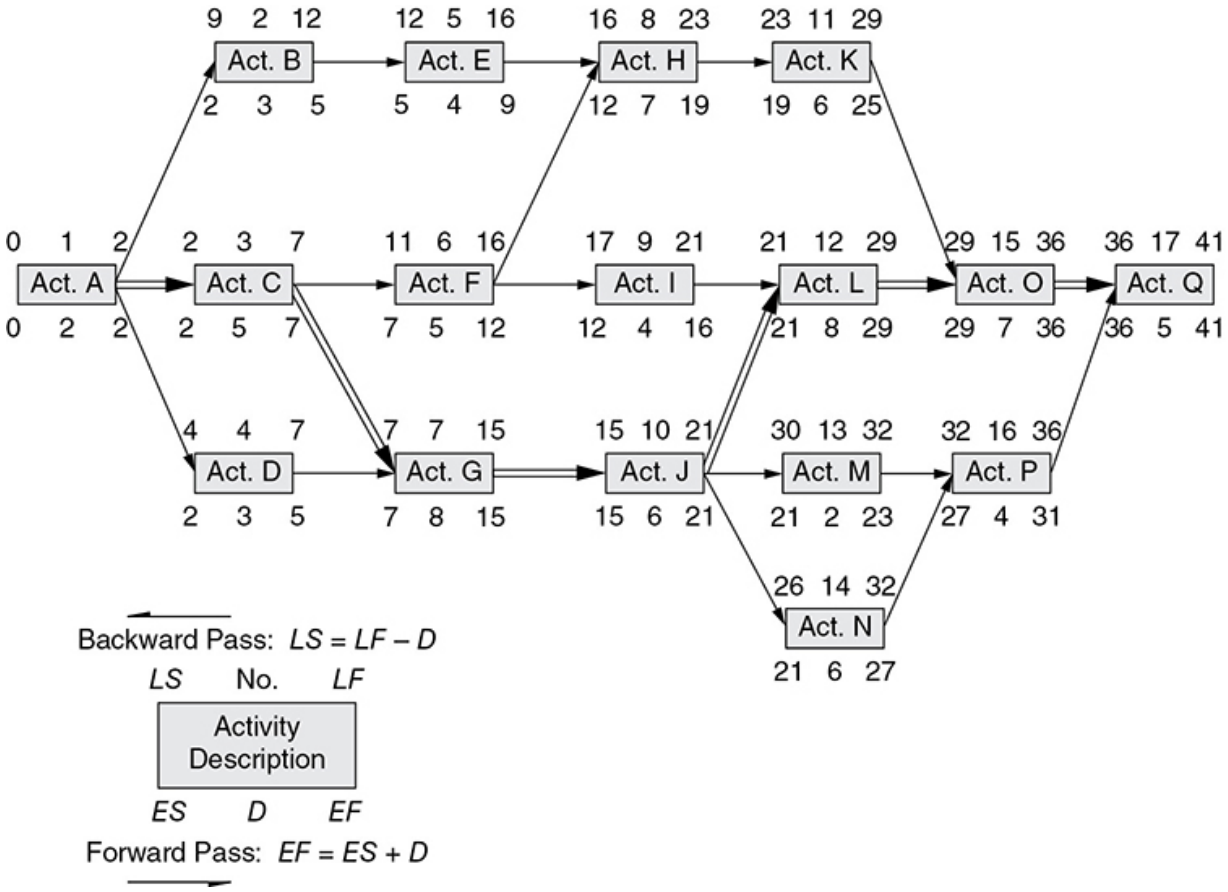


FIGURE 10-2 Time computations for simple precedence diagram.

After the CPM diagram has been prepared, the duration of each activity can be assigned, and the forward-pass calculations performed to calculate the early start and early finish of each activity. The largest early finish of all preceding activities defines the early start of all following activities. For example, Activity H cannot be started until Activities E and F are both completed. Since the largest early finish of the two preceding activities is 12, the early start for Activity H is 12. The forward-pass calculations are performed on all activities from the first Activity A to the last Activity Q. The early finish of the last activity defines the project completion, which is 41 days for this particular project. This project duration is a calculated value based on

the duration and interdependences of all activities in the project.

A backward-pass can be performed to calculate the late start and late finish of each activity. The smallest late start of all following activities defines the late finish of all preceding activities. For example, Activities H and I cannot both be started until Activity F is completed. Since the smallest early start of the two following activities is 16, the late finish for F is 16. The backward-pass calculations are performed on all activities from the last Activity Q to the first Activity A.

The difference between starts and finishes determines the amount of free and total float. For example, the total float for Activity M is 9 days, the difference between its late start (30) and early start (21). The free float for Activity M is 4 days, the difference between its early finish (23) and the early start (27) of the immediately following Activity P.

The critical path, as noted by the double line on Figure 10-2, is defined by the series of interconnected activities that have zero total float. Since these activities have no float time available, any delay in their completion will delay the completion date of the project. Therefore, they are called critical activities.

The basic steps that can be used to develop a network analysis system for project planning and scheduling is provided in Table 10-5.

1. Develop a Work Breakdown Structure (WBS) including work packages containing activities a. Consider activities that require time b. Consider activities that require cost c. Consider activities that need to be arranged d. Consider activities that need to be or will be monitored
2. Design the schedule a. Consider the schedule's purpose b. Consider the project execution plan c. Consider reporting requirements c. Prepare an outline of the schedule d. Consider the level of detail for the schedule e. Consider risk management results
3. Prepare a drawing (network diagram) that shows each activity in the order it must be performed to complete the project a. Consider which activities immediately precede each activity b. Consider which activities immediately follow each activity c. The interrelationship of activities is a combination of how the work must be done (constraints) and how you want the work to be done
4. Determine the time, cost, and resources required to complete each activity a. Review work packages of the WBS b. Obtain input from project team members
5. Compute the schedule to determine start, finish, and float times a. Perform a forward pass to determine early starts and finishes b. Perform a backward pass to determine late starts and finishes c. Determine the differences between start and finish times to determine float time and critical activities
6. Analyze costs and resources for the project a. Compute the cost per day for each activity and for the entire project b. Compute the labor-hours per day and/or other resources that are required to complete the project
7. Communicate the results of the plan and schedule a. Display time schedule for activities b. Display cost schedule for activities c. Display schedule for other resources

TABLE 10-5 Steps in Planning and Scheduling

In developing a CPM network, it is not always possible to complete a step without some readjustments. For example,

the CPM diagram of step 2 may need readjusting after evaluation of the time and resources of steps 4 and 5. Some activities that were originally planned in a series may need to occur in parallel to meet a time requirement. Each project manager and his or her team must work together to develop a project plan and schedule that achieve the required project completion date with the resources that are available.

Development of the CPM Diagram from the WBS

The development of the WBS is the most important first step that is often neglected. Attempting to develop the CPM logic diagram without a WBS usually leads to numerous revisions to the diagram. Each project manager and his or her team must work together to develop a project plan and schedule that achieves the required project completion date with the resources that are available.

Figure 10-3 is an example of a WBS for the design of a service facility project that consists of two buildings: site work and on-site utilities. As discussed in Chapter 3, a WBS can be developed in a graphical or outline format. Figure 10-3 shows the WBS in a graphic format, and Figure 10-4 shows the same project in an outline format. A discussion of a typical owner's study for this type of project was presented in Chapter 2. Part of the execution strategy for this project is to use in-house personnel to design the onsite utilities, site work, and the industrial maintenance building (denoted as Building A). This is commonly called performing work by the force-account method. A contract is assigned to an outside design organization for design of the commercial building (denoted as Building B), which is to be used as an employees office building.

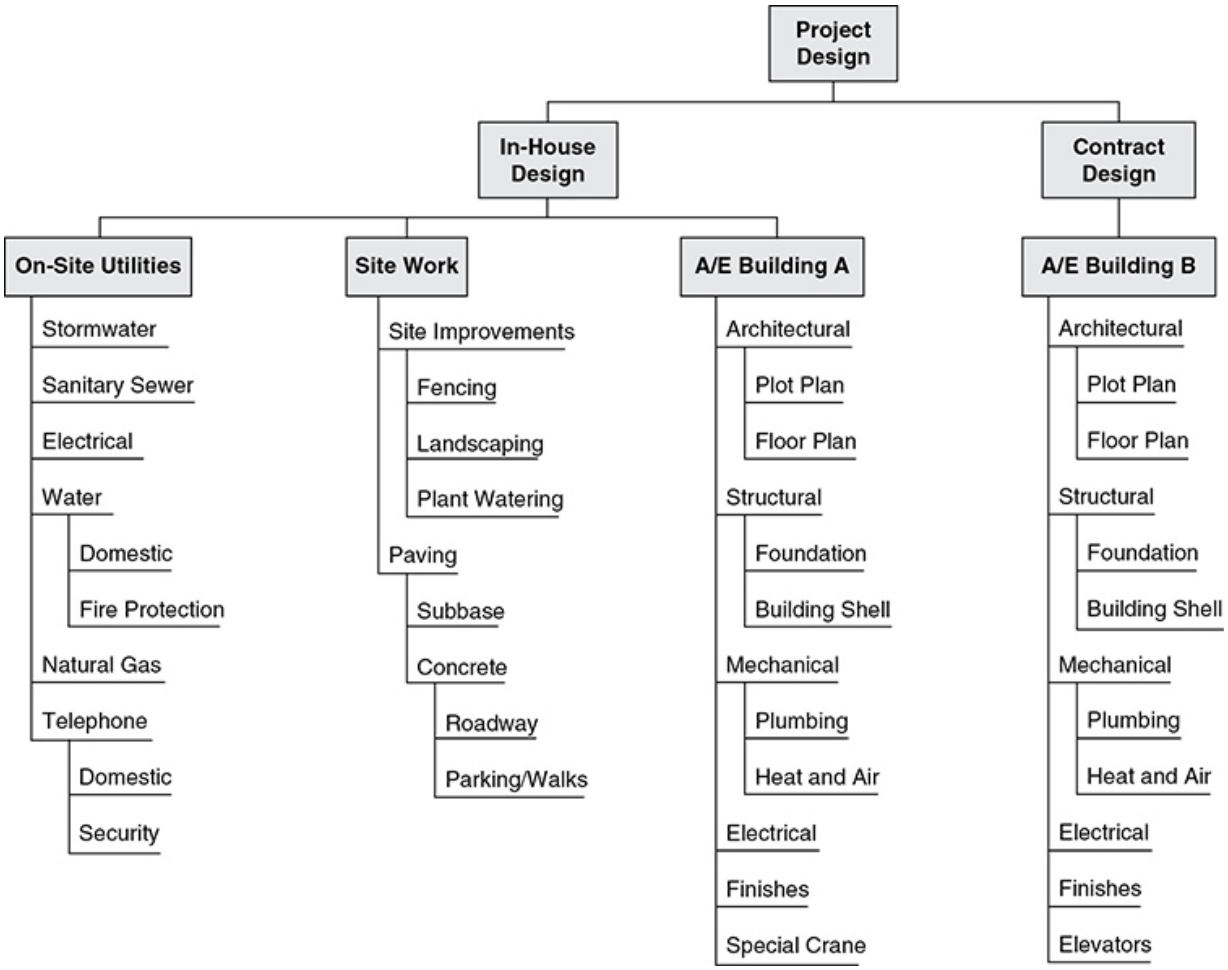


FIGURE 10-3 Work breakdown structure (WBS) for design of service facility project (graphic format).

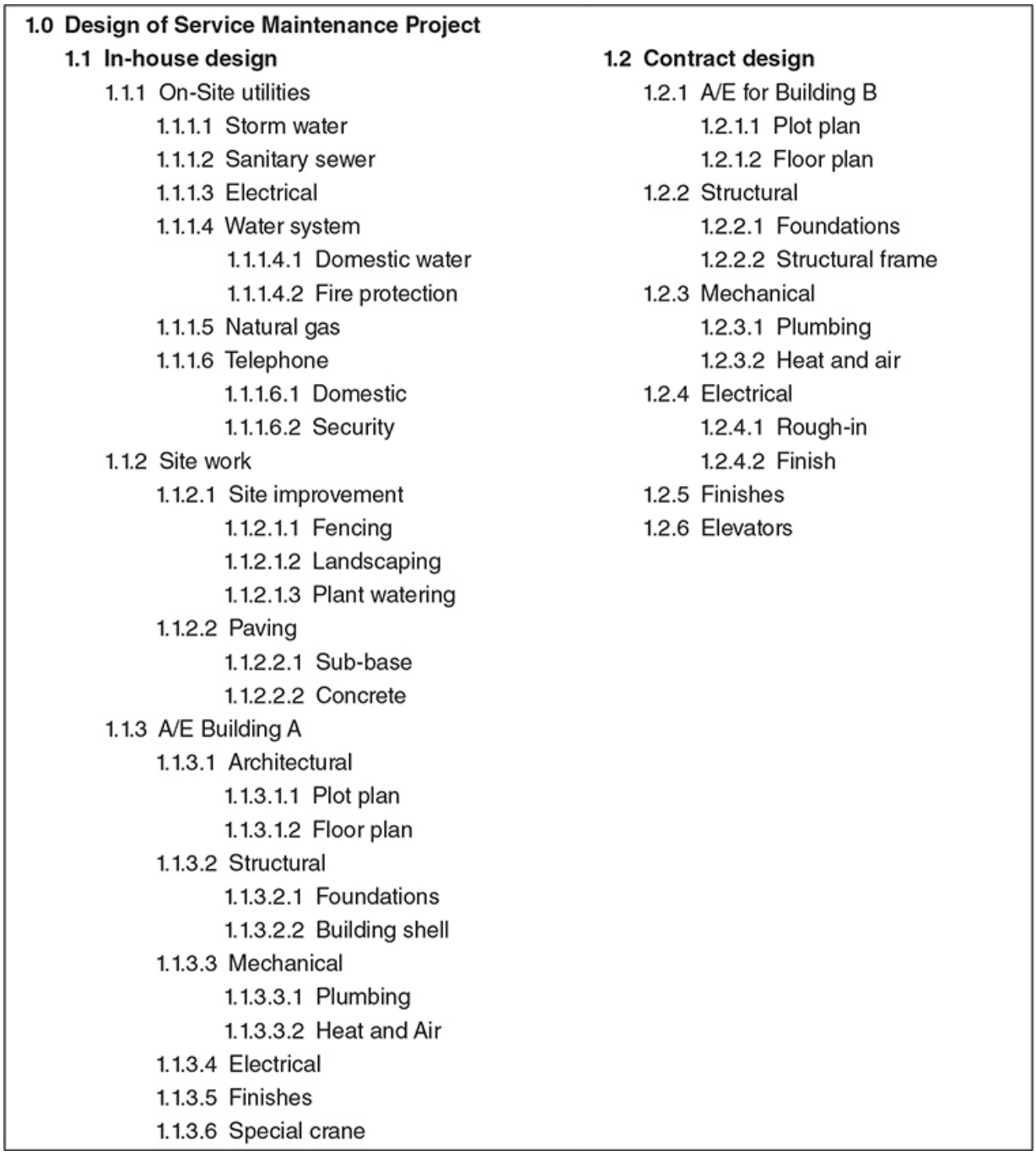


FIGURE 10-4 WBS for design of service maintenance facility (outline format).

The WBS identifies the tasks and activities that must be performed, but does not provide the order in which they must occur. The CPM network diagram is prepared to show

the sequencing and interdependences of the activities in the WBS. The diagram can be prepared by traditional drafting techniques, or it can be prepared using the computer. The development on a computer can use either a computer-aided drafting and design (CADD) program, or a software package that is specifically written for CPM scheduling.

Regardless of the method that is used, the initial logic of the diagram must be arranged by the person who is developing the diagram. In simplest terms, a person must tell the computer how to draw the diagram. An efficient way to accomplish this task is a sticky note exercise. In a schedule planning meeting, each team member records their assigned activities on a large sticky note. Each team member then places their activities in sequential order using a large wall or a series of flip charts. As each team member places their activities onto the wall, dependencies, constraints, reviews, approvals, and other considerations can be discussed and included, if necessary, into the sequence of activities. Once all the activities, milestones, and other components of the schedule are captured, the scheduler can take photos of the preliminary diagram to use for data entry into the selected scheduling software package.

Figure 10-5 is a CPM diagram that was developed from the WBS shown in Figure 10-3. Note that each activity on the CPM is derived from the work tasks that are shown on the WBS. Thus, the project manager plans the project around the work to be performed, which has been defined by the people who will perform the work. Activities that are related are grouped together and arranged in the order they are to be performed. For example, the architectural floor plans are developed before the structural, mechanical, and electrical designs. A careful planning of the interface of activities at the start of the project is necessary for successful management of a project.

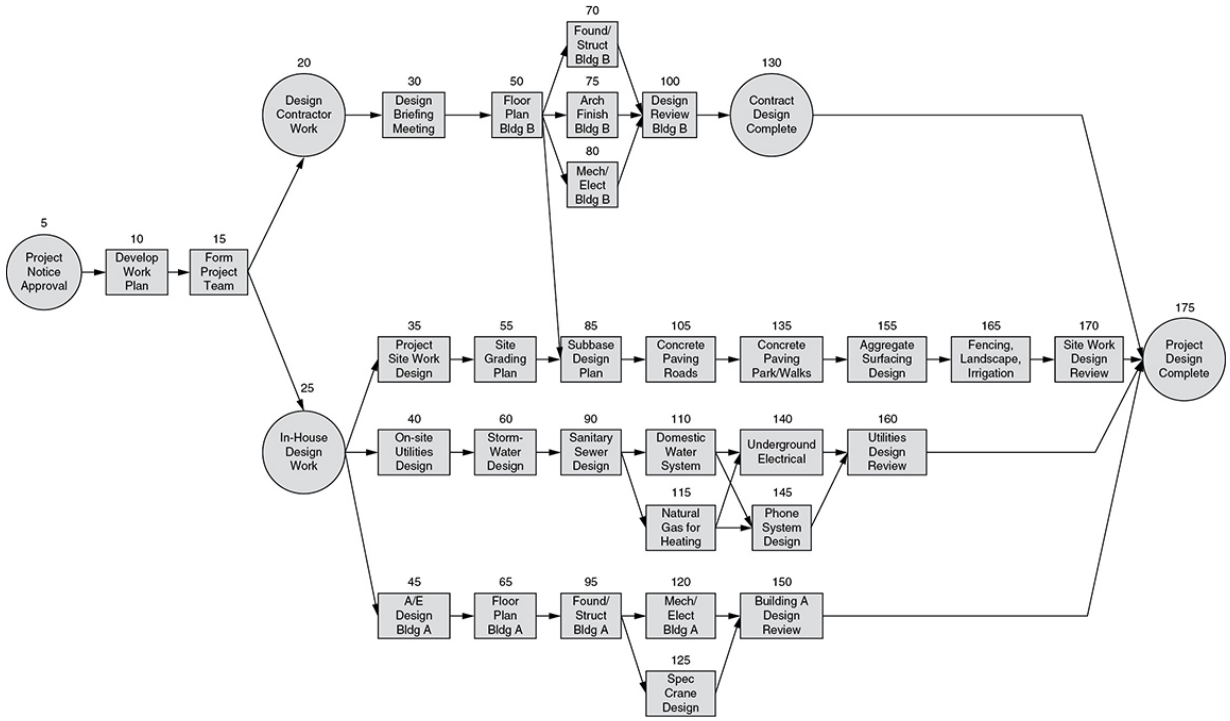


FIGURE 10-5 CPM diagram for design engineering.

The purpose of CPM is to plan the work to guide the progress of a project and provide a baseline for project control. Chapter 13 discusses linking the WBS to the CPM for project control by expanding Figures 10-3 and 10-4 to include procurement and construction activities.

Assigning Realistic Durations

The CPM network diagram defines the activities, and sequencing of activities, to be performed to accomplish the project; however, the anticipated time that is required to complete each activity must be determined in order to schedule the entire project. The durations that are assigned to activities are important because the critical path, timing of activities, distribution of costs, and utilization of resources are all a function of activity durations. The durations must be verified against those assumed or provided in the cost estimate.

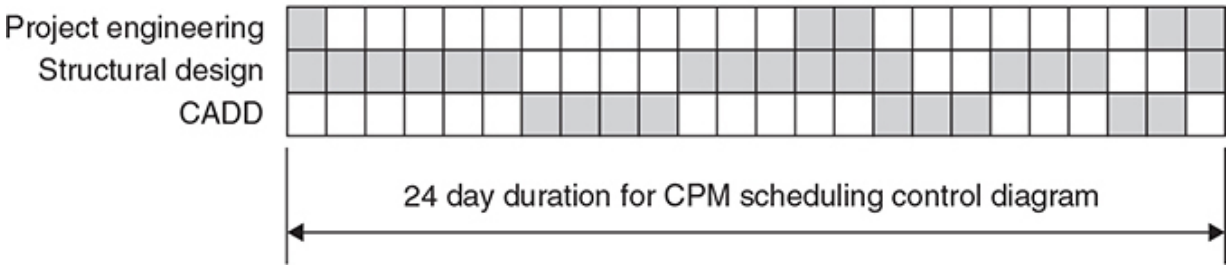
The assignment of the duration that is required to accomplish an activity will vary depending on many factors: quantity and quality of work, number of people and/or equipment that is assigned to the activity, level of worker skills, availability of equipment, work environment, effectiveness of supervision of the work, and other conditions. Although these variations exist, a special effort must be made to determine a realistic duration for each activity because the duration that is assigned to activities in a CPM network diagram has a large impact on the schedule and overall management of a project.

Many activities in a project are routine in nature, which enables a reasonably accurate determination of the probable time of completion. For these types of activities, the duration can be determined by dividing the total quantity of work by the production rate, which is a function of the number of individuals that are assigned to the activity. A common mistake that is made by many people is to calculate the time to accomplish an activity assuming a continuous flow of uninterrupted work. However, all work is subject to delays, interruptions, or other events that can impact time. Thus, a reasonable amount of time (allowance) must be added to the calculated time to determine a realistic duration for each activity.

Generally, the duration of an activity can be determined by one of three methods: by analyzing historical records from previously completed projects, by referencing commercially available manuals that provide costs and production rates for various types of work, or from the experience and judgement of the person who will be performing the work. It is often desirable to determine the probable duration by several methods so the results can be compared to detect any significant variations that may occur.

The schedule for the design work is the total time to produce the final drawings, including the overlap of design calculations and design drafting. As previously discussed, most engineers prefer a bar chart for scheduling individual design tasks. However, for project control, the individual bar charts must be developed into activities on the CPM diagram to develop the total project schedule. The start and finish of each activity of the CPM engineering design schedule is a composite of all tasks of the work package. The following illustrates the evaluation of overlapping tasks of the work package to determine the duration of an activity on the CPM diagram.

Tasks of Work Package	Duration
Project engineering	5 days
Structural design	16 days
CADD	9 days
Total design days	30 days



Computer Applications

The CPM network diagram, by itself, identifies the sequencing of activities but does not provide the scheduled start and finish dates, the distribution of costs, or the allocation of resources. This information can easily be determined by assigning the duration, cost, and resources that are required of each activity as identified in the work packages.

There are many CPM computer programs available to perform the numerous calculations necessary to determine

the scheduled time, cost, and resources of activities. Although the number, type, and format of the computer-generated output reports vary widely, depending on the software, the basic input data required for each is the same information. The information required for the input data consists of activity number, description, duration, cost, and resources, such as, labor-hours. The sequencing, or interrelationship of activities, is defined by the CPM network diagram. The input data is the same information that is compiled during preparation of the design work packages for the WBS, or during preparation of the estimate for a project by the construction contractor. Thus, the computer application of CPM is appropriate for both the design and construction phase of a project.

The information that must be assembled for a CPM computer analysis is illustrated in Figures 10-6 and 10-7. Figure 10-6 is a simple CPM precedence network diagram for a sewer and water lines construction project. Construction activities are selected for this illustrative example because they are easily recognizable by most readers. Each activity in Figure 10-7 is shown with its time, cost, and successor/predecessor information. Resources are excluded for simplicity of this presentation and are discussed in the following section. A hand analysis of starts and finishes is shown in Figure 10-6 to illustrate the calculations and to relate them to the computer output reports discussed in the following paragraphs. The times that are shown on the diagram all represent end-of-day. A listing of the computer input data for this project is shown in Figure 10-7.

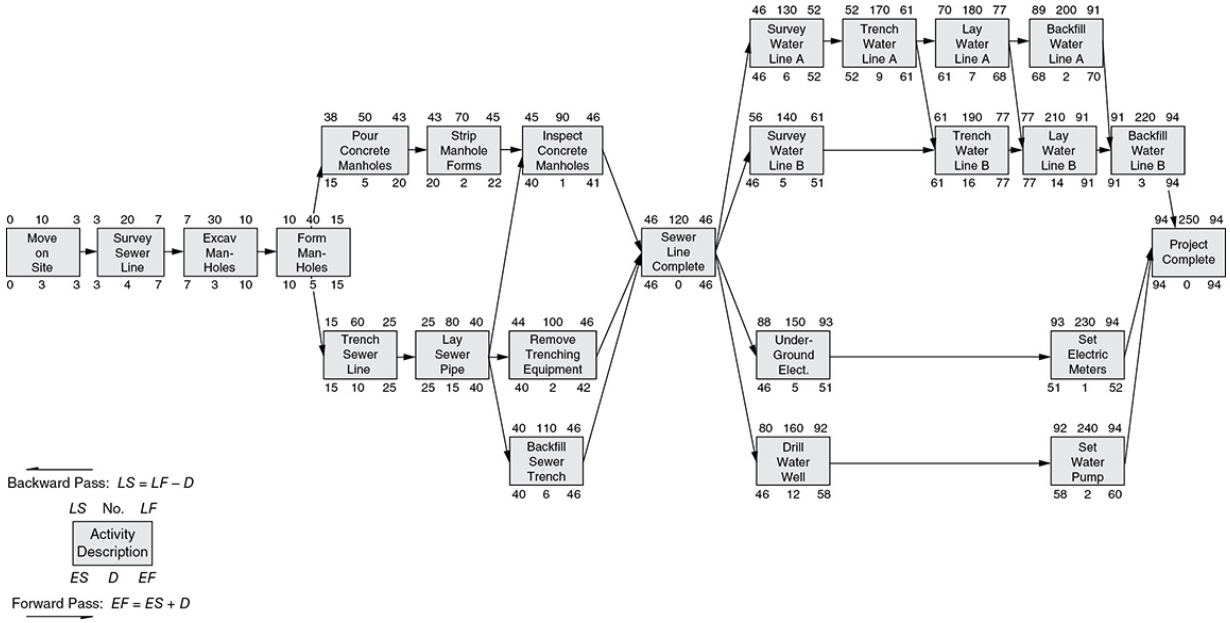


FIGURE 10-6 CPM diagram for construction phase of sewer and water lines project.

Activities		Description	Duration	Cost
Number	Code			
10	5000	Move on-site	3	$1,400
20	1100	Survey sewer lines	4	$2,700
30	1200	Excavate for manholes	3	$3,500
40	1200	Install manhole formwork	5	$6,000
50	1200	Place concrete manholes	5	$4,700
60	1300	Trench sewer line	10	$12,600
70	1200	Strip manhole formwork	2	$2,100
80	1400	Lay sewer pipe	15	$11,250
90	1200	Inspect manholes	1	$800
100	1300	Remove trenching equipment	2	$1,400
110	1500	Backfill sewer trench	6	$3,600
120	5000	Sewer line complete	0	$0
130	2110	Survey water line A	6	$4,000
140	2120	Survey water line B	5	$3,400
150	3000	Underground electrical	5	$2,500
160	4000	Drill water well	12	$7,000
170	2310	Trench water line A	9	$8,800
180	2410	Lay pipe for water line A	7	$16,800
190	2320	Trench for water line B	16	$15,600
200	2510	Backfill water line A	2	$900
210	2420	Lay pipe for water line B	14	$33,600
220	2520	Backfill water line B	3	$2,850
230	3000	Install water meters	1	$600
240	4000	Set water pump	2	$1,400
250	5000	Project complete	0	$0

Sequence of Activities			
From	To	From	To
10	20	120	150
20	30	120	140
30	40	130	170
40	50	140	190
40	60	150	230
50	70	160	240
60	80	170	180
70	90	170	190
80	90	180	200
80	110	180	210
80	100	190	210
90	120	200	220
100	120	210	220
110	120	220	250
120	130	230	250
120	160	240	250

FIGURE 10-7 Input data file for sewer and water lines projects.

For this project, two surveying crews are available, which allow Activities 130 and 140 to occur simultaneously. Only one trenching machine is available; therefore, trenching work for Water Line A, Activity 170, is planned before trenching of Water Line B, Activity 190. Other similar constraints are shown in the network to illustrate that planning must be done before project scheduling can be accomplished. The input data required for a computer scheduling analysis are shown in Figure 10-7. The first part of the input data defines information related to each activity. The second part defines the order in which the activities are performed, that is, the sequencing or interfacing of activities. The project title and other pertinent information is shown above the activity list.

Figures 10-8a and 10-8b show an activity schedule report for the project with calendar days and working days, respectively. Start dates represent beginning of the day while finish dates represent end of the day. The free and total floats are shown for each activity. Critical activities are indicated with bold italic text. The calendar dates in Figures 10-8a and 10-8b are based on a 5-day work week (Monday through Friday) and neglects holidays.

Sewer and Water Lines Project
Activity Schedule—All Activities

Number	Description	Duration	ES	EF	LS	LF	Total Float	Free Float
10	***Move on-site***	3	1-Apr-2033	5-Apr-2033	1-Apr-2033	5-Apr-2033	0	0
20	***Survey sewer lines***	4	6-Apr-2033	11-Apr-2033	6-Apr-2033	11-Apr-2033	0	0
30	***Excavate for manholes***	3	12-Apr-2033	14-Apr-2033	12-Apr-2033	14-Apr-2033	0	0
40	***Install manhole formwork***	5	15-Apr-2033	21-Apr-2033	15-Apr-2033	21-Apr-2033	0	0
50	Place concrete manholes	5	22-Apr-2033	28-Apr-2033	25-May-2033	31-May-2033	23	0
60	***Trench sewer line***	10	22-Apr-2033	5-May-2033	22-Apr-2033	5-May-2033	0	0
70	Strip manhole formwork	2	29-Apr-2033	2-May-2033	1-Jun-2033	2-Jun-2033	23	18
80	***Lay sewer pipe***	15	6-May-2033	26-May-2033	6-May-2033	26-May-2033	0	0
90	Inspect manholes	1	27-May-2033	27-May-2033	3-Jun-2033	3-Jun-2033	5	5
100	Remove trenching equipment	2	27-May-2033	30-May-2033	2-Jun-2033	3-Jun-2033	4	4
110	***Backfill sewer trench***	6	27-May-2033	3-Jun-2033	27-May-2033	3-Jun-2033	0	0
120	***Sewer line complete***	0	6-Jun-2033	6-Jun-2033	6-Jun-2033	6-Jun-2033	0	0
130	***Survey water line A***	6	6-Jun-2033	13-Jun-2033	6-Jun-2033	13-Jun-2033	0	0
140	Survey water line B	5	6-Jun-2033	10-Jun-2033	20-Jun-2033	24-Jun-2033	10	10
150	Underground electrical	5	6-Jun-2033	10-Jun-2033	3-Aug-2033	9-Aug-2033	42	0
160	Drill water well	12	6-Jun-2033	21-Jun-2033	22-Jul-2033	8-Aug-2033	34	0
230	Install water meters	1	13-Jun-2033	13-Jun-2033	10-Aug-2033	10-Aug-2033	42	42
170	***Trench water line A***	9	14-Jun-2033	24-Jun-2033	14-Jun-2033	24-Jun-2033	0	0
240	Set water pump	2	22-Jun-2033	23-Jun-2033	9-Aug-2033	10-Aug-2033	34	34
180	Lay pipe for water line A	7	27-Jun-2033	5-Jul-2033	8-Jul-2033	18-Jul-2033	9	9
190	***Trench for water line B***	16	27-Jun-2033	18-Jul-2033	27-Jun-2033	18-Jul-2033	0	0
200	Backfill water line A	2	6-Jul-2033	7-Jul-2033	4-Aug-2033	5-Aug-2033	21	21
210	***Lay pipe for water line B***	14	19-Jul-2033	5-Aug-2033	19-Jul-2033	5-Aug-2033	0	0
220	***Backfill water line B***	3	8-Aug-2033	10-Aug-2033	8-Aug-2033	10-Aug-2033	0	0
250	***Project complete***	0	10-Aug-2033	10-Aug-2033	10-Aug-2033	10-Aug-2033	0	0

Bold Italicized Activities are critical

FIGURE 10-8a Activity schedule (calendar days) report for entire sewer and water lines project.

Sewer and Water Lines Project
Activity Schedule—All Activities

Number	Description	Duration	ES	EF	LS	LF	Total Float	Free Float
10	***Move on-site***	3	1	3	1	3	0	0
20	***Survey sewer lines***	4	4	7	4	7	0	0
30	***Excavate for manholes***	3	8	10	8	10	0	0
40	***Install manhole formwork***	5	11	15	11	15	0	0
50	Place concrete manholes	5	16	20	39	43	23	0
60	***Trench sewer line***	10	16	25	16	25	0	0
70	Strip manhole formwork	2	21	22	44	45	23	18
80	***Lay sewer pipe***	15	26	40	26	40	0	0
90	Inspect manholes	1	41	41	46	46	5	5
100	Remove trenching equipment	2	41	42	45	46	4	4
110	***Backfill sewer trench***	6	41	46	41	46	0	0
120	***Sewer line complete***	0	47	47	47	47	0	0
130	***Survey water line A***	6	47	52	47	52	0	0
140	Survey water line B	5	47	51	57	61	10	10
150	Underground electrical	5	47	51	89	93	42	0
160	Drill water well	12	47	58	81	92	34	0
230	Install water meters	1	52	52	94	94	42	42
170	***Trench water line A***	9	53	61	53	61	0	0
240	Set water pump	2	59	60	93	94	34	34
180	Lay pipe for water line A	7	62	68	71	77	9	9
190	***Trench for water line B***	16	62	77	62	77	0	0
200	Backfill water line A	2	69	70	90	91	21	21
210	***Lay pipe for water line B***	14	78	91	78	91	0	0
220	***Backfill water line B***	3	92	94	92	94	0	0
250	***Project complete***	0	94	94	94	94	0	0

Bold Italicized Activities are critical

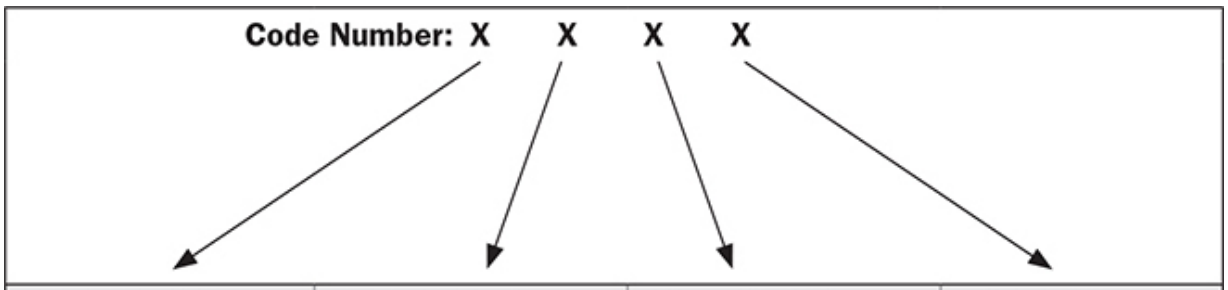
FIGURE 10-8b Activity schedule (working days) report for entire sewer and water lines project.

Schedule Coding Systems

One of the advantages of CPM scheduling with software is the ability to filter and to sort specific activities from the complete list of activities for the project. For example, the project manager may only want information about sewer activities, the time required for trenching equipment, or the assignment of the surveying crew. The sorting of these activities can easily be accomplished by a coding system.

Table 10-6 is a simple four-digit coding system to illustrate sorting capabilities for the sewer and water lines CPM schedule that is shown in Figure 10-6. All activities related to the sewer line are represented by the number “1” in the first digit. Water line activities are represented by the

number “2.” The second code digit represents the type of work, such as surveying, forming manholes, trenching, laying pipe, and backfilling. Thus, a four-digit code is assigned to each activity in the project. For example, the code for activity number 180 is 2410. This code indicates that the activity pertains to water line, laying pipe, and line A. The four-digit code number for each activity in the sewer and water lines project is shown in the activity list of Figure 10-7.



Code Digit 1	Code Digit 2	Code Digit 3	Code Digit 4
0—Unassigned	0—Unassigned	0—Unassigned	0—Unassigned
1—Sewer Line	1—Surveying	1—Line A	1—Unassigned
2—Water Line	2—Manholes	2—Line B	2—Unassigned
3—Water Meter	3—Trenching	3—Unassigned	3—Unassigned
4—Water Pump	4—Laying Pipe	4—Unassigned	4—Unassigned
5—Milestones	5—Backfill	5—Unassigned	5—Unassigned
6—Unassigned	6—Unassigned	6—Unassigned	6—Unassigned
7—Unassigned	7—Unassigned	7—Unassigned	7—Unassigned
8—Unassigned	8—Unassigned	8—Unassigned	8—Unassigned
9—Unassigned	9—Unassigned	9—Unassigned	9—Unassigned

TABLE 10-6 Coding System for Sewer and Water Lines Project

The coding system provides numerous options for selection of activities by the project manager. For example, all sewer line activities can be sorted from the complete list of project activities by selecting those activities that have a

"1" in the first digit. A schedule report for these activities is shown in Figure 10-9. A project manager may also print a bar chart for these activities as shown in Figure 10-10. A coding system provides a means of obtaining many other reports. For example, a sort of all activities related to trenching and laying pipe can be obtained by selecting activities that have a second code digit number that is greater than "2" and less than "5" (reference Table 10-6).

Sewer and Water Lines Project
Activity Schedule—Sewer Line Activities

ID	Description	Duration	ES	EF	LS	LF
20	***Survey sewer lines***	4	6-Apr-2033	11-Apr-2033	6-Apr-2033	11-Apr-2033
30	***Excavate for manholes***	3	12-Apr-2033	14-Apr-2033	12-Apr-2033	14-Apr-2033
40	***Install manhole formwork***	5	15-Apr-2033	21-Apr-2033	15-Apr-2033	21-Apr-2033
50	Place concrete manholes	5	22-Apr-2033	28-Apr-2033	25-May-2033	31-May-2033
60	***Trench sewer line***	10	22-Apr-2033	5-May-2033	22-Apr-2033	5-May-2033
70	Strip manhole formwork	2	29-Apr-2033	2-May-2033	1-Jun-2033	2-Jun-2033
80	***Lay sewer pipe***	15	6-May-2033	26-May-2033	6-May-2033	26-May-2033
90	Inspect manholes	1	27-May-2033	27-May-2033	3-Jun-2033	3-Jun-2033
100	Remove trenching equipment	2	27-May-2033	30-May-2033	2-Jun -2033	3-Jun-2033
110	***Backfill sewer trench***	6	27-May-2033	3-Jun-2033	27-May-2033	3-Jun-2033

Bold Italicized Activities are critical

FIGURE 10-9 Sewer line activities report (sort of activities list by code digit #1 equal to 1).

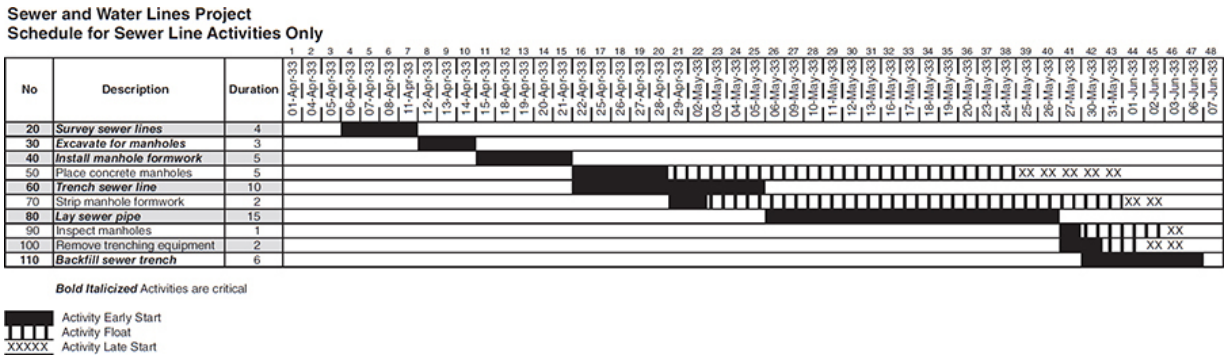


FIGURE 10-10 Bar chart for sewer line activities only (code digit 1 = 1).

Cost Distribution

The distribution of costs, with respect to time, must be known to successfully manage a project. In the preceding sections, the scheduled early and late starts, and finishes, were calculated based on the duration and sequencing of activities. A cost analysis can also be performed by assigning the cost that is anticipated to complete each activity. The cost of an activity may be distributed over the duration of the activity; however, the activity may be performed over a range of time, starting from the early to late start and ending from the early to late finish.

Because activities can occur over a range of time, a cost analysis must be performed based on activities starting on an early start, late start, and target schedule. The target schedule is the midpoint between the early start and late start. Table 10-7 illustrates the early start cost analysis calculations for the sewer and water lines project shown in Figure 10-6. For each day in the project, the cost per day of each activity that is in progress is summed to obtain the total cost of the project for that day. Cumulative project costs are divided by the total project cost of $147,500 to obtain the percentage cost for each day. The percentage time for each day is calculated by dividing the number of the working days by the total project duration of 94 days. Similar calculations can be performed for activities starting on a late start schedule and target schedule.

Total Project Duration = 94 Working Days Total Project Cost = $147,500								
		Activities in Progress			Act cost	Project	Cumulative	%
Day	% Time	No.	Cost	Duration	per day	cost/day	project cost	Cost
1	1.06%	Act. 10	$1,400	3 days =	$466.67	$466.67	$467	0.32%
2	2.13%	↓	↓	↓	↓	↓	$933	0.63%
3	3.19%						$1,400	0.95%
4	4.26%	Act. 20	$2,700	4 days =	$675.00	$675.00	$2,075	1.41%
5	5.32%	↓	↓	↓	↓	↓	$2,750	1.86%
6	6.38%						$3,425	2.32%
7	7.45%						$4,100	2.78%
8	8.51%	Act. 30	$3,500	3 days =	$1,166.67	$1,166.67	$5,267	3.57%
9	9.57%	↓	↓	↓	↓	↓	$6,435	4.36%
10	10.64%						$7,600	5.15%
11	11.70%	Act. 40	$6,000	5 days =	$1,200.00	$1,200.00	$8,800	5.97%
12	12.77%	↓	↓	↓	↓	↓	$10,000	6.78%
13	13.83%						$11,200	7.59%
14	14.89%						$12,400	8.41%
15	15.96%						$13,600	9.22%
16	17.02%	Act. 50	$4,700	5 days =	$940.00			
		Act. 60	$12,600	10 days =	$1,260.00	$2,200.00	$15,800	10.71%
17	18.09%	↓	↓	↓	↓	$2,200.00	$18,000	12.20%
18	19.15%					$2,200.00	$20,200	13.69%
19	20.21%					$2,200.00	$22,400	15.19%
20	21.28%					$2,200.00	$24,600	16.68%
21	22.34%	Act. 60	$12,600	10 days =	$1,260.00			
↓	↓	Act. 70	$2,100	2 days =	$1,050.00	$2,310.00	$26,910	18.24%
							↓	↓
94	100.0%						$147,500	100.0%

TABLE 10-7 Calculations for Project Costs per Day on an Early Start Basis

Although the calculations for a cost analysis are simple, many are required, as illustrated by the small sewer and water lines project that has only 25 activities and a 94-day

project duration. The use of software is a necessity for large projects.

Figure 10-11 is a computer printout of the daily distribution of costs for the calculations illustrated in Table 10-7. A similar analysis can be performed for other resources, such as labor and equipment. For example, a daily distribution of labor-hours, similar to Figure 10-11, can be used to detect periods of time when the need for labor is high or low. The project manager and his or her team can detect this problem early and appropriately adjust the project plan or acquire additional personnel if needed and available.

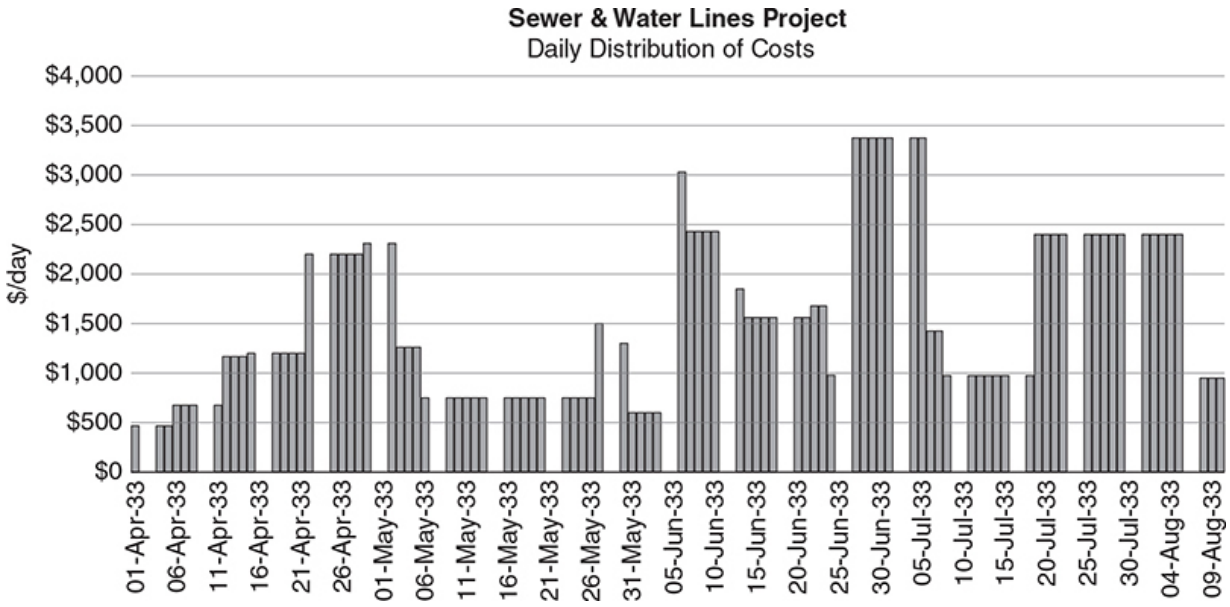


FIGURE 10-11 Daily distribution of costs for sewer and water lines project.

A tabular format of the distribution of costs on an early start, late start, and target basis is presented in Figure 10-12. The target scheduled costs are average values between the early and late start schedules. The two right-hand columns of Figure 10-12 show the percentage-cost and percentage-time values for the target schedule. As shown in

the figure there is a nonlinear relationship between the time and cost for a project.

Project: Sewer & Water Lines Project
Project Manager: W. T. Sherman
Start Date: 1 April 2033 **Finish Date:** 10 August 2033

Work Day	Date	Early Start		Late Start		Target Schedule			
		Cost/ Day	Cumulative Cost	Cost/ Day	Cumulative Cost	Cost/ Day	Cumulative Cost	% Time	% Cost
1	01-Apr-33	$467	$467	$467	$467	$467	$467	1.1%	0.3%
2	04-Apr-33	$467	$933	$467	$934	$467	$933	2.1%	0.6%
3	05-Apr-33	$467	$1,400	$467	$1,401	$467	$1,400	3.2%	0.9%
4	06-Apr-33	$675	$2,075	$675	$2,076	$675	$2,075	4.3%	1.4%
5	07-Apr-33	$675	$2,750	$675	$2,751	$675	$2,750	5.3%	1.9%
6	08-Apr-33	$675	$3,425	$675	$3,426	$675	$3,425	6.4%	2.3%
7	11-Apr-33	$675	$4,100	$675	$4,101	$675	$4,100	7.4%	2.8%
8	12-Apr-33	$1,167	$5,267	$1,167	$5,268	$1,167	$5,267	8.5%	3.6%
9	13-Apr-33	$1,167	$6,434	$1,167	$6,435	$1,167	$6,434	9.6%	4.4%
10	14-Apr-33	$1,167	$7,601	$1,167	$7,602	$1,167	$7,601	10.6%	5.2%
11	15-Apr-33	$1,200	$8,801	$1,200	$8,802	$1,200	$8,801	11.7%	6.0%
12	18-Apr-33	$1,200	$10,001	$1,200	$10,002	$1,200	$10,001	12.8%	6.8%
13	19-Apr-33	$1,200	$11,201	$1,200	$11,202	$1,200	$11,201	13.8%	7.6%
14	20-Apr-33	$1,200	$12,401	$1,200	$12,402	$1,200	$12,401	14.9%	8.4%
15	21-Apr-33	$1,200	$13,601	$1,200	$13,602	$1,200	$13,601	16.0%	9.2%
16	22-Apr-33	$2,200	$15,801	$1,260	$14,862	$1,730	$15,331	17.0%	10.4%
17	25-Apr-33	$2,200	$18,001	$1,260	$16,122	$1,730	$17,061	18.1%	11.6%
18	26-Apr-33	$2,200	$20,201	$1,260	$17,382	$1,730	$18,791	19.1%	12.7%
19	27-Apr-33	$2,200	$22,401	$1,260	$18,642	$1,730	$20,521	20.2%	13.9%
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
85	28-Jul-33	$2,400	$130,250	$2,983	$120,769	$2,692	$125,756	90.4%	85.1%
86	29-Jul-33	$2,400	$132,650	$2,983	$123,752	$2,692	$128,448	91.5%	86.9%
87	01-Aug-33	$2,400	$135,050	$2,983	$126,735	$2,692	$131,140	92.6%	88.7%
88	02-Aug-33	$2,400	$137,450	$2,983	$129,718	$2,692	$133,832	93.6%	90.7%
89	03-Aug-33	$2,400	$139,850	$3,483	$133,201	$2,692	$136,524	94.7%	92.6%
90	04-Aug-33	$2,400	$142,250	$3,933	$137,134	$3,167	$139,691	95.7%	94.7%
91	05-Aug-33	$2,400	$144,650	$3,933	$141,067	$3,167	$142,858	96.8%	96.9%
92	08-Aug-33	$950	$145,600	$2,033	$143,100	$1,492	$144,350	97.9%	97.9%
93	09-Aug-33	$950	$146,550	$2,150	$145,250	$1,550	$145,900	98.9%	98.9%
94	10-Aug-33	$950	$147,500	$2,250	$147,500	$1,600	$147,500	100.0%	100.0%

FIGURE 10-12 Daily costs for all activities for the sewer and water lines project.

The cumulative cost graph for a project is commonly called the *S-curve* because it resembles the shape of the letter "S." The early, late, and target cumulative distribution of costs can be superimposed onto one graph to form the envelope of time over which costs may be distributed for the project (reference Figure 10-13). This graph links two of the basic elements of a project—time and cost. The third element, accomplished work, must also be linked to time and cost. Chapter 13 discusses linking accomplished work to the S-curve.

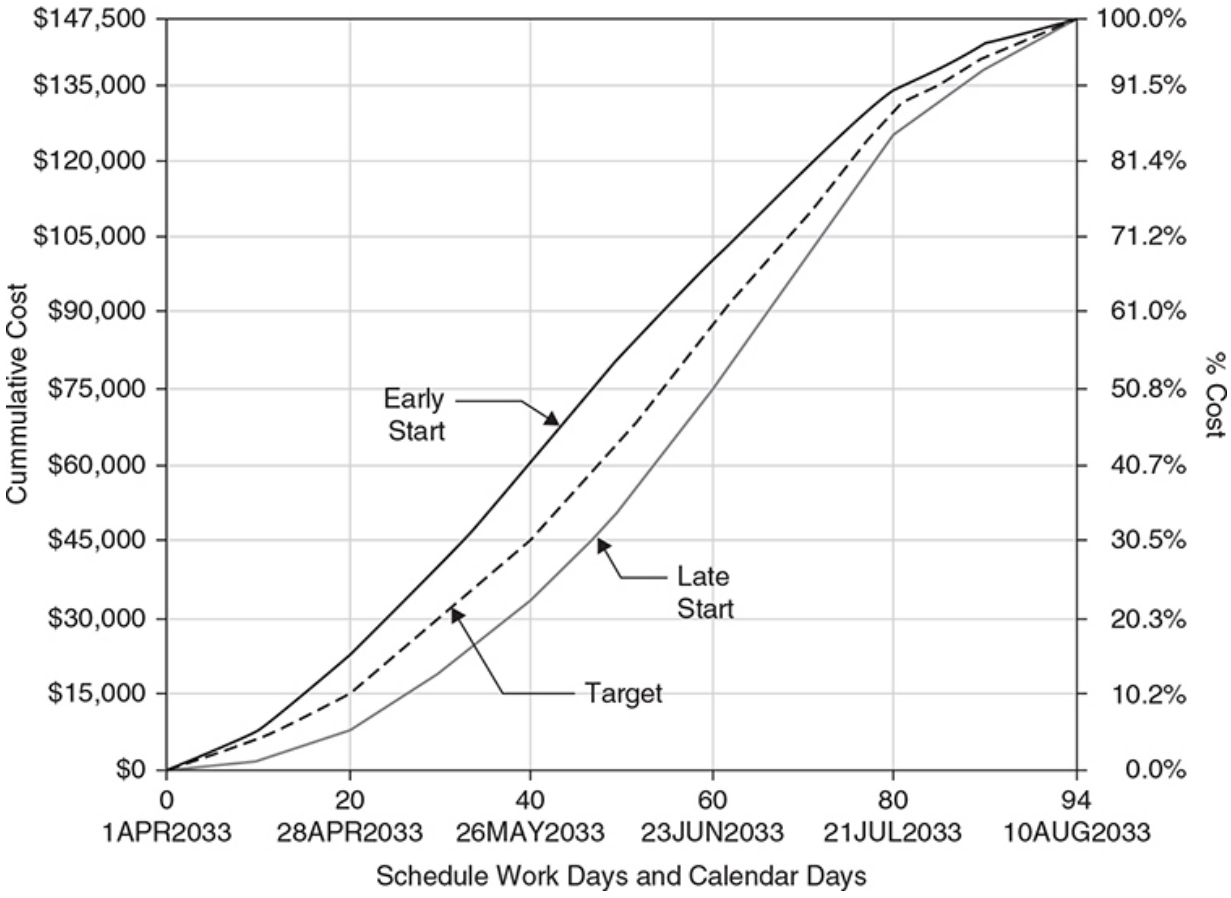


FIGURE 10-13 Illustrative S-curve for cumulative cost curve on an early start, late start, and target basis.

The types of reports presented in this section are typical examples of the reports that can be obtained from the many scheduling software programs available on the market. The only input data that a project manager must prepare, to obtain the described analyses, are shown in Figure 10-7.

Resource Allocations for Design

Efficient utilization of resources is critical to successful project management. The primary resource during design is the work-hours of the design team. The project manager depends on the design team to create design alternatives, produce drawings, and write specifications for the proposed project. To properly coordinate all aspects of the design effort, the project manager must ensure that the correct expertise is available when needed. Generally, design team members are assigned to the project by their respective home departments. Since each designer is often involved in several projects at the same time, the project manager must develop a resource allocation plan for each project. The plan should then be distributed to each design team member's home department to ensure that each resource will be available when needed.

The project manager can resource load the project schedule to include the number of work-hours required for each design discipline. The resource plan is similar to the cost distribution analysis presented earlier in this chapter, except work-hours are used in place of dollars of cost. Thus, the resource plan for design is simply a histogram of work-hours versus time for each design discipline. The project manager should provide the resource plan for each project to the design team's manager. The design managers can then integrate the resource plans of all active projects into their department's demand for technical expertise. This is

necessary to ensure adequate resources are available for the projects when required.

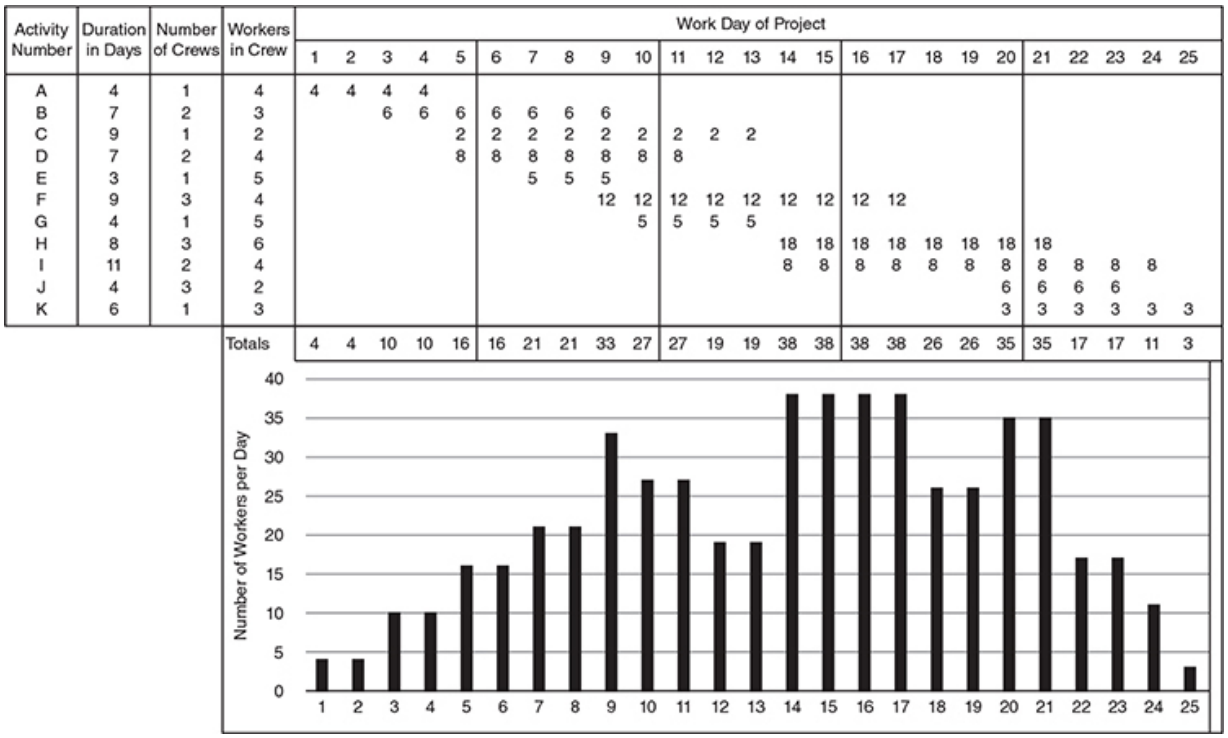
Resource Allocations for Construction

During the construction phase, the primary resources are labor, materials, and equipment. The correct quantity and quality of material must be ordered and delivered to the jobsite at the right time to ensure efficiency of labor. Equipment to be installed in the project often requires a long lead time from the fabricator. Thus, the project execution plan and schedule should include material and equipment required by the construction work force.

Construction labor represents a major cost of construction. The labor force on the job operates construction equipment and installs the materials. A resource allocation plan for construction is required to ensure high efficiency and productivity during construction. The project manager can resource load the project schedule to include the number of work-hours required for each craft of construction labor. The resource plan is a histogram of work-hours versus time, similar to the cost distribution analysis presented earlier in the chapter.

The construction plan shows the desired sequence of work. However, to be workable, the plan must also show the distribution of resources, such as the required labor for each craft on the job. The demand for labor should be uniformly distributed for each craft on the project, to prevent irregularities. The construction resource plan can be used as a tool to ensure a relatively uniform distribution of labor on the project. Resource loading the construction schedule also helps to identify and to prevent an over concentration of work in a particular area of the jobsite. Figure 10-14 is a simple bar chart for a project, showing each work activity, number of crews, and number of people in the crew for all

labor in the project. The lower portion of Figure 10-14 shows irregularity in the distribution of workers per day during the middle of the project.



Activity Number	Duration in Days	Number of Crews	Workers in Crew	Work Day of Project																						
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	4	1	4	4	4	4	4																				
B	7	2	3			6	6	6	6	6	6	6															
C	9	1	2					2	2	2	2	2	2	2	2	2											
D	7	2	4					8	8	8	8	8	8	8													
E	3	1	5							5	5	5															
F	9	3	4									12	12	12	12	12	12	12	12	12							
G	4	1	5										5	5	5	5											
H	8	3	6														18	18	18	18	18	18	18				
I	11	2	4														8	8	8	8	8	8	8	8	8	8	8
J	4	3	2																			6	6	6	6		
K	6	1	3																			3	3	3	3	3	3
			Totals	4	4	10	10	16	16	21	21	33	27	27	19	19	38	38	38	38	26	26	35	35	17	17	11	3

FIGURE 10-14 Irregular distribution of labor.

Figure 10-15 illustrates the same project as Figure 10-14, except Activity F is started 1 day later and Activity H is started 2 days earlier. The lower portion of Figure 10-15 shows a relative uniform distribution of labor by making these two minor adjustments in the project plan. A similar analysis can be made for each craft of labor to ensure uniform distributions of workers on the project. A resource allocation for a particular craft typically has a flat appearance on the graph, whereas a resource allocation for all crafts typically has a bell-shaped graph as shown in Figure 10-15.

Activity Number	Duration in Days	Number of Crews	Workers in Crew	Work Day of Project																					
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
A	4	1	4	4	4	4	4																				
B	7	2	3			6	6	6	6	6	6	6															
C	9	1	2					2	2	2	2	2	2	2	2	2											
D	7	2	4					8	8	8	8	8	8	8													
E	3	1	5							5	5	5															
F	9	3	4										12	12	12	12	12	12	12	12	12						
G	4	1	5										5	5	5	5											
H	8	3	6												18	18	18	18	18	18	18	18					
I	11	2	4														8	8	8	8	8	8	8	8	8	8	
J	4	3	2																				6	6	6		
K	6	1	3																				3	3	3	3	3
			Totals	4	4	10	10	16	16	21	21	21	27	27	37	37	38	38	38	38	38	26	17	17	17	17	11	3

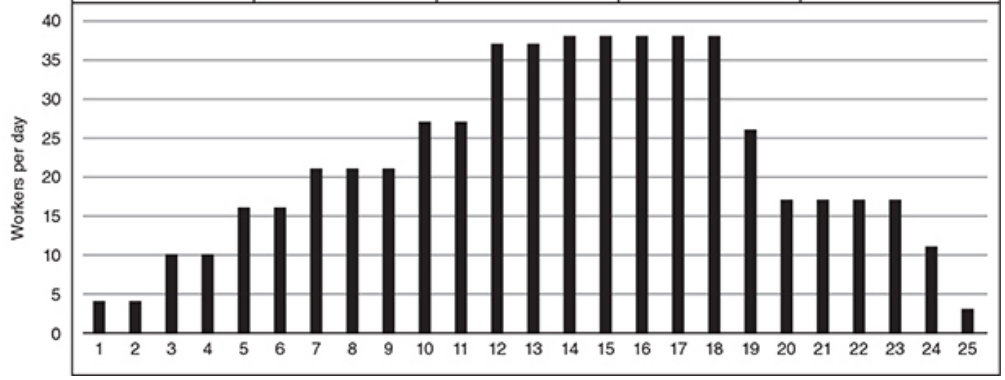


FIGURE 10-15 Labor distribution after starting Activity F 1 day later and Activity H 2 days earlier.

Calculations to Verify Schedules and Cost Distributions

Previous sections of this chapter presented the principles of planning, techniques of developing schedules, and methods of cost-loading CPM schedules to obtain the distribution of costs. Planning identifies the activities and sequencing of activities that must be performed to complete the project. Scheduling establishes the start and finish times of activities based on durations and interdependency of activities. The distribution of costs over the life of a project is obtained by assigning costs to activities from the cost estimate of the project.

The cost-loaded project schedule is crucial to managing a project because it connects the three fundamental components of a project: what needs to be done (scope),

when will it be done (time), and how much it will cost (cost). Thus, a good-quality schedule and cost estimate are essential to managing projects. The schedule is the essential tool for managing the project according to the project work plan.

Scheduling software is used to perform the many calculations in a CPM schedule. Scheduling software is good for quickly performing calculations for early/late start and finish times of activities, total and free float times, and cost distributions on an early, late, and target basis. However, scheduling software cannot identify activities and cannot determine the logical sequencing of activities. Only people can identify and sequence work activities. Therefore, entering the project plan data into the scheduling software should be the last activity of project planning.

Before entering data into a scheduling software package, a careful review of the list of activities should be performed to ensure that work is sufficiently defined to complete the project. A logic diagram should be created and reviewed to ensure that activities are sequenced in a realistic order to guide field operations. There should also be a careful check of the duration that is assigned to each activity to ensure the work can be accomplished in a reasonable time. These items can only be accomplished by experienced people, not the software.

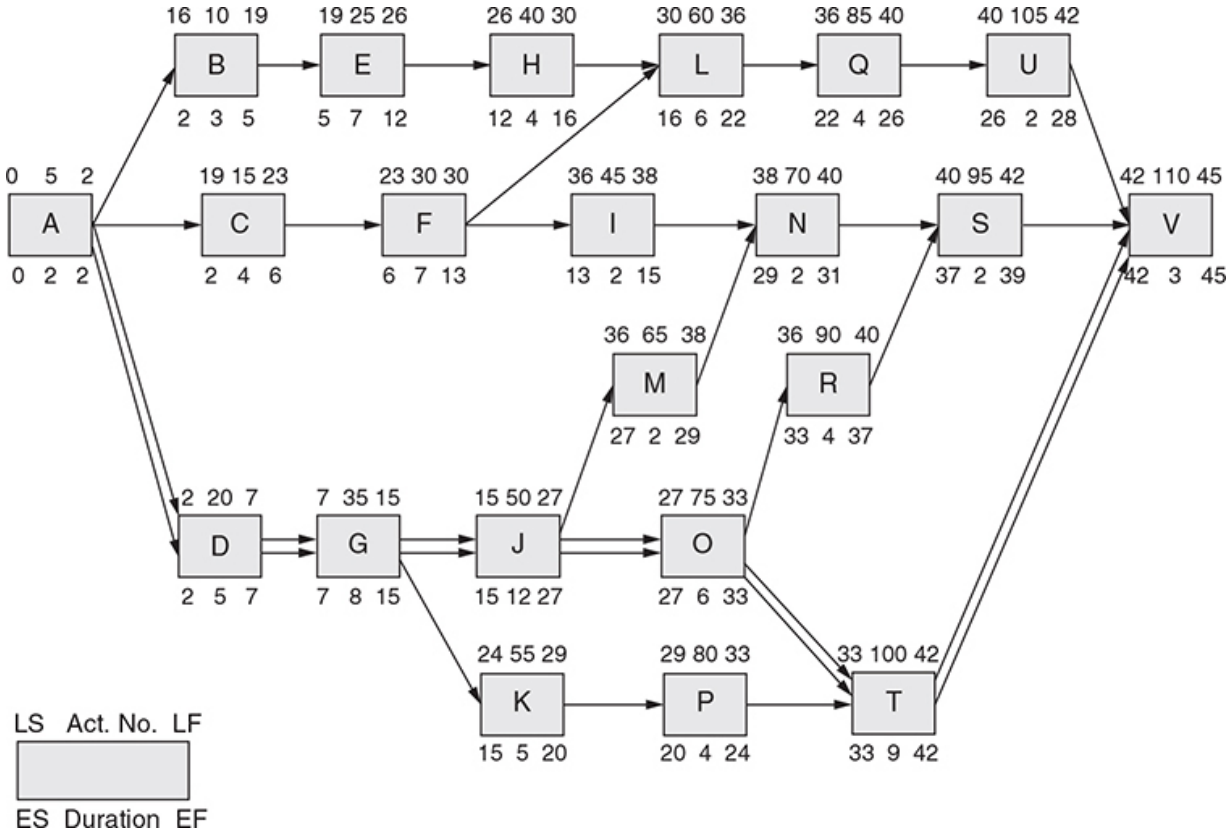
It is easy for people to become complacent and depend too much on computer analysis. Although the computer can perform calculations in seconds, it is highly likely that errors are created in the process of entering data in the computer. Therefore, it is necessary to check the output from the computer to ensure a quality schedule. Example 10-1 shows hand calculations that are easily performed to check and verify the results of computer analysis of a cost-loaded CPM diagram. For example, it is easy to perform a forward pass on the CPM diagram to calculate the early start and finish of

an activity as a check to verify the correct output from the computer.

Example 10-1 A project team has identified the following activities required to complete a project. The duration of each activity is based on the quantity of work, available resources, and productivity of crews. The cost of each activity is based on quantity of work and historical cost data from previously completed projects.

Activity	Activity No.	Duration (days)	Cost	Predecessor(s)	Successor(s)
A	5	2	$500	None	B, C, D
B	10	3	$900	A	E
C	15	4	$1,600	A	F
D	20	5	$500	A	G
E	25	7	$1,400	B	H
F	30	7	$1,500	C	I, L
G	35	8	$2,400	D	J, K
H	40	4	$800	E	L
I	45	2	$1,000	F	N
J	50	12	$3,600	G	M, O
K	55	5	$2,000	G	P
L	60	6	$1,200	F, H	Q
M	65	2	$900	J	N
N	70	2	$700	I, M	S
O	75	6	$1,800	J	R, T
P	80	4	$1,200	K	T
Q	85	4	$2,000	L	U
R	90	4	$1,600	O	S
S	95	2	$1,400	N, R	V
T	100	9	$1,800	O, P	V
U	105	2	$1,200	Q	V
V	110	3	$300	S, T, U	None

From the preceding information, a CPM precedence diagram can be developed to calculate the schedule for the project. The critical path is shown as double arrows between critical activities.



Example 10-1 Precedence diagram using data table above. (All time calculations are based on end of working day.)

From the calculations shown on the CPM diagram, the following table is prepared, which shows the early/late starts and finishes as well as the total and free float for each activity. All times are end of workday. For example, Activity A starts at the end-of-day 0, which is the beginning of day 1.

The early start is the earliest time an activity can be started. It is governed by the largest early finish of the immediately preceding activity. The early finish is the earliest time an activity can be finished and is equal to the early start plus the duration of the activity. The late start is the latest time an activity can be started without delaying the completion date of the project. It is calculated as the late finish minus the duration of the activity. The late finish is the latest time an activity can be finished without delaying the completion date of the project. It is governed by the smallest late start of the immediately following activity.

The total float is the amount of time an activity may be delayed without delaying the completion date of the project. It is calculated as the late finish minus the early finish, or as the late start minus the early start of the activity. The free float is the amount of time an activity may be delayed without delaying the early start time of the immediately following activity. The free float of an activity is calculated as the early start of the following activity minus the early finish of the activity. Critical activities are those activities that

have a total float and free float equal to zero. The critical path activities are noted as C in the right-hand column of the following table.

Activity no.	Activity	Pred.(s)	Succ.(s)	Duration, days	Total cost	Note: All time calculations are based on end of working day						Critical
						ES	EF	LS	LF	TF	FF	
5	A	None	B, C, D	2	$500	0	2	0	2	0	0	C
10	B	A	E	3	$900	2	5	16	19	14	0	
15	C	A	F	4	$1,600	2	6	19	23	17	0	
20	D	A	G	5	$500	2	7	2	7	0	0	C
25	E	B	H	7	$1,400	5	12	19	26	14	0	
30	F	C	I, L	7	$1,500	6	13	23	30	17	0	
35	G	D	J, K	8	$2,400	7	15	7	15	0	0	C
40	H	E	L	4	$800	12	16	26	30	14	0	
45	I	F	N	2	$1,000	13	15	36	38	23	14	
50	J	G	M, O	12	$3,600	15	27	15	27	0	0	C
55	K	G	P	5	$2,000	15	20	24	29	9	0	
60	L	F, H	Q	6	$1,200	16	22	30	36	14	0	
65	M	J	N	2	$900	27	29	36	38	9	0	
70	N	I, M	S	2	$700	29	31	38	40	9	6	
75	O	J	R, T	6	$1,800	27	33	27	33	0	0	C
80	P	K	T	4	$1,200	20	24	29	33	9	9	
85	Q	L	U	4	$2,000	22	26	36	40	14	0	
90	R	O	S	4	$1,600	33	37	36	40	3	0	
95	S	N, R	V	2	$1,400	37	39	40	42	3	3	
100	T	O, P	V	9	$1,800	33	42	33	42	0	0	C
105	U	Q	V	2	$1,200	26	28	40	42	14	14	
110	V	S, T, U	None	3	$300	42	45	42	45	0	0	C

Management is always interested in both time and cost. The cost of each activity is distributed over the duration of the activity. However, some activities may begin on their early start date, whereas other activities may begin on their late start date. Likewise, some activities may finish on their early finish date, whereas other activities may finish on their late finish dates. Therefore, costs may be analyzed on an early start basis, or a late start basis. Following is a cost analysis of the project on an early start and late start basis. The S-curve for the project shows the cost/time relationship with percent costs and percent times.

Early Start Cost Analysis (Note Activity F cost of $214.29 is used as $214.00 on days 7 through 13. The rounding is adjusted in the early start

cumulative cost on Day 13.)

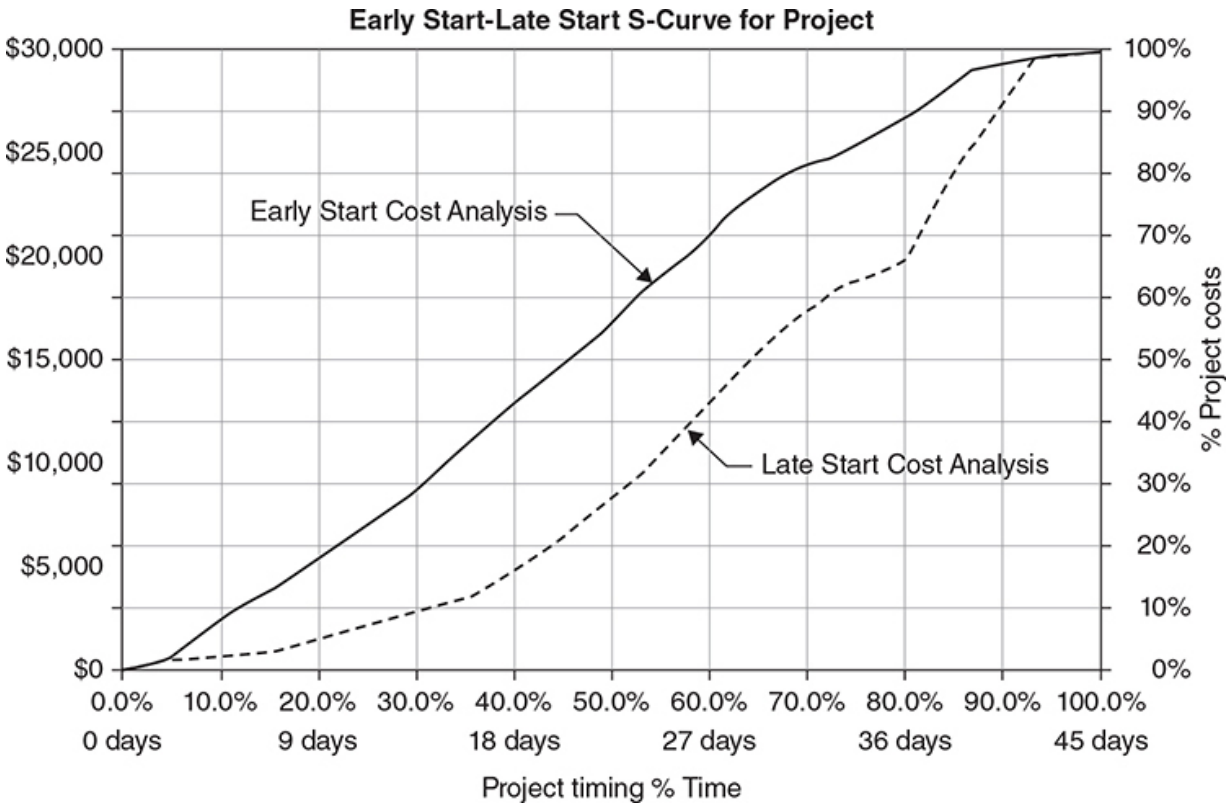
Day	ES % time	Early start basis activities in progress	ES $/day	ES Cum. $	ES % Cost
1	2.2%	A@$250	$250	$250	0.8%
2	4.4%		$250	$500	1.7%
3	6.7%	B@$300 + C@$400 + D@$100	$800	$1,300	4.3%
4	8.9%		$800	$2,100	6.9%
5	11.1%		$800	$2,900	9.6%
6	13.3%	C@$400 + D@$100 + E@$200	$700	$3,600	11.9%
7	15.6%	D@$100 + E@$200 + F@$214	$514	$4,114	13.6%
8	17.8%	E@$200 + F@$214 + G@$300	$714	$4,828	15.9%
9	20.0%		$714	$5,542	18.3%
10	22.2%		$714	$6,256	20.6%
11	24.4%		$714	$6,970	23.0%
12	26.7%		$714	$7,684	25.4%
13	28.9%	F@$214 + G@$300 + H@$200	$714	$8,400	27.7%
14	31.1%	G@$300 + H@$200 + I@$500	$1,000	$9,400	31.0%
15	33.3%		$1,000	$10,400	34.3%
16	35.6%	H@$200 + J@$300 + K@$400	$900	$11,300	37.3%
17	37.8%	J@$300 + K@$400 + L@$200	$900	$12,200	40.3%
18	40.0%		$900	$13,100	43.2%
19	42.2%		$900	$14,000	46.2%
20	44.4%		$900	$14,900	49.2%
21	46.7%	J@$300 + L@$200 + P@$300	$800	$15,700	51.8%
22	48.9%		$800	$16,500	54.5%
23	51.1%	J@$300 + P@$300 + Q@$500	$1,100	$17,600	58.1%
24	53.3%		$1,100	$18,700	61.7%
25	55.6%	J@$300 + Q@$500	$800	$19,500	64.4%
26	57.8%		$800	$20,300	67.0%
27	60.0%	J@$300 + U@$600	$900	$21,200	70.0%
28	62.2%	M@$450 + O@$300 + U@$600	$1,350	$22,550	74.4%
29	64.4%	M@$450 + O@$300	$750	$23,300	76.9%
30	66.7%	N@$350 + O@$300	$650	$23,950	79.0%
31	68.9%		$650	$24,600	81.2%
32	71.1%	O@$300	$300	$24,900	82.2%
33	73.3%		$300	$25,200	83.2%
34	75.6%	R@$400 + T@$200	$600	$25,800	85.1%
35	77.8%		$600	$26,400	87.1%
36	80.0%		$600	$27,000	89.1%
37	82.2%		$600	$27,600	91.1%
38	84.4%	S@$700 + T@$200	$900	$28,500	94.1%
39	86.7%		$900	$29,400	97.0%
40	88.9%	T@$200	$200	$29,600	97.7%
41	91.1%		$200	$29,800	98.3%
42	93.3%		$200	$30,000	99.0%

43	95.6%		$100	$30,100	99.3%
44	97.8%	V@$100	$100	$30,200	99.7%
45	100.0%		$100	$30,300	100.0%

Late Start Cost Analysis (Note Activity F daily cost of $214.29 is rounded to $214 on days 24 through 30. The rounding is adjusted in the late start cumulative cost on Day 30.)

Day	LS % time	Late start basis activities in progress	LS $/day	LS Cum. $	LS % Cost
1	2.2%	A@$250	$250	$250	0.8%
2	4.4%		$250	$500	1.7%
3	6.7%	D@$100	$100	$600	2.0%
4	8.9%		$100	$700	2.3%
5	11.1%		$100	$800	2.6%
6	13.3%		$100	$900	3.0%
7	15.6%		$100	$1,000	3.3%
8	17.8%	G@$300	$300	$1,300	4.3%
9	20.0%		$300	$1,600	5.3%
10	22.2%		$300	$1,900	6.3%
11	24.4%		$300	$2,200	7.3%
12	26.7%		$300	$2,500	8.3%
13	28.9%		$300	$2,800	9.2%
14	31.1%		$300	$3,100	10.2%
15	33.3%		$300	$3,400	11.2%
16	35.6%	J@$300	$300	$3,700	12.2%
17	37.8%	B@$300 + J@$300	$600	$4,300	14.2%
18	40.0%		$600	$4,900	16.2%
19	42.2%		$600	$5,500	18.2%
20	44.4%	C@$400 + E@$200 + J@$300	$900	$6,400	21.1%
21	46.7%		$900	$7,300	24.1%
22	48.9%		$900	$8,200	27.1%
23	51.1%		$900	$9,100	30.0%
24	53.3%	E@$200 + F@$214 + J@$300	$714	$9,814	32.4%
25	55.6%	E@$200 + F@$214 + J@$300 + K@$400	$1,114	$10,928	36.1%
26	57.8%		$1,114	$12,042	39.7%
27	60.0%	F@$214 + H@$200 + J@$300 + K@$400	$1,114	$13,156	43.4%
28	62.2%	F@$214 + H@$200 + K@$400 + O@$300	$1,114	$14,270	47.1%
29	64.4%		$1,114	$15,384	50.8%
30	66.7%	F@$214 + H@$200 + O@$300 +P@$300	$1,014	$16,400	54.1%
31	68.9%	L@$200 + O@$300 + P@$300	$800	$17,200	56.8%
32	71.1%		$800	$18,000	59.4%
33	73.3%		$800	$18,800	62.0%
34	75.6%	L@$200 + T@$200	$400	$19,200	63.4%
35	77.8%		$400	$19,600	64.7%
36	80.0%		$400	$20,000	66.0%
37	82.2%	I@$500 + M@$450 + Q@$500 + R@$400 + T@$200	$2,050	$22,050	72.8%
38	84.4%		$2,050	$24,100	79.5%
39	86.7%	N@$350 + Q@$500 + R@$400 + T@$200	$1,450	$25,550	84.3%
40	88.9%		$1,450	$27,000	89.1%
41	91.1%	S@$700 + T@$200 + U@$600	$1,500	$28,500	94.1%
42	93.3%		$1,500	$30,000	99.0%
43	95.6%	V@$100	$100	$30,100	99.3%
44	97.8%		$100	$30,200	99.7%
45	100.0%		$100	$30,300	100.0%

S-Curve for the Project:



Program Evaluation and Review Technique

In the CPM of scheduling projects, the duration of each activity is usually defined with a reasonable degree of certainty. For most projects, the type and amount of work is known, which enables the project manager to establish the approximate duration for each work activity. For example, the time to produce drawings may be 4 weeks, the time to perform a soil investigation to gather and test soil samples may be 2 weeks, or the time to erect forms for concrete may be 3 days. Using the CPM, the assignment of one duration to each activity provides a deterministic process for the start and finish dates of each activity and a single finish date for the entire project.

For some projects, it may be difficult to estimate a reasonable single duration for one or more of the activities in the project schedule. There may be a range of durations that may apply to a particular activity, which makes it difficult to select just one duration to assign to the activity. The Program Evaluation and Review Technique (PERT) method of scheduling uses three durations for each activity and the fundamental statistics to determine the probability of a project finishing earlier or later than expected. Although the PERT method is not used extensively in engineering and construction projects, it provides valuable information for assessing the risks of schedule slippage of a project.

The PERT method uses an arrow network diagram to show the logical sequence of activities in a project, whereas the CPM uses a precedence diagram as discussed in preceding sections of this book. In a PERT diagram, activities are represented by arrows with circles at each end of the arrow. The circles are called events that represent an instant in time. The circle at the beginning of the activity represents the start of an activity and the circle at the end of the arrow represents the finish of the activity.

The major difference between the PERT method and CPM is the estimation of durations of activities. PERT is applicable for projects where there is a high degree of uncertainty about how long any given activity will take to complete, where even the most experienced manager can give only an educated guess of the estimated time, and that guess is subject to a wide margin of error. Using PERT there are three durations that are assigned to each activity:

$$a = \text{optimistic time}$$
$$b = \text{pessimistic time}$$
$$m = \text{most likely time}$$

The optimistic time is the shortest possible time in which the activity could possibly be completed, assuming that

everything goes well. There is only a very small chance of completing the activity in less than this time. The pessimistic time is the longest time the activity could ever require, assuming that everything goes poorly. There is only a very small chance of expecting this activity to exceed this time. The most likely time is the time the activity could be accomplished if it could be repeated many times under exactly the same conditions. It is the time that it would take more often than any other time. The most likely time is the time the manager would probably give if asked for a single time estimate. It is important to note that the optimistic time and the pessimistic time may not deviate the same amount from the most likely time. In simple mathematical terms, *a* and *b* may not be symmetrical about *m.*

PERT uses a weighted average of the three times to find the overall project duration. This average is called the expected time, t_e, and is found by the following simple equation:

$$t_e = \frac{a+4m+b}{6}$$

where t_e is the expected time of an activity.

The above equation is used to calculate a single duration for each activity in the PERT network diagram. Then a forward pass can be performed to calculate the early start and early finish for each activity in the PERT network and a total project duration, similar to the CPM scheduling method. A backward pass can be performed to calculate the last start and late finish for each activity. Total float, free float, and the critical path can be identified. At this stage of a PERT analysis, it is identical to the CPM analysis.

The three time estimates of PERT can be used to measure the degree of uncertainty involved in the activity. The measure of the spread of the distribution is called the

standard deviation and is denoted by the Greek letter σ. To determine the probability of the project completing earlier or later than expected using PERT, the variance of each activity along the critical path must be calculated. The variance of an activity is the square of the standard deviation of the activity and can be calculated using the following equation:

$$v = \sigma^2 = \left[\frac{(b-a)}{6}\right]^2$$

where v is the variance of an activity.

Since the duration (t_e) of each of the activities in the arrow network diagram is uncertain, the time of occurrence of each event is also subject to uncertainty. The expected time of an event is denoted as T_E. Although the distribution of uncertainty of individual activities may not necessarily be symmetrical, the distribution for event times is assumed symmetrical because there are numerous activities in the chain ahead of the event. For example, the T_E for the final event in a project has all the critical path activities in the chain that lead up to the final event in the project.

The measure of uncertainty of the final event in a PERT diagram is the standard deviation of the expected time, denoted as σ_{TE}. The σ_{TE} is the square root of the sum of the activities ahead of the event. Thus, the σ_{TE} for the last event in a PERT diagram is the square root of the sum of the variance of all activities along the critical path. The σ_{TE} is calculated with the following equation:

$$\sigma_{TE} = \sqrt{v_{1-2} + v_{2-3} + v_{3-4} + \cdots + v_{i-j}}$$

where σ_{TE} is the standard deviation of the expected time.

The final calculation necessary to perform PERT calculations is the deviation, which is denoted by the symbol z in the following equation:

$$z = \frac{T_S - T_E}{\sigma_{TE}}$$

where z is the deviation.

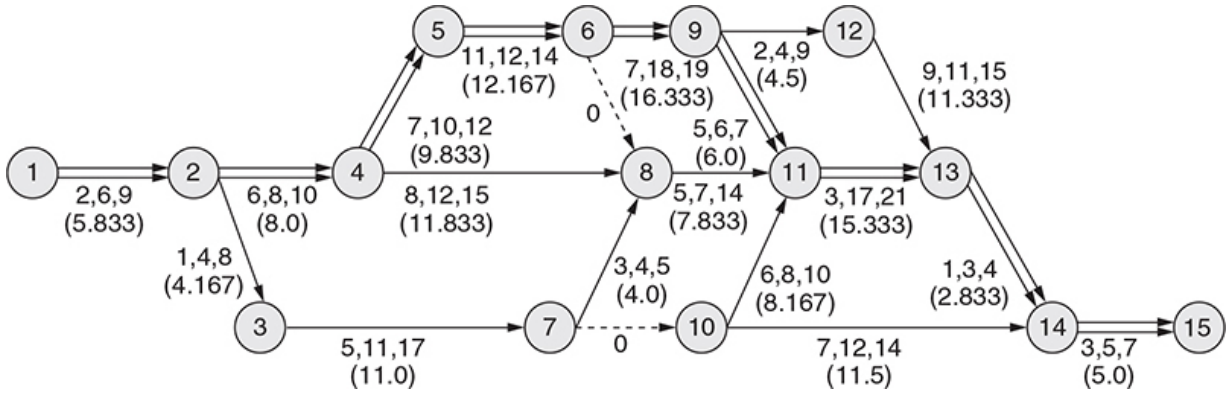
Table 10-8 provides the value of z for various probabilities of certainty. The term T_E is the expected time of the event, which is calculated from the PERT diagram, and T_S is the scheduled time.

Value of deviation, z	Probability of completion
–3.0	0.00
–2.5	0.01
–2.0	0.03
–1.5	0.07
–1.4	0.08
–1.3	0.09
–1.2	0.11
–1.1	0.14
–1.0	0.16
–0.9	0.18
–0.8	0.21
–0.7	0.24
–0.6	0.27
–0.5	0.31
–0.4	0.35
–0.3	0.38
–0.2	0.42

−0.1	0.46
0.0	0.50
0.1	0.54
0.2	0.58
0.3	0.62
0.4	0.66
0.5	0.69
0.6	0.73
0.7	0.76
0.8	0.79
0.9	0.82
1.0	0.84
1.1	0.86
1.2	0.88
1.3	0.90
1.4	0.92
1.5	0.93
2.0	0.98
2.5	0.99
3.0	1.00

TABLE 10-8 PERT Probability Table

Example 10-2 The following PERT diagram shows the optimistic time (a), the most likely time (t_m), and the pessimistic time (b) at the bottom of each activity. The number shown in parentheses below each activity is the expected time (t_e) for the activity, calculated from the equation, $t_e = (a + 4m + b)/6$. All times denote working days in the project.



The duration of the project can be calculated by performing a forward pass to calculate the start and finish times using the optimistic duration (smallest duration) of each activity. For the data in this PERT diagram, the optimistic project duration is 48 days, which follows through events 1, 2, 4, 5, 6, 9, 12, 13, 14, and 15.

The pessimistic duration of the project can be calculated by performing a forward pass to calculate the start and finish times using the pessimistic (largest duration) of each activity. For the data in this PERT diagram, the pessimistic project duration is 103 days, which follows through events 1, 2, 4, 5, 6, 9, 11, 13, 14, and 15.

The project duration (T_e) for event 15 can be calculated by performing a forward pass to calculate the start and finish times using the expected duration (t_e) of each activity. For the data in this PERT diagram, the expected time of the last event number 15 is T_e = 81.3 days, which follows through events 1, 2, 4, 5, 6, 9, 11, 13, 14, and 15.

In summary, for this PERT diagram, the optimistic project duration is 48 days; the pessimistic project duration is 103 days; and the expected project duration is 81.3 days. The probability of completing the project ahead or behind day 81.3 will depend on the σ_{TE} of event 15. The value of σ_{TE} can be calculated as the square root of the sum of the variances of all activities along the critical path. Based on the expected time of each activity, the critical path for this PERT network follows events 1, 2, 4, 5, 6, 9, 11, 13, 14, and 15. The σ_{TE} for the final event, number 15, is the square root of the variances of these events, which can be calculated as follows:

$$\sigma_{TE} = \sqrt{v_{1\text{–}2} + v_{2\text{–}4} + v_{4\text{–}5} + v_{5\text{–}6} + v_{6\text{–}9} + v_{9\text{–}11} + v_{11\text{–}13} + v_{13\text{–}14} + v_{14\text{–}15}}$$

$$= \sqrt{\left(\frac{9-2}{6}\right)^2 + \left(\frac{10-6}{6}\right)^2 + \left(\frac{12-7}{6}\right)^2 + \left(\frac{14-11}{6}\right)^2 + \left(\frac{19-7}{6}\right)^2 + \left(\frac{7-5}{6}\right)^2 + \left(\frac{21-3}{6}\right)^2 + \left(\frac{4-1}{6}\right)^2 + \left(\frac{7-3}{6}\right)^2}$$

$$= \sqrt{1.3611 + 0.4444 + 0.6944 + 0.2500 + 4.0000 + 0.1111 + 9.0000 + 0.2500 + 0.4444}$$

$$= \sqrt{16.5554}$$

$$= 4.07$$

All the calculations necessary to perform an analysis of the project finishing ahead or behind the expected project duration of 81.3 days can be determined from the deviation equation. For example, it may be desired to determine the probability of the project finishing later than expected, that is, later than 81.3 days. The probability of completing the project by the 84th day can be calculated as follows:

$$\begin{aligned} z &= \frac{T_S - T_E}{\sigma_{TE}} \\ &= \frac{84.0 - 81.3}{4.07} \\ &= 0.663 \end{aligned}$$

From Table 10-8, based on a deviation z of 0.663, the probability is 0.75. Thus, there is a 75% probability that the project will be completed by the 84th day.

Other probability scenarios can be calculated. For example, the probability of the project finishing earlier than expected, such as in 78 days, can be calculated as follows:

$$\begin{aligned} z &= \frac{T_S - T_E}{\sigma_{TE}} \\ &= \frac{78.0 - 81.3}{4.07} \\ &= -0.811 \end{aligned}$$

From Table 10-8, based on a deviation z of −0.811, the probability is 0.21. Thus, there is only a 21% probability that the project will be completed by the 78th day.

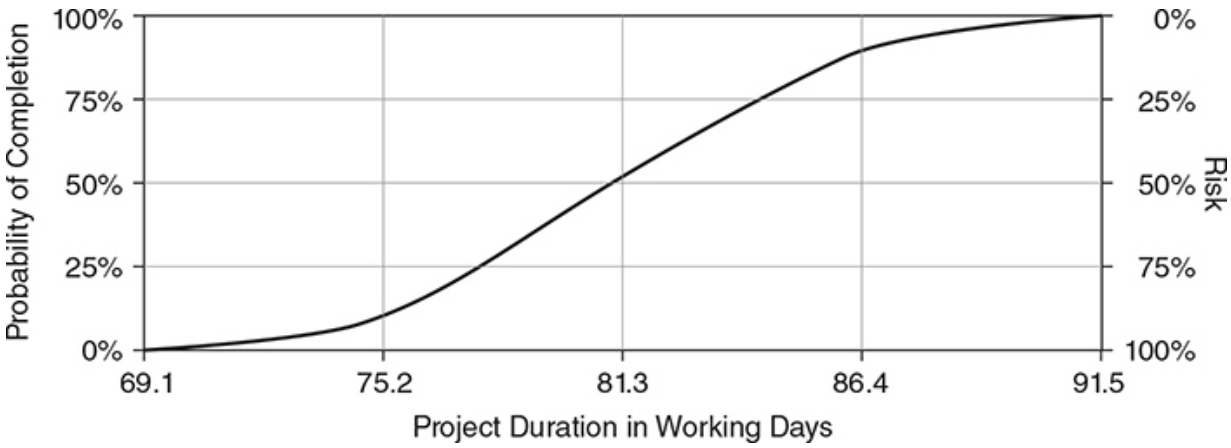
It may be desired to calculate the number of days to complete the project based on a 70% probability. This scenario can be calculated as follows. For a 70% probability, the value of z from Table 10-8 is 0.5333:

$$\begin{aligned} z &= \frac{T_S - T_E}{\sigma_{TE}} \\ 0.533 &= \frac{T_S - 81.3}{4.07} \\ T_S &= 83.5 \text{ days} \end{aligned}$$

Thus, there is a 70% probability that the project will be completed by 83.5 days.

The following is a graphical plot of the probability versus the project duration. This curve provides the full range of probabilities for assessing the

risks of finishing the project ahead of or behind the expected duration of 81.3 days.



This analysis is based on a σ_{TE} for event 15 based on the critical path activities. A full analysis is more complex if all near-critical paths are analyzed. For example, it is possible to have another path through the PERT diagram that is near critical, which would yield a shorter T_e for event 15 and a higher value for σ_{TE} due to larger variances in the activities in the noncritical path.

Successor/Predecessor Relationships

The CPM diagram is a graphical representation that shows the sequencing of activities in the project. The purpose of the CPM diagram is to model the logical flow of work, showing each activity and one or more activities that follow each activity. In the activity relationships, the preceding activity is called the predecessor activity, and the following activity is called the successor activity. In a pure CPM network diagram, a finish-to-start (F-S) relationship of each activity is assumed. That is, the preceding activity must be completed before starting the following activity. All the CPM diagrams and calculations presented earlier in this book are based on an F-S relationship of activities to depict a pure CPM logic network diagram.

Most commercially available computer software programs for CPM provide activity relationships other than F-S. These additional activity relationships include start-to-start (S-S),

start-to-finish (S-F), and finish-to-finish (F-F). The S-S relationship means the successor activity can start at the same time or later than the predecessor activity. The F-F relationship means the successor activity can finish at the same time as or later than the predecessor activity. The S-F relationship means the predecessor activity must start before the successor activity can finish. There is no practical application of the S-F relationship in the engineering and construction industry. It is presented here just to show all possible successor/predecessor relationships.

Delays in the relationship of one activity to another is defined by lag. *Lag* is the amount of time that an activity follows or is delayed from the start or finish of its predecessor. For example, an F-S relationship with a 2-day lag means the start of the successor activity cannot occur until 2 days after the finish of the predecessor activity. Lag can be assigned to any activity relationship, including F-S, F-F, S-S, and S-F. In addition, the lag can also be a negative number. Lead is the opposite of lag, which is the amount of time that an activity precedes the start or finish of its successor. Thus, the use of successor/predecessor relationships provides many options for modeling the network logic to show constraints between activities and the sequential flow of work in the project.

A model of the F-S with lag relationship is illustrated in Figure 10-16a. An alternative of this model is shown in Figure 10-16b, which shows the same results without using the F-S with lag relationship. Thus, adding one intermediate activity between the successor and predecessor activities clearly produces the same results as the F-S relationship.

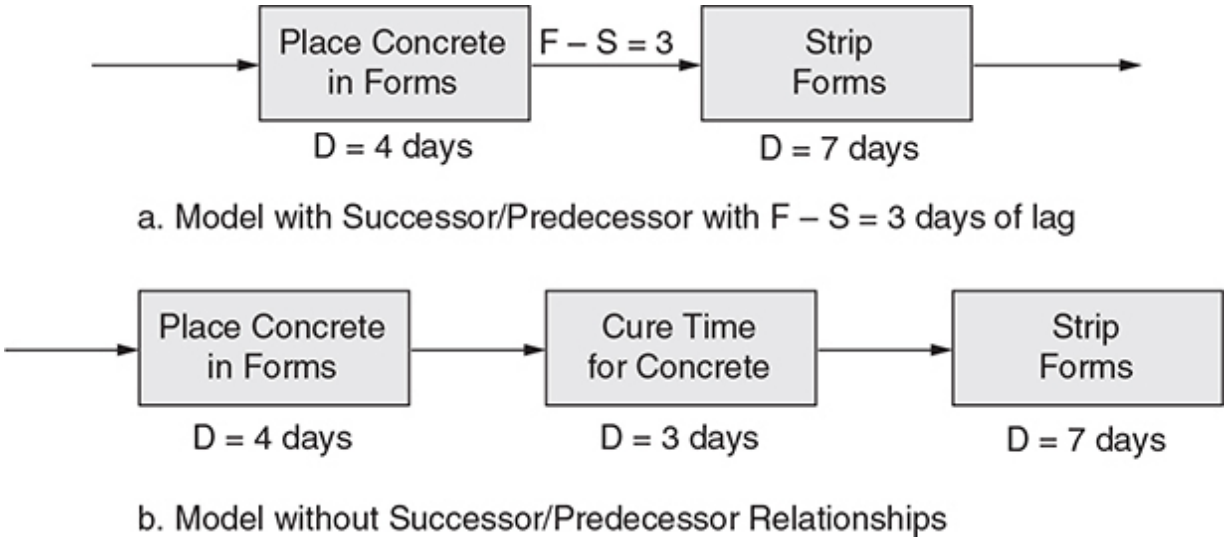
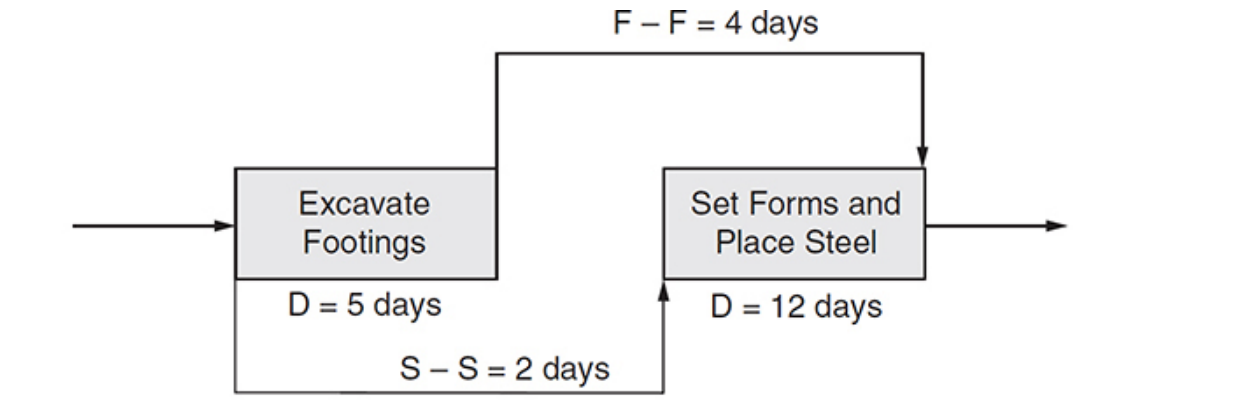
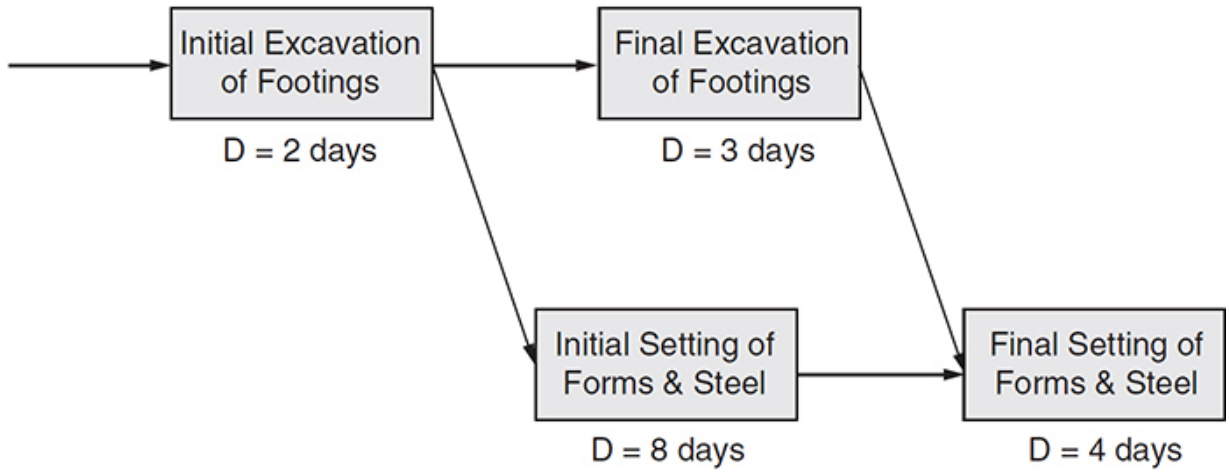


FIGURE 10-16 Comparison of CPM diagrams with and without a finish-to-start (F-S) successor/predecessor relationship.

The S-S relationship is used to overlap activities, allowing the successor activity to start before the predecessor activity is completed. To tie the finish of the predecessor activity to the successor activity, the F-F relationship is normally used together with the S-S relationship. Figure 10-17a illustrates S-S and F-F with lag relationships between two activities. Figure 10-17b is a model of the activities without the S-S and F-F relationships. Thus, for any CPM diagram, the S-S and F-F activity relationships can be eliminated by adding additional activities. Although additional activities may appear as a disadvantage, the additional activities provide a clearer understanding of the sequence of work.



a. Model with Successor/Predecessor S – S = 2 days and F – F = 4 days of lag



b. Model without Successor/Predecessor Relationships

FIGURE 10-17 Comparison of CPM diagrams with and without a start-to-start (S-S) successor/predecessor relationship.

As previously stated, there is no practical application of the S-F relationship in the engineering and construction industry. Some computer scheduling software packages do not allow the use of the S-F relationship.

Problems Using Successor/Predecessor Relationships

Successor/predecessor relationships between activities allow overlapping of concurrent activities, thereby reducing the number of activities in CPM precedence diagrams. However, misunderstandings, confusion, and serious problems have been created by assigning successor/predecessor relationships to activities in the project schedule. Too often, a good CPM schedule at the beginning of the project becomes a schedule that is incoherent and unmanageable due to successor/predecessor relationships that are assigned to activities, particularly during schedule updates.

In a pure CPM diagram, successor/predecessor activity relationships are not used. During the forward pass, the path that yields the largest early finish of the preceding activities becomes the early start of the following activities. During the backward pass, the path that yields the smallest late start of the following activities is the late finish of the preceding activities. Thus, in a pure CPM diagram, there are no questions regarding the start and finish times of activities.

When successor/predecessor activity relationships are introduced into a CPM diagram, the start, finish, and float times may be governed by the successor and predecessor relationships, which makes the calculations more complex. Using successor/predecessor activity relationships with positive or negative lag provides numerous opportunities to model the network logic, but it can also create numerous opportunities for creating errors, confusion, and misunderstandings in the project schedule.

Figure 10-18 illustrates problems that can occur in calculating the start and finish dates when modeling multiple successor/predecessor activity relationships. Each successor/predecessor path must be evaluated to determine start and finish times. A forward pass for the activities in Figure 10-18 shows Activity B can start as early as 2 days or

as late as 7 days after the start of Activity A, depending on the path chosen. Also, depending on the successor/predecessor path chosen, the early finish for Activity B is 9, 12, 14, or 19 days. Similarly, a backward pass will result in multiple late starts and late finishes for these activities. All these multiple calculations can cause confusion and a lack of confidence in the project schedule.

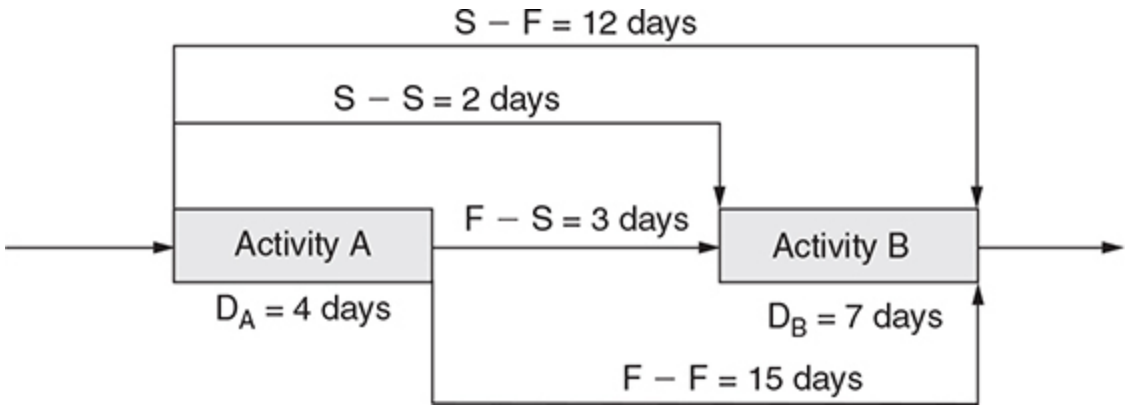


FIGURE 10-18 Example of multiple successor/predecessor activity relationships.

Figure 10-19 is a CPM diagram with successor/predecessor relationships of construction work related to foundation construction work. Figure 10-20 is a pure CPM diagram, without successor/predecessor activity relationships, for the same construction work. These figures are presented to illustrate the complexity of successor/predecessor calculations. As shown in Figure 10-19, the early start of 10 days for Activity 30 is calculated by subtracting its duration from the latest early finish time. The largest early finish of Activity 30 is 16 days, which is governed by the F-F relationship between Activities 20 and 30.

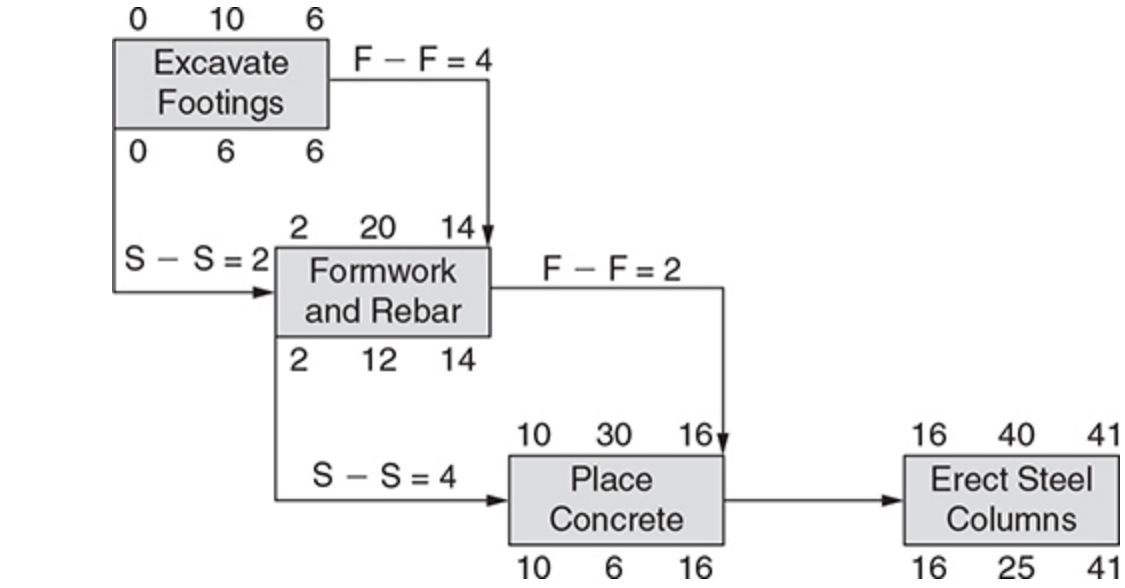


FIGURE 10-19 Successor/predecessor activity relationships. (Note all activities appear critical.)

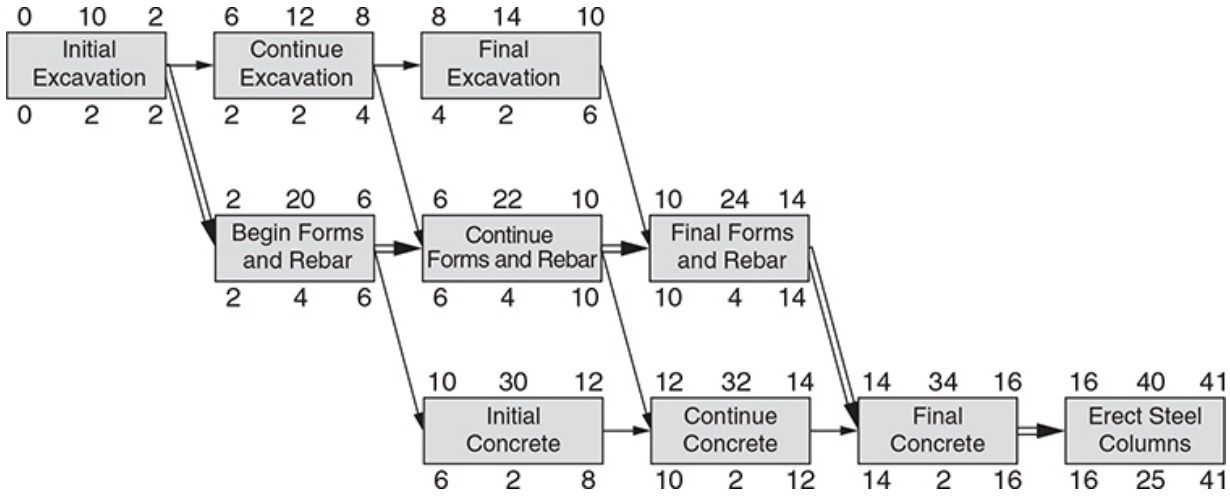


FIGURE 10-20 Pure CPM diagram without successor/predecessor activity relationships. (Double arrows denote path of critical activities: 10, 20, 22, 24, 34, and 40.)

When multiple S-S and F-F relationships are used to relate the predecessor activity to its successor activities, the calculations of total and free float are very complex and require a close examination of the relationships. Using

multiple relationships, it is possible to show activities that are critical, when they are really not critical.

A review of Figure 10-19 indicates that all the activities are critical, although that is not the case. Figure 10-20 is a pure CPM diagram for the same work shown in Figure 10-19. Figure 10-20 eliminates the S-S and F-F relationships by splitting activities to show the actual sequencing of work. As shown in Figure 10-20, much of the work is actually non-critical, compared to that of Figure 10-19. For example, the network of Figure 10-20 shows all formwork as critical, but most of the excavation work and placement of concrete is non-critical. A pure CPM diagram as illustrated in Figure 10-20 provides an accurate description of the work without raising questions regarding start/finish times, total/free float, or critical path activities. Thus, a pure CPM diagram is recommended, rather than modeling with successor/predecessor activity relationships.

Unfortunately, there is no industry standard to define how to finalize the early/late starts and finishes using successor/predecessor relationships with lags. Each computer software developer defines the algorithm used by his or her software to determine start and finish dates using successor/predecessor activity relationships. Since different software packages handle the calculations differently, it is possible to get different results in the schedule, depending on the software used, which creates problems in understanding and interpreting project schedules.

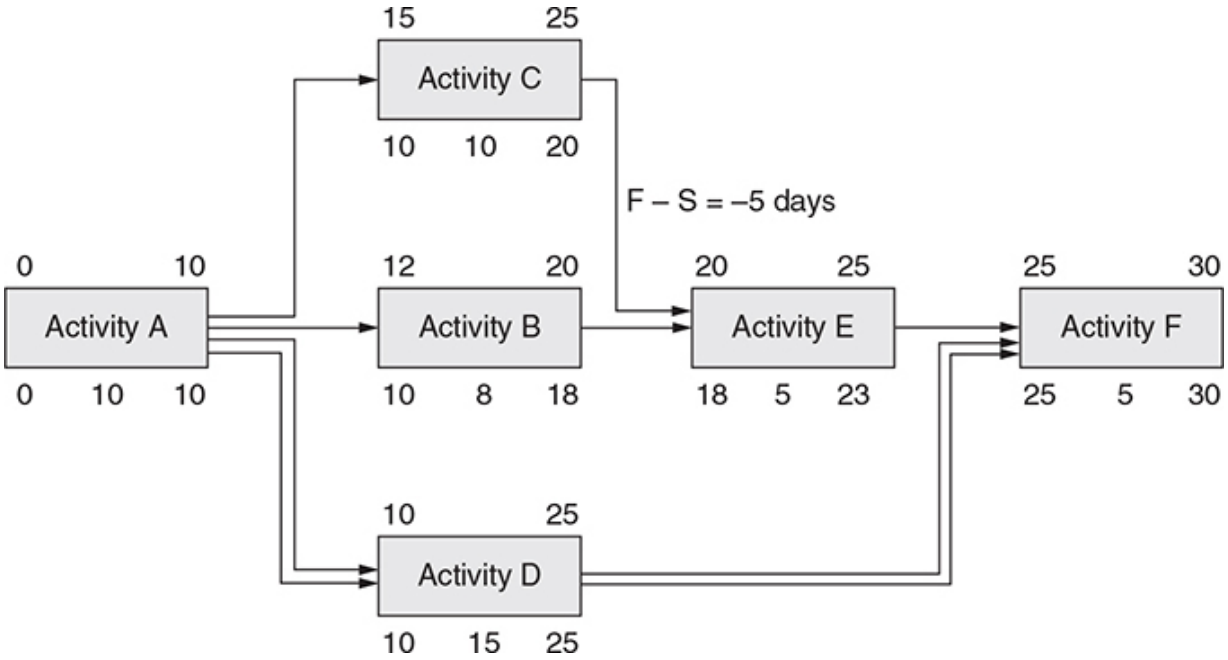
Exercise extreme caution when considering successor/predecessor activity relationships other than finish to start due to the serious problems that can arise using the other three options. Some potential pitfalls can occur when providing status updates and progress to the schedule. Delays represented on the other three options' successor relationships may not be well documented, and when using retained logic, activities can be pushed out

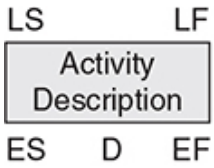
unintentionally. Relationships may have to be altered or deleted to maintain the project end date. To prevent these problems, a pure CPM diagram (finish to start only) can be developed without using the other three optional successor/predecessor relationships by simply adding additional activities to represent known delays. Although additional activities may appear as a disadvantage, adding additional activities provides a clear documentation and understanding of the sequence of work, thus preventing confusion and misunderstandings of the intended project schedule sequence of work. In all likelihood, the additional activities result from an improved decomposition of the work to be performed. The schedule is an essential tool that needs to provide useful information for project control every time it is updated. If the schedule logic is finicky or requires special maintenance to maintain useful information with each progress update, it undermines its purpose. Also, the team and other stakeholders will lose confidence in the information and schedule predictions, thereby undermining the project manager's ability to manage the project to the stated objectives.

The following examples are presented to illustrate calculations based on each of the successor/predecessor activity relationships, F-S, S-S, F-F, and S-F. These examples show how each path must be carefully investigated to determine the start, finish, and float times. When the calculations are performed by computer software, it is possible to get project schedules that sometimes do not make logical sense. Thus, it is important to understand the calculations and be able to check the results of computer outputs to ensure the results are presented as intended by the person who prepared the schedule as well as by the persons who will be interpreting and using the schedule.

Example 10-3: Finish-to-Start Activity Relationships Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activities C and E have an F-S relationship with a 5-day negative lag.

The 5-day negative lag is equivalent to a 5-day lead, which means the finish of Activity C must occur no later than 5 days after the start of Activity E, given by the relationship: $EF_C \leq ES_E + 5$. The use of negative lags is not recommended because they lead to much confusion with respect to the meaning of the relationship and the schedule as discussed in the following paragraphs. The following diagram and accompanying table show the early and late start, early and late finish, and the total and free float for each activity.





For Activity C, the calculation for total and free float are:

$$TF_C = LF_C - EF_C = 25 - 20 = 5 \text{ days}$$

$$FF_C = ES_E - EF_C - \text{Lag} = 18 - 20 - (-5) = 3 \text{ days}$$

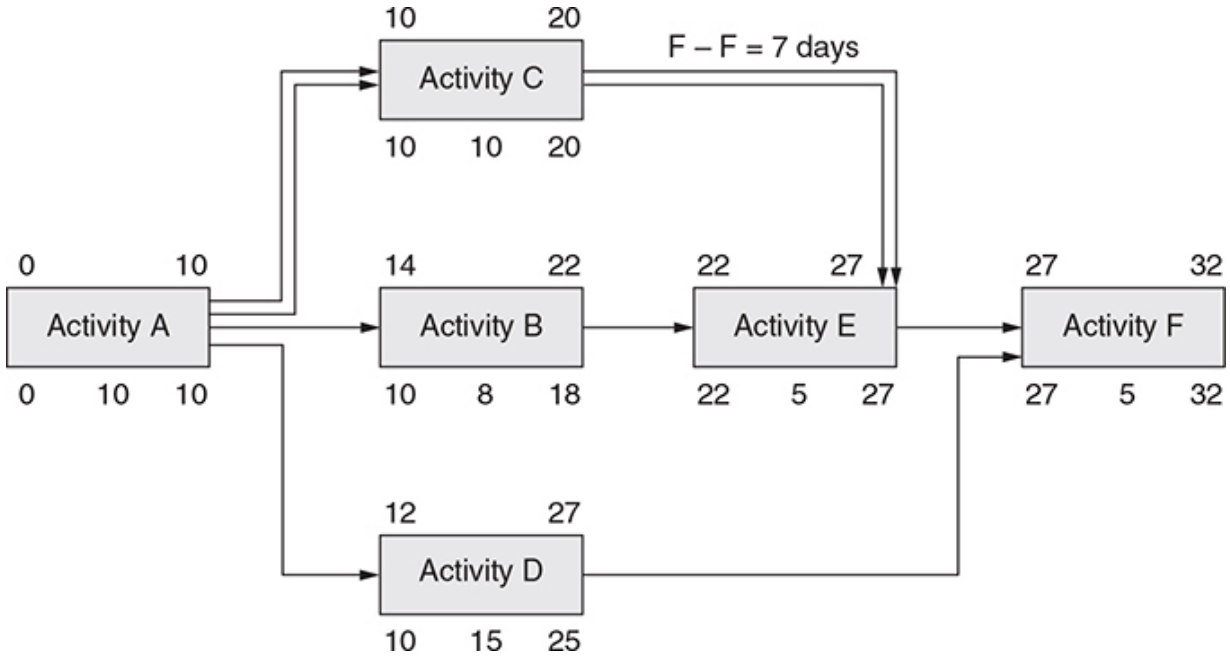
Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	12	20	2	0
C	10	10	20	15	25	5	3
D*	15	10	25	10	25	0	0
E	5	18	23	20	25	2	2
F*	5	25	30	25	30	0	0

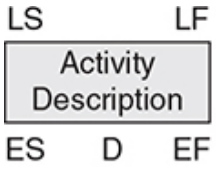
*Denotes critical activities.

Based on the forward and backward pass calculations, the critical path is through Activities A, D, and F. Note the impact on the schedule and possible confusion due to the F-S relationship with 5 days of negative lag between Activities C and E. The EF_C is 20 days (governed by the equation $EF_C = ES_C + D = 10 + 10 = 20$). The EF_C is not governed by the equation $EF_C \leq ES_E + 5 = 18 + 5 = 23$ days, because the ES_E is governed by 18 from the EF_B. Also, a review of the diagram shows the preceding activity $EF_C = 20$, which is greater than the following activity $ES_E = 18$, which is illogical. A computer schedule that shows the ES of a following activity to be earlier than the EF of a preceding activity will make no sense to workers in the field and will cause them to lose confidence in the schedule.

Similar confusion exists for the free float of Activity C. The FF_C is governed by the equation $FF_C = ES_E - EF_C - Lag = 18 - 20 - (-5) = 3$ days. However, a review of the diagram shows the $EF_C = 20$, which is greater than the ESE = 18. Thus, the use of F-S relationships with negative lag is not recommended.

Example 10-4: Finish-to-Finish Activity Relationships Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activities C and E have an F-F relationship with a lag of 7 days. The following diagram and accompanying table show the early and late start, early and late finish, and the total and free float for each activity.





For Activity C, the calculation for total float and free float are:

$$TF_C = LF_C - EF_C = 20 - 20 = 0 \text{ days}$$

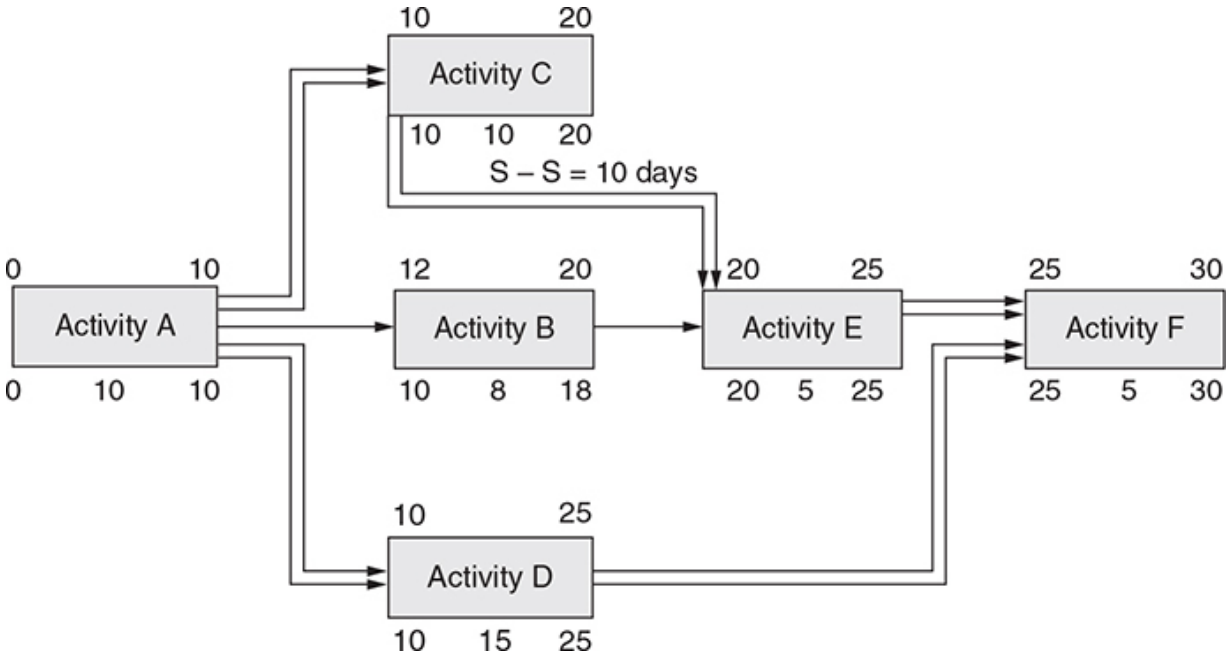
$$FF_C = LF_E - LF_C - \text{Lag} = 27 - 20 - 7 = 0 \text{ days}$$

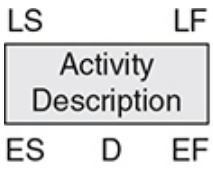
Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	14	22	4	4
C*	10	10	20	10	20	0	0
D	15	10	25	12	27	2	2
E*	5	22	27	22	27	0	0
F*	5	27	32	27	32	0	0

*Denotes critical activities.

Based on the forward and backward pass calculations, the critical path is through Activities A, C, E, and F. Note that the free float of Activity C is governed by the F-F relationship.

Example 10-5: Start-to-Start Activity Relationships Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activities C and E have an S-S relationship with a lag of 10 days. The following diagram and accompanying table show the early and late start, early and late finish, and the total and free float for each activity.





For Activity C, the calculation for total float and free float are:

$$TF_C = LF_C - EF_C = 20 - 20 = 0 \text{ days}$$

$$FF_C = ES_E - ES_C - \text{Lag} = 20 - 10 - 10 = 0 \text{ days}$$

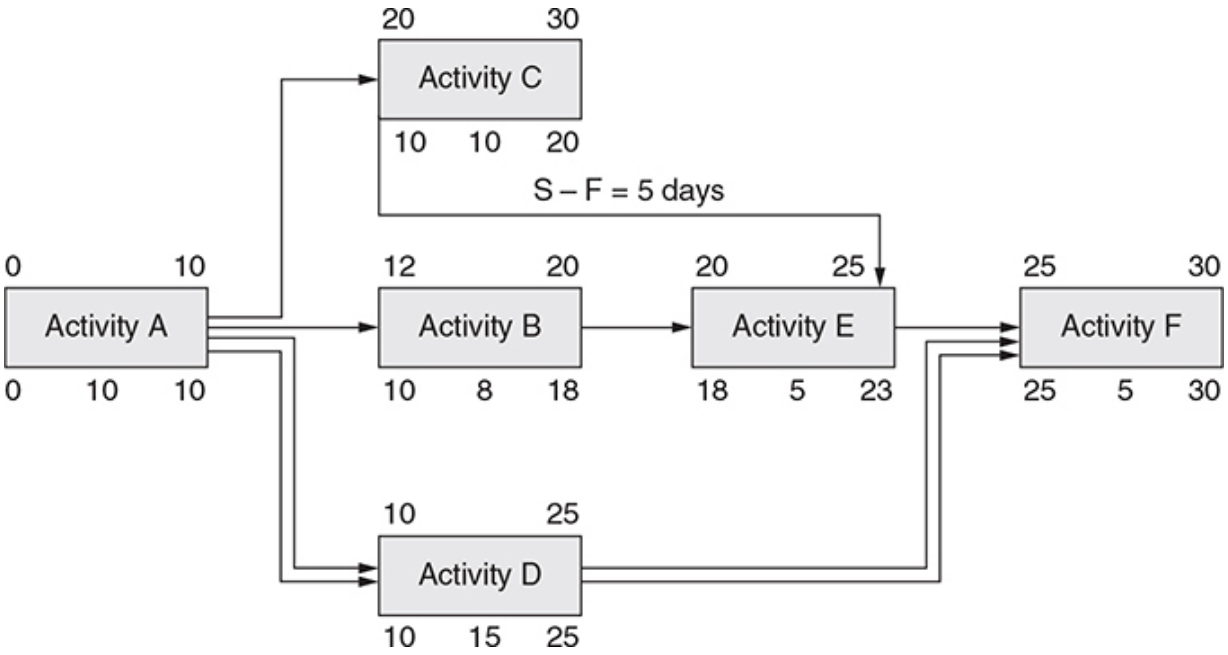
Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	10	20	2	2
C*	10	10	20	10	20	0	0
D*	15	10	25	12	25	0	0
E*	5	20	25	20	25	0	0
F*	5	25	30	25	30	0	0

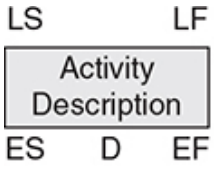
*Denotes critical activities.

Based on the forward and backward pass calculations, the critical path is through Activities A, C, D, E, and F. Note the free float of Activity C is governed by the S-S relationship between Activities C and E.

Example 10-6: Start-to-Finish Activity Relationships Although the start-to-finish relationship is seldom used, this example is presented to illustrate the calculations for an S-F relationship with a lag of 7 days between Activities C

and E. The following diagram and accompanying table show the early and late start, early and late finish, and the total and free float for each activity.





For Activity C, the calculation for total and free float are:

$$TF_C = LF_C - EF_C = 30 - 20 = 10 \text{ days}$$

$$FF_C = EF_E - ES_C - \text{Lag} = 23 - 10 - 5 = 8 \text{ days}$$

Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	12	20	2	0
C	10	10	20	20	30	10	8
D*	15	10	25	10	25	0	0
E	5	18	23	20	25	2	2
F*	5	25	30	25	30	0	0

*Denotes critical activities.

Based on the forward- and backward-pass calculations, the critical path is through Activities A, D, and F.

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CHAPTER 11
Design Coordination

Common Problems in Managing Design

Managing the design phase of a project is difficult because the work begins with limited information, only the information that was approved in the design proposal. There is pressure to start work immediately, although the scope is often not well defined, the budget is not tied to the scope, and the schedule only consists of a start and end date with possibly a few intermediate milestone dates and the increasing number and fluidity of environmental and regulatory requirements and restrictions. All of these issues lead to problems for the project manager in charge of design. Common complaints of design project managers include the following:

- Project scopes are not well defined.
- No overall, understandable work plan.
- Too much growth from the beginning to the end of projects.
- Project budgets are not tied to scope.
- Inconsistency of workload, either too busy or nothing to do.
- Trying to handle too many projects at the same time.

- Shifting priorities from one project to another.
- Poor communications, misunderstandings, and too much rework.
- The company is not organized to handle projects.
- No system exists to handle projects.

The biggest concern with design coordination is that the owner and the design firm both understand the need for timely decision making; indecision is the costliest aspect of a project. Both parties must allow sufficient time for subsequent work to occur based on the decisions made. Decision making relies on adequate and timely information. The essential method of providing information is through adequate reporting and distribution of documents. This topic was discussed in Chapter 5 on Document Control.

Delaying decisions or waiting to make changes during construction drives the project cost up and can adversely affect the schedule. Changes during design have schedule impacts because designs have to be redone or changed which take time and can impact permitting and long lead materials, but construction costs can still be effectively controlled. In Chapter 2, Figure 2-4 shows the relative impacts of decisions during design versus construction.

Managing Multiple Small Projects

It is common for a project manager of small projects to have simultaneous responsibility for multiple projects. The problem is not the management of any one project. The problem is the project manager’s ability to give each project the attention needed, which complicates schedule and resource control. For small projects, the project manager must share resources with other project managers because minimal staff is available. This means that the few individuals that are assigned to the project must take

responsibility for multiple functions. Time management is crucial. The project manager often finds himself or herself either waiting for information or trying to address pressing needs of several projects at the same time.

The relatively short duration of small projects provides insufficient time for detailed planning or correction of problems at the time the work is being performed. The learning curve for personnel is generally still climbing by the time the project is completed.

To manage multiple small projects, the project manager must develop a single master schedule that contains all the projects under his or her responsibility. This will assist in reducing situations when two or more support personnel are needed at the same time. The problem is scheduling the multiple tasks of the project manager, rather than scheduling the tasks on only one of the projects.

There are more project managers managing small projects than large projects. Many engineering companies create organizational units dedicated to project management of small projects. A special attitude and attention are needed by upper management to recognize the problems associated with management of small projects. Table 11-1 provides attributes of project team personnel who work well in managing small projects.

1. Have a “can do” attitude
2. Prefer a hands-on approach to work
3. Dislike bureaucracy
4. Make decisions
5. Need little or no supervision
6. Have a value system to make the customer satisfied
7. Are good communicators
8. Prefer to address and resolve problems directly
9. Know when to stop an activity when things are going wrong
10. Has the personality and people skills to compel people to be responsive to his or her needs
11. Has the ability to navigate through the various departments of his or her company to get things done
12. Possess excellent time management skills

TABLE 11-1 Attributes of Small Projects Team Personnel

Design Work Plan

To effectively coordinate the design process, the design team leader must develop a work plan. The design work plan should be developed during the design proposal preparation as discussed in Chapter 9. As presented in Chapter 3, any work plan must include the scope, budget, and schedule for performing the work. The design work plan becomes the basis for integrating and interfacing the work to be performed by the various design disciplines. The plan also forms the basis for monitoring scope, cost, and schedules of the design effort.

For design, the scope of work defines the design deliverables, the drawings, and specifications, for each discipline in the design effort. The design cost is usually measured in work-hours, rather than dollars of cost. Typically, a milestone bar chart is used to schedule the design work packages. However, for large projects a CPM schedule is recommended.

After reviewing all backup material, the design team leader develops a Work Breakdown Structure (WBS) that defines the various work packages required to generate the design deliverables, the drawings and specifications. Then, the number of design-hours is assigned to each work package for each discipline, including architectural, civil, structural, electrical, and mechanical. Then, a milestone bar chart is developed for the design work packages. The milestone bar chart is cost loaded as presented in Chapter 10 by assigning the number of work-hours to each task in the bar chart. Output from the cost loaded bar chart is usually produced on a weekly basis for monitoring and coordinating the project during design. Then, a simple earned-value analysis as presented in Chapter 13 can be performed for each week during the design process. By multiplying the percent complete times, the budgeted design-hours for each task, the earned value can be determined. The earned value can be compared to actual design-hours billed to the job and the planned design-hours to measure the performance of the design process.

Indexes

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the index templates.

The final product of design work is a set of contract documents (drawings, specifications, and other documents) to guide the physical construction of the project. As presented in Chapters 3 and 9, the project manager must develop a project work plan before starting design. A part of the work plan includes preparation of work packages by each design team member. Included in each work package is a list of anticipated drawings, specifications, permits, or other output along with their expected completion dates.

Drawing Index

A drawing index lists all of the drawings from all design team members. This drawing index is extremely valuable to the project manager because it can be used as a checklist of how many drawings to expect, when to expect them, and to assist in scheduling construction. Figure 11-1 illustrates the contents of a drawing index. It is helpful to include the revision number and date for each drawing because a common problem in design coordination is keeping track of the most current version of a drawing.

Drawing Index

Project: Infr-1 Project
Update as of: 26 July 2033

Sheet No.	Title	Expected date	Actual date	Revision No 1 2 3 4
C0	**Site work Drawings**			
C1	Plot Plan	6/15/2033	6/17/2033	1—7/5/2033
C2	Grading	7/12/2033	6/28/2033	
C3	Paving, Sh 1	7/20/2033	7/1/2033	
C4	Paving, Sh 2	7/25/2033	7/8/2033	
A0	**Architectural Drawings**			
A1	First Floor Plans	7/12/2033	7/12/2033	
A2	Second Floor Plans	7/17/2033	7/18/2033	
A3	Room Schedules	7/22/2033	7/22/2033	
A4	Door/Wall Finish Schedues	7/25/2033	7/25/2033	
A5	Window Schedules	8/5/2033		
S0	**Structural Design**			
S1	Foundations	7/17/2033	7/20/2033	
S2	Floor Slabs	7/30/2033		
S3	Columns & Beams, Sh 1	8/15/2033		
S4	Columns & Beams, Sh 2	8/20/2033		
S5	Roof Framing Plan	8/25/2033		
M0	**Mechanical Drawings**			
M1	Compressor	8/3/2033		
M2	HVAC Ductwork	8/10/2033		
E0	**Electrical Drawings**			
E1	Control Boxes	8/5/2033		
E2	Wiring Diagram, Sh 1	8/12/2033		
E3	Wiring Diagram, Sh 2	8/19/2033		
P0	**Plumbing Drawings**			
P1	Piping	7/5/2033	7/12/2033	
P2	Fixtures	7/15/2033	7/20/2033	

FIGURE 11-1 Illustrative drawing index.

The drawing index is in a continuous state of change as design progresses. As work progresses, the number of drawings may increase or decrease, depending on the final design configuration that is selected. Changes in drawings

are a necessary part of work, and it is the duty of each designer to revise the list as necessary and to keep the design project manager informed.

Equipment Index

Similar to the drawing index, an equipment index can be developed that lists major equipment to be purchased and installed in the project. Creating an equipment index during design provides the design project manager a checklist for specifications that accompany each piece of equipment. If the design firm provides procurement services, the equipment index allows for tracking the purchase and delivery of equipment to the construction warehouse or jobsite. Figure 11-2 illustrates the contents of an equipment index. Each major piece of equipment is listed along with the drawing number, vendor, purchase order date, and expected delivery date. The project manager can use this index as a reference guide and checklist to contact vendors in advance of delivery dates to ensure the equipment will arrive on schedule. A common source of delay during construction is late delivery of major equipment and material.

Equipment Index

Project: Infr-1 Project
Update as of: 15 May 2033

Description	Drawing number	Vendor	Purchase Order		Expected delivery
			Number	Date	
Transformer	E14	XYZ Company	PO 73925	4/18/2033	10/1/2033
Switch Assy	E19	ABC Company	PO 83401	4/20/2033	8/25/2033
Compressor	M12	CIB Company	PO 84294	4/30/2033	7/18/2033
Pump Assy	M3	BWA Company	PO 17835	4/1/2033	6/28/2033

FIGURE 11-5 Illustrative equipment index.

Permit Index

As regulatory requirements have increased significantly, a permit index allows the design project manager to track the number of required permits, their status, and the required drawings or specifications to acquire the permit. The permit index supports evaluation of impacts from design development or scope changes. The owner's project manager can utilize the permit index to understand which permits will have to be renewed during the life of the asset and what will be required for renewal. Figure 11-3 is an example of a permit index or matrix.

Permit Index

Project: Infr-1 Project
Update as of: 8 July 2033
Functional Lead: R. Miller

Permit	*Agency*	*Plan Submittal*	*Actual Submittal*	*Plan Approval*	*Actual Approval*
Federal Permits					
Certificate of Public Convenience and Necessity	Federal Energy Regulatory Commission	8/1/2033			
	US Army Corp of Engineers	7/30/2033			
	US Fish and Wildlife	7/30/2033			
	Environmental Protection Agency	7/30/2033			
State Permits					
Water quality certification	PA Department of Ecology	6/1/2033	6/1/2033	7/28/2033	
County Permits					
Major construction permit	Buhl County	6/1/2033	6/5/2033	7/1/2033	
Road crossing permits	Buhl County	6/1/2033	6/5/2033	7/1/2033	7/5/2033
Local/Municipal Permits					
Grading permit	Stevensville	6/1/2033	6/5/2033	7/1/2033	
Landfill use permit	Jonesborough	6/1/2033	6/5/2033	7/1/2033	6/16/2033

FIGURE 11-3 Illustrative permit index.

Managing Scope Growth during Design

There is a tendency for some designers to make changes during design to please the client without regard to the impact of the change on the project's cost and schedule. Changes can be cataloged as either project development or scope growth. Project development relates to changes that are needed to accommodate the scope as currently defined. Scope growth relates to changes that alter the project's original scope, the scope that was approved before starting the design process.

For any design effort, there must be a process to control scope growth. Both the owner and the engineer must be committed to scope and change control. The owner must be serious about freezing project scope after the conceptual design stage. Every proposed change must be subjected to a formal review and approval process that considers cost and schedule implications, plus consequential effects on other activities. The authority to approve changes during design must be limited.

The owner and engineer should agree on a change management philosophy and plan. For example, under what conditions will changes be considered: If it won't work? If there are legal implications? If there are environmental impacts? When changes are proposed, there must be an answer to such questions as: Does the change add value and is the change necessary? A "no-later-than" date for freezing scope should be agreed to by the owner and the engineer.

Although freezing project scope after the conceptual design stage is the best practice for successful project management, it should be recognized that on some projects the owner must operate in a very competitive market to produce a product. In a competitive market environment,

the owner may want the flexibility to modify the project scope during design, and even during construction, to best suit the functionality of the completed project. For this type of situation, the work of the design team is more complicated, and a special effort must be made to keep the owner informed of the full impact of scope changes. The cost of engineering and construction for the scope change must be evaluated against the future financial benefits to the owner, including revenues, operations, and maintenance of the completed facility.

The budget for the project should include a contingency for anticipated (known unknown) or relatively minor changes in design. Management reserve is not part of the budget and is used at the discretion of the owner's management. Any proposed change must be transmitted to all discipline managers or others whose work may be affected by the change. These managers then should determine and report the cost and schedule impacts if the change is implemented. Work must not proceed on the change until the above impacts have been reviewed and approved by the owner's representative, the engineering manager, and the project manager. Once a change has been approved, it is important to communicate the reasons for the change to those affected by the change.

Authority/Responsibility Checklist

A project manager is often responsible for one or more projects at a time. Some of the projects may be in the early stage of development while others are in full progress, and some are in the close out phase. The problem that confronts a project manager who must handle multiple projects generally is not the management of any one project, but it is the difficulty in handling all projects simultaneously. This

type of work condition requires some systematic means of knowing the work status of numerous people.

To facilitate and keep track of team members, the project manager can develop an authority/responsibility checklist for each project (reference Figure 11-4). This list is continuously revised to show the status of completed, active, and pending work of each team member. It is especially useful in preparing agendas for team meetings. It also assists the project manager in organizing his or her own work and preparing reports to upper management and the owner's representative.

Authority/Responsibility Checklist

Project: Infr-1
Date: 28 February 2033

Task/Work item	Authority/Responsibility	Status	Date
Soil testing specifications	John Smith, Civil	Issued	2/26/2033
Confirmation of wind loads	Tim Jones, Structural	Pending	4/22/2033
Approval of shield wire angle	Dan Banks, Owner's Rep.	Approved	3/9/2033
Final tower configuration	Tim Jones, Structural	Expected	5/26/2033
Steel supplier's bid list	Ron Mitchell, Purchasing	Will Call	4/3/2033
Right of way hearings	Joe Thomas, Legal	Pending	6/1/2033

FIGURE 11-4 Authority/responsibility checklist for project manager.

Checklist of Duties for Design

Table 11-2 provides a comprehensive checklist of duties for the design phase of a project that is handled by the construction management (CM) type of contract. For projects other than the CM type of contract, the duties of the CM are distributed between the owner and designer, depending on the contract arrangement. The architect is the principal design professional for a building type project,

whereas the engineer is the principal design professional for a heavy/industrial type project.

Design Phase	Owner	CM	Designer*	Contractor
1 Project team	Head	Member	Member	X
2 Program information	Provide	Review	Obtain/Approve	X
3 Information required for design	Provide	Review	Determine requirements Obtain, approve	X
4 Meetings—Project team	Participate as required	Organize, conduct, record	Participate	X
5 Meetings—Design team as required	Participate as required	Participate, document	Organize, conduct	X
6 Budget	Provide	Evaluate	Evaluate	X
7 Budget contingency	Provide	Recommend	Recommend	X
8 Scheduling—Program	Participate, approve, comply	Prepare, monitor, enforce, comply	Participate, approve, comply	Comply
9 Scheduling—Milestone	Review	Provide	Review, approve	X
10 Soil bearings	Review & pay	Review	Arrange, review, & recommend	X
11 Drawings—Preliminary	Review, comment, approve	Review, comment, advise	Provide	X
12 Approvals—Design	Approve	Recommend	Issue documents	X
13 Drawings—Schematic, design development & working	Review, comment, approve	Review, comment, advise	Provide	X
14 Specifications—Conceptual	Review, comment, approve	Review, comment, advise	Provide	X
15 Specifications—Technical	Review, approve	Review, comment, advise	Provide	X
16 Design alternates	Approve as required	Recommend	Recommend, prepare	X
17 Value engineering & value management	Approve as required	Provide	Assist, review	X
18 Estimating	Approve as required	Provide	Assist, review	X
19 Agency plan reviews	Monitor	Monitor	Facilitate	X
Design Phase	**Owner**	**CM**	**Designer***	**Contractor**
20 Permits—Not assigned to contractors in bid documents	Pay	Arrange for & obtain	Assist, consult with agencies	X
21 Insurance—All risk-builders risk	Provide	Assist, recommend	X	X
22 Insurance—Owner's protective liability	Provide	Assist, recommend	X	X
23 Cash flow projections	Provide, utilize	Provide, update	Assist	X
24 Specifications—Instructions to bidders	Approve	Provide	Review & advise	X
25 Specifications—Proposal section	Approve	Provide	Review & advise	X
26 Bidding alternates	Approve as required	Recommend, review	Recommend, review, issue	X

Source: NSPE/PEC Reporter, Vol. VII, No. 2.
*The referenced NSPE/PEC publication cited "Architect"; however, the term "Designer" is used here to imply the architect may be the principal design professional for building projects, whereas the engineer may be the principal design professional for heavy/industrial projects.

TABLE 11-2 Checklist of Duties for Design Phase

Producing Contract Documents

The design firm's objective is to produce a comprehensive, coordinated, and complete set of contract documents to be

used to construct the project. The contract documents include, but are not limited to, the following:

- Bid tender documents
- General terms and conditions
- Special conditions
- Engineering specifications
- Engineering drawings
- Environmental specifications
- Environmental drawings
- Permits and permit restrictions

Each component of the contract documents is a work scope for a member of the project team. Each team member is responsible for the content of their work product and following the work process flow for their respective functional team.

While computers facilitate the preparation of documents, they present a real risk to completing the design package and contract documents without error and within the requirements specified by the owner. The computer allows for evaluating numerous design alternatives, layouts, and alignments. Without effective work processes, excessive use of computers leads to overdesigning, word smithing, overdrafting, and complacency with respect to checking for errors and accepting last minute changes.

Examples include the process engineer or hydraulics engineer wanting to run one more simulation, or the structural engineer wanting one more computer run for another load check. Other examples include the computer-aided drafting and design (CADD) operator wanting to see how a drawing will look if another change is made, or the specification writer continuing to cut and paste a new section in the contract documents. Sometimes

overanalyzing, overdesigning, or continued editing can lead to errors and conflicts in the contract documents.

The design leads must develop a system of monitoring the design effort to ensure the work is progressing without excessive billable hours, but is still producing adequately defined plans and specifications that can be used for construction. This will reduce construction contractor complaints of useless drawings full of errors and lacking constructability.

Depending on the organization structure of the design firm, the functional group has control over all technical content of the respective team member's work product. For example, the manager of environmental will ensure that the environmental designs, specifications, and permit applications meet internal standards and those of the owner as specified in the design contract.

Specific team members are assigned the responsibility to collect completed contract documents. The CADD lead will collect and assemble all of the drawings. The specification lead or contract lead will collect and assemble all of the written specifications. These are then assembled for internal review. The complete contract package is provided to the owner for bidding and award of the construction contract.

Design and Document Review

The design process requires the timely distribution of documents and exchange of information. Generally, there is a sense of urgency among team members to complete work at the earliest possible date. When information is inefficiently distributed, it increases the workload of everyone and leads to delays in work, inefficient productivity, and frustration.

During the design process, several reviews should occur. Some of these reviews are internal to the design firm while

others are reviews with the owner's representative and owner's internal project team. Document review, squad checks, verification of calculations, code review, and cross-checking between drawings must be included in the design work plan and the design schedule. Once construction begins, the design firm will review shop drawings (detailing of design) and requested changes to the design via a formal request for information (RFI) or scope change process. These activities need to be included in the design contract and time allocated for prompt replies to contractor requests.

Document workflow, previously discussed in Chapter 5, needs to describe the design review process. It should be included in the project work plan and reflected in the design schedule whether it is a parallel or sequential workflow.

Document control should initiate the document review utilizing a form similar to Figure 11-5, the document review workflow sheet. The designated functional team member responsible for the review of the particular document collects the review comments following the design firm's internal review process and resolves conflicting comments. The design project manager submits the reviewed documents to the owner's representative for review and approval or modifications based on the owner's requirements or internal standards.


Document Review Workflow Sheet
Infr-1 Project

Send to	Name	Title	Email Address	Phone	Date

Comments:

Action: _____ See me _____ Call me _____ Review

Distributed by: _____ Date: _____

FIGURE 11-5 Document review workflow sheet.

Constructability

Traditionally, engineering and construction have been separated early in the project. The adoption of new technology such as three-dimensional computer-aided drafting and design (CADD), robotics, and automation in construction has generated increased interest in the constructability of a project. With these new innovations, designs can be configured to enable efficient construction, which places more emphasis on merging engineering and construction to include constructability's input in the design effort. The desired result is to facilitate the exchange of ideas between construction and design before and during design, rather than after design.

The Construction Industry Institute (CII) has sponsored research and published reports related to constructability. CII Publication No. 3-3, entitled *Constructability Concepts File*, provides a good description of constructability concepts related to conceptual planning, design and procurement, and field operations. The following paragraphs contain excerpts from the report to illustrate the contents of the report.

There are several factors that should be considered in constructability deliberations related to design configurations for efficient construction:

- Simplicity
- Flexibility
- Sequencing
- Accessibility
- Workspace
- Substitution

- Labor skill level and availability

Simplicity is a desirable element of any constructable design. Unwarranted complexity introduces unnecessary risks to the project. It is not in the best interest of anyone and markedly increases the probability of an unsatisfactory finished product. Special drawings and instruction may be required to improve the constructability process, particularly for retrofit or rebuild projects.

Flexibility for the field construction personnel to select alternative methods or innovative construction approaches is highly desirable. Designs should specify the desired results and not limit approaches to attain these results. In the fully open and competitive market, it is highly desirable to provide designs that do not limit the construction methods or approaches.

Sequencing of installation is as much a design consideration as it is a procurement and construction consideration. Many times, completed designs have unnecessarily restricted installation sequences during construction. Design should include careful consideration of layout and spacing of facilities, so more than one construction operation has access to and workspace for concurrent construction activities.

Substitutions or alternatives warrant attention, but too often are neglected because the attitude prevails that it has always been done a particular way. Improperly considered material applications will impact constructability, resulting in costly modifications. These impacts can be lessened and eliminated when addressed during the design phase by constructability programs.

Labor skill levels and availability are often not considered early enough in a project lifecycle. The availability of labor and the skill level of the workers should be fully explored. The absence of either skilled labor or the unavailability of a

suitable work force can have a costly impact on a project. As the design work progresses, the team should consider changing aspects of the design that require specialized labor or large amounts of labor.

CII research has shown that company or project size is no barrier to constructability and the implementation of a constructability program. The involvement of construction in the design phase results in better projects, lower costs, better productivity, and earlier project completion. A major obstacle to the implementation of effective constructability programs is the concept that designs are merely reviewed by construction to select the design that is easiest to build. CII Publication No. 3-2 provides guidelines for implementing a constructability program.

Post Design Review

Evaluation is a continuous process and necessary for improvement of project management. The system used by the project manager's organization to handle work must be flexible enough to respond to differences in individual projects. At the beginning of each project, the project manager must determine what modifications and improvements need to be made in the system that are appropriate for the project.

After completion of the design for each project, the project manager and his or her team should conduct a complete and candid evaluation of the design effort and the management of the design process. This evaluation should include each member of the project team as well as other key participants that were involved in design including the owner's representative.

A checklist should be prepared to evaluate all aspects of the project including scope growth, match of quality and scope, design effectiveness, owner's expectations and

satisfaction, conflicts within the team or other parties, excessive changes in schedules, comparison of final costs with the original budget, and a list of precautions for management of future projects.

After a thorough discussion of the design process, a brief summary report should be prepared by the project manager that should include a list of recommendations to improve the system for future projects.

Evaluation of Design Effectiveness

Design is a complex process involving the application of technical knowledge to creative ideas in order to produce a set of specific instructions for construction of the project. It is the focal point of definition of the project and has a significant impact on cost and schedule. Thus, it is essential to have the most effective design possible.

Most of the efforts related to measurement and evaluation of productivity and performance of project work have been directed toward the construction phase. The CII has sponsored research and published numerous papers on a variety of topics related to project management. *Evaluation of Design Effectiveness* is a CII document that provides a thorough description of outputs, or products, of the design process.

The following paragraphs are a summary of excerpts from the CII report *Evaluation of Design Effectiveness.* The report states this method is not intended to be, nor should it be, used as an evaluation of a designer or the design process. It is instead a measure of design effectiveness and an evaluation of design outputs.

Measurement of design productivity is perhaps more difficult than measuring productivity in the construction phase. Simplistic measurements such as cost per drawing or work-hours per drawing have obvious limitations because of

variations in drawing size and content. Also, there is increasing realization that the true measures of the effectiveness of the design effort are found in the construction of a project and use of the project by the owner after construction is complete. Thus, it may be more beneficial to develop a method for evaluating the effectiveness of design rather than the productivity during the design activity itself.

The ability to measure design effectiveness using the following proposed method represents an important step in a broader effort to improve the total design process. Such an effort encompasses the identification of the consequence on design effectiveness of various inputs to the design process and of the systems and techniques employed by the designer.

CII researchers have suggested the use of a technique called an *objectives matrix* for productivity evaluation. The same concept can be used to develop an effectiveness measurement for design. An objectives matrix consists of four main components: criteria, weights, performance scale, and performance index.

The criteria define what is to be measured. The weights determine the relative importance of the criteria to each other and to the overall objective of the measurement. The performance scale compares the measured value of the criterion to a standard or selected benchmark value. Using these three components, the performance index is calculated, and the result is used to indicate and track performance.

Use of the objectives matrix is illustrated in Figure 11-6. The seven criteria of design effectiveness are given as column headings; the criteria weights are shown near the bottom of each column. The performance scale of 0 to 10 is given at the right of the matrix. A score of 10 represents perfection, and a score of 3 is average.

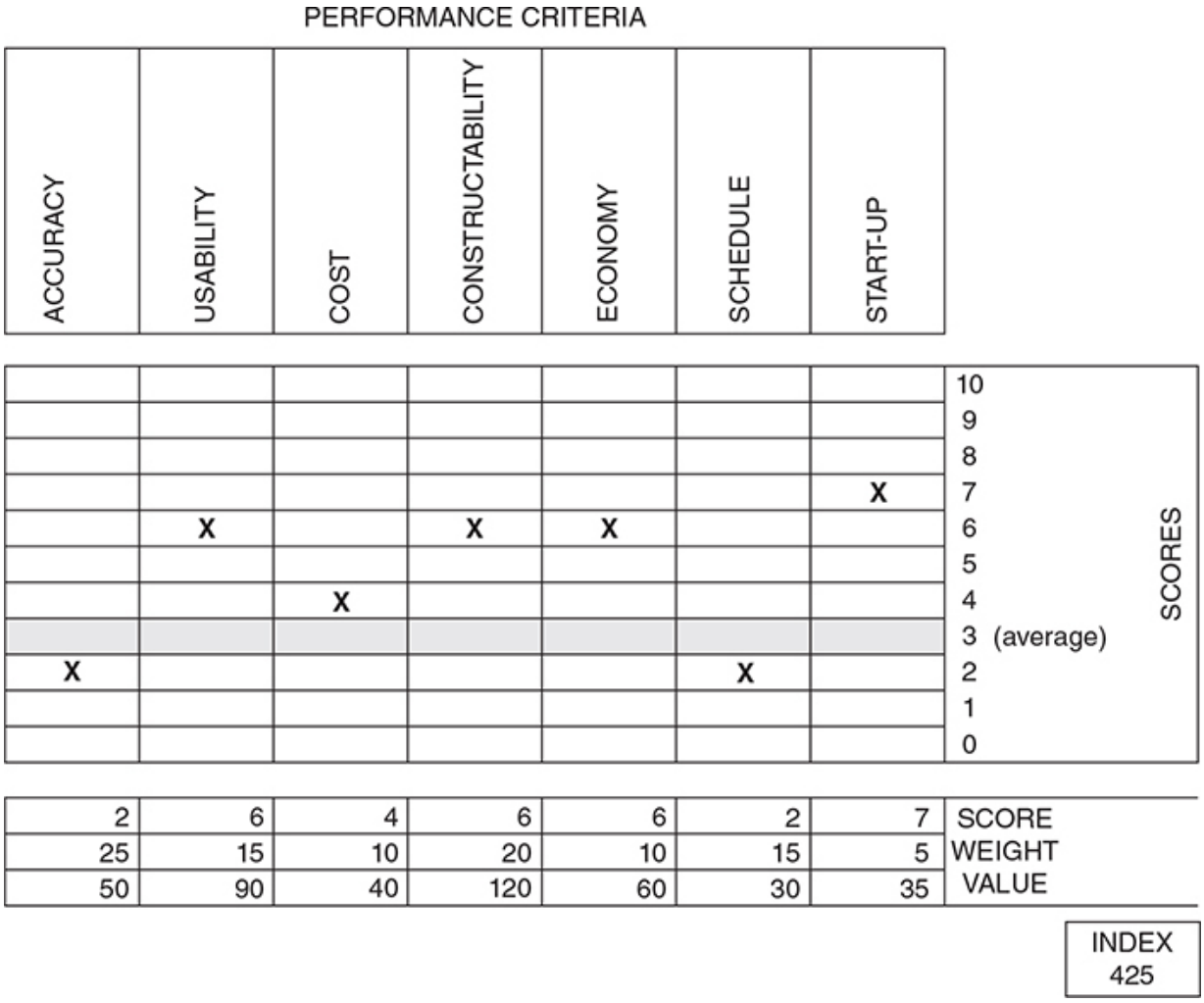


FIGURE 11-6 Design evaluation matrix. (*Source:* Construction Industry Institute, Publication No. 8-1.)

A score for each of the seven criteria is represented by an "X" in the appropriate box and is entered at the bottom of the matrix. Each criterion's score is multiplied by its weight to obtain its value. The sum of all values constitutes the performance index, which is shown at the bottom right of the matrix.

The score for a criterion can be obtained in at least three ways: judgmental, based on a single quantitative measurement, or based on a combination of several subcriteria that are represented by a matrix.

Judgmental scoring can be used for some or all criteria. The scoring in Figure 11-6 is representative of judgmental scoring. Although judgmental ratings have the limitation of subjectivity, the objectives matrix approach still allows their appropriate application with multiple criteria of different weights.

For some criteria, quantitative measures can be used instead of judgements to determine scores. For example, the accuracy of the design documents can be evaluated by measuring the amount of drawing revisions per total drawings. The score for performance against the schedule criterion can be determined by using the percent of design document release dates attained. This approach is illustrated in Figure 11-7, in which these two criteria are represented by quantitative measures.

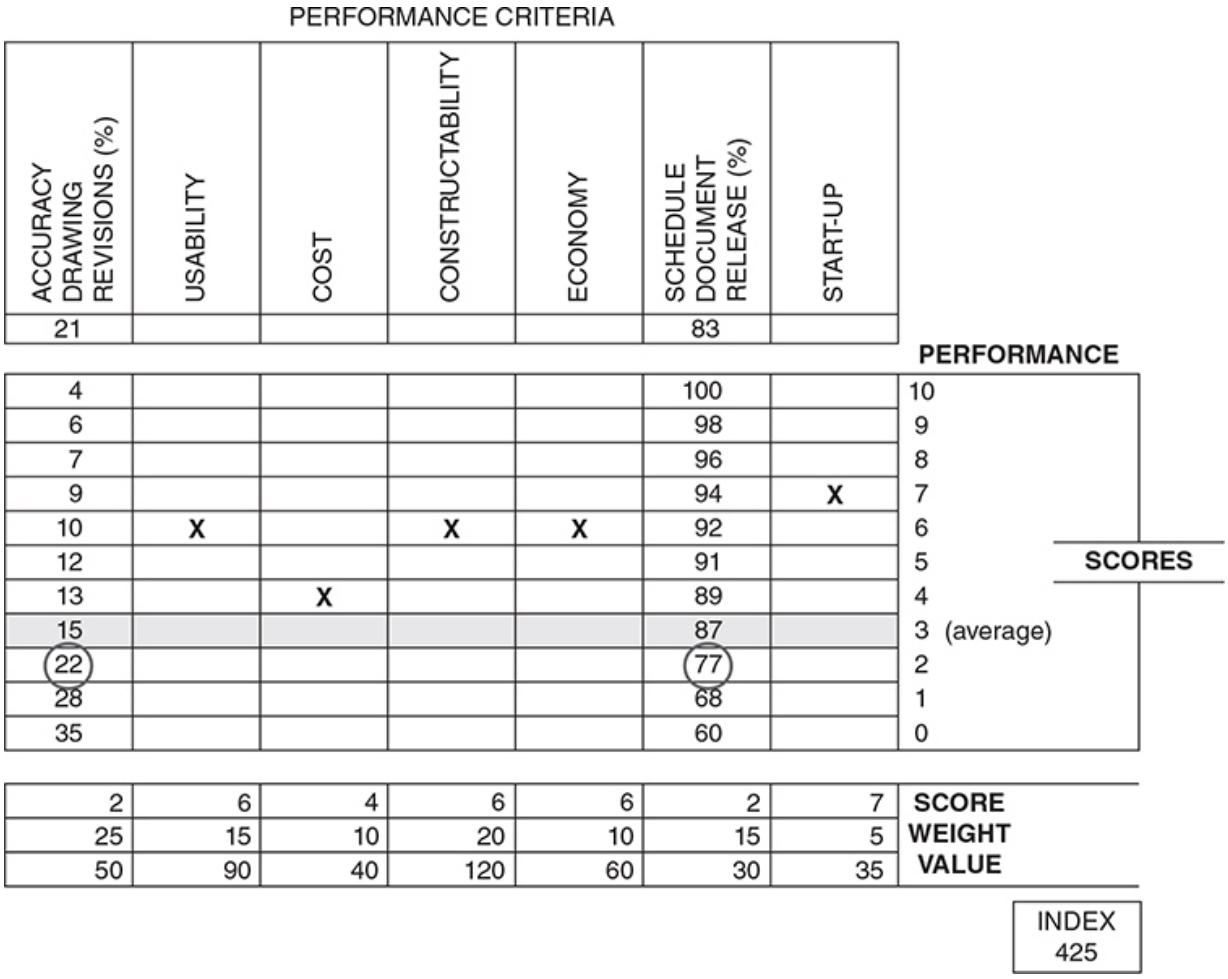


FIGURE 11-7 Design evaluation matrix using quantitative evaluation. (*Source:* Construction Industry Institute, Publication No. 8-1.)

In the example of Figure 11-7, predetermined benchmark values are entered into the boxes representing appropriate scores for accuracy and schedule. The benchmark value for a score of 3 is considered normal or average, while that for a level of 0 represents the minimum level of accomplishment realized in recent years. The benchmark value for a level of 10 represents the ultimate expected in the foreseeable future. The score of 3 is used for normal rather than 5 to allow more opportunity for improvement.

The performance value attained is entered at the top of each column. The appropriate score representing that

performance is then determined and is circled in Figure 11-7. If a performance level falls between two scores, the lower score is used. A score is not given until it is attained.

A third approach is to measure each criterion through the use of several subcriteria. The subcriteria themselves can have differing weights and measurements. These can be combined into a single criterion score through the use of a submatrix for that criterion.

Given the many complexities and variables of the total design process, no measurement system can yield absolute quantitative results that are applicable without an interpretation of all the design situations and circumstances. However, the method outlined can be utilized for three purposes: to develop a common understanding between the owner, designer, and contractor concerning the criteria by which design effectiveness on a given project will be measured; to compare design effectiveness of similar projects in a systematic and reasonable quantitative manner, highlighting performance trends; and to identify opportunities to improve the effectiveness of the entire design process as well as the contributions toward the ultimate result made by all participants. Selecting an evaluation method and applying it consistently with each project will provide valuable insights to improve designs where needed.

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CHAPTER 12
Construction Phase

Importance of Construction

The construction phase is important because construction builds the assets to achieve the owner's objectives. The quality of the completed project is highly dependent on the workmanship and management of construction. This phase is where the details of the design become reality. The quality of construction depends on the completeness and quality of the contract documents that are prepared by the designer and three other factors: laborers who have the skills necessary to produce the work, field supervisors who have the ability to coordinate the numerous activities that are required to construct the project in the field, and the quality of materials that are used for construction of the project. Skilled laborers and effective management of the skilled laborers are both required to achieve a quality project.

The construction phase is also important because a majority of the total project budget and schedule is expended during construction. As presented in previous chapters, the design costs for a project generally range from 7% to 12%. Using a 10% median value, then 90% of the cost of a project is expended during construction. Thus, a 15% variation in design costs may impact the project by only 1.5%, whereas a 15% variation in construction costs may impact the project by 13.5%. Figure 12-1 illustrates the

comparative significance of construction costs to project development costs. The figure shows that for the project with an estimated P50 cost at completion of $5 billion, approximately $200 million has been spent from project feasibility to the beginning of detailed design and procurement.

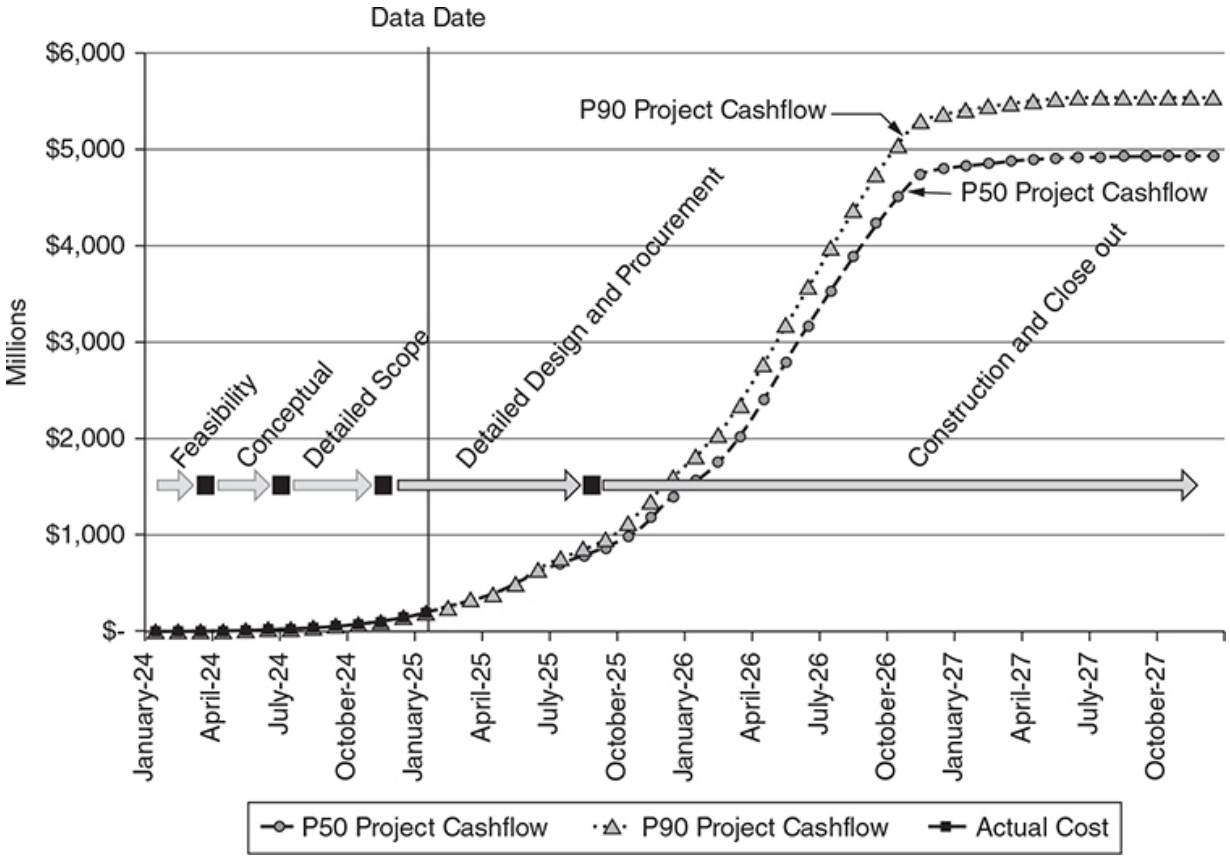


FIGURE 12-1 Cumulative cost curve for a mega-project showing significance of construction costs compared to project development costs.

Similar to costs, the time required to build a project is always disproportionally greater than the time required to design it. Most owners have an economic driver for the use of their projects at the earliest possible date; therefore, any delay from a planned completion date can cause significant problems for both the owner and contractor. Due to the risks

that are inherent to construction, and the many tasks that must be performed, the construction contractor must carefully plan, schedule, and manage the project in the most efficient manner.

Much information and many resources are available and provide detailed explanations of all of the different aspects of construction. These range from contracting, scheduling, inspection, safety, managing labor, and progress measurement. This chapter provides basic information that can be supplemented by the reader with other resources or references.

Assumptions for Construction Phase

The objective during the construction phase is to build the project in accordance with the plans and specifications, within budget, and on schedule. To achieve this objective, there are three assumptions as shown in Table 12-1.

Scope	The design plans and specifications are complete, contain no errors and meet the owner's requirements and appropriate codes and standards.
Budget	The budget is acceptable. It is what the owner can afford and what the contractor can build it for, with a reasonable profit.
Schedule	The schedule is reasonable. It is short enough to finish when the owner needs it and long enough for the contractor to properly do the work.

TABLE 12-1 Assumptions for Construction Phase

A project is a single, nonrepetitive enterprise. Although the assumptions are reasonable, there are often variations due to the nature of construction work. Because each project is unique, its outcome can never be predicted with absolute confidence. To construct a project, the owner generally assigns a contract to a contractor who provides all labor, equipment, material, and construction services to fulfill the requirements of the plans and specifications. This

requires simultaneously coordinating many tasks and operations, interpreting drawings, and contending with adverse weather conditions.

It is difficult for some individuals to acknowledge the fact that plans and specifications do have errors. The preparation of a design requires many individuals who must perform design calculations, coordinate related work, and produce many sheets of drawings that have elevations, sections, details, and dimensions. Although every designer strives to achieve a flawless set of plans and specifications, this is rarely achieved.

The owner generally accepts and approves the contract documents before commencing construction. However, the plans and specifications do not always completely represent what the owner wants. The interest of some owners, particularly nonprofit organizations or public agencies, is represented by individuals who are members of a board of trustees, board of directors, or a commission. These individuals generally have a background in business enterprises and/or professional occupations with little or no knowledge of project work or interpretation of drawings. Thus, they may approve the selection of a material or configuration of a project without fully understanding what it looks like until it is being installed during construction.

Serious problems can arise for both the owner and contractor if the contractor submits a bid price that is lower than that required to build the project with a reasonable profit. A contractor that has underbid a project can also cause significant problems for the design organization. A construction company is a business enterprise that must achieve a profit to continue operations. A careful evaluation of each contractor’s bid is necessary before award of a construction contract; because if a project is underbid by the construction contractor, the management of the project will be difficult regardless of the ability of the individuals

that are involved. Evaluation of bids to determine the most responsible bid is a key aspect for successful construction.

Conditions can arise that alter the project budget and schedule, such as changes desired by the owner during construction, modifications of design, or differing site conditions. To reduce the impact of these conditions, there should be a reasonable contingency to allow for these types of variations that can adversely affect the project budget and schedule. Chapter 7 covered risk assessment and analysis including risk mitigation. It discussed how to establish a contingency fund for use during construction to offset risk events.

Sufficient time must be allowed for contractors to perform their work. If a reasonable time is not allowed, the productivity of workers and quality of the project will be adversely affected. There are always conditions that arise during construction that can disrupt the continuous flow of work, such as weather, delivery of materials, clarification of questions related to design, and inspection. The contractor must plan and anticipate the total requirements of the project and develop a schedule to allow for a reasonable variation of time that is inherent in the construction process.

The project manager must contend with problems as described above. He or she must always be alert to these situations and must continually plan, alter, and coordinate the project to handle the situations as they arise.

Contract Pricing Formats

The method that is selected to compensate the construction contractor can have a large impact on a project's cost, schedule, and the level of involvement by the owner and designer. Contract pricing may be divided into two general categories: fixed price and cost reimbursable. For fixed-price contracts the contractor may be compensated on a lump-

sum or unit-price basis. Cost-reimbursable contracts may include methods of payment by any one or combination of the following: cost plus a percentage or fixed fee, guaranteed maximum price, or incentive.

Many books and articles have been written that discuss the advantages, disadvantages, and conditions that are favorable for the use of the above methods of payment for construction services. The following paragraphs are presented as a summary of what has already been written, to assist the project manager. Chapter 2, Project Definition, discussed the importance of developing a contract strategy for the project and included comparisons of contract types. Please see our online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information.

The intent of lump-sum contracts is to fix the cost of the project by providing a complete set of plans and specifications that are prepared by the designer prior to construction. However, the contractor is entitled to extra compensation for any changes that may be necessary during construction. For lump-sum contracts, changes during construction are a major source of cost overruns. For these types of projects, it is necessary to ensure a complete design that is as error free as possible and to keep any owner changes to a minimum. There should be an adequate review of the contract documents before bidding to detect any discrepancies that may exist and to confirm the constructability of the project. The project manager should work with the owner during construction to evaluate the full impact of a project change, including the effect on the project's cost and schedule, because a change in one area of the project often affects other areas of the project. There should be a rate schedule for labor and equipment for extra work related to project changes that is agreed upon before the construction contract is signed.

Unit-price contracts are awarded because the quantity of work may not be determined with a degree of accuracy to enable a contractor to submit a lump-sum bid. A major source of cost overruns for unit-price contracts is errors in the estimated pay quantities. Errors in estimated pay quantities can lead to unbalanced bids by contractors, which can cause significant increases in the expected cost of the project and expensive legal disputes. There should be a thorough review of all estimated pay quantities of unit-price contracts before the request for contractor bids. There should also be a clear definition of what constitutes a pay quantity. For example, the excavation unit prices will be paid based on neat lines as shown on the drawings. After receipt of all the bids, a careful review of each unit-cost bid item should be performed to detect any bid unbalancing. In particular, there should be a review of large quantity pay items and any unusually large unit-cost bid items to detect irregularities.

For some projects, it is desirable to start construction before design is complete, for example, projects that are complex in nature, or projects that must be completed due to emergency situations when it is not practical to produce a complete detailed design of the entire project before starting construction. Cost-reimbursable projects require extensive monitoring of material deliveries and measurement of work. The owner’s organization must establish a field office to review and approve the costs of material, labor, equipment, and other costs associated with the project. This method of contracting can be efficient for owner organizations that need the flexibility of modifying the project as required, during construction, to produce the best end results to meet their needs. However, the owner must have extensive experience with handling projects.

Design/Bid/Build Method of Project Delivery

Design/Bid/Build (D/B/B) is often considered the traditional project delivery method. All design work is completed before starting the bid and construction process. This delivery method is usually selected for projects when cost is primary, schedule is secondary, and the scope is well defined.

The D/B/B project delivery method is a three-party arrangement involving the owner, designer, and contractor. The owner signs one contract with the designer for design services and signs another contract with the contractor for construction services. Both the designer and contractor work for the owner. The contractor does not work for the designer; however, the owner usually designates the designer as their representative during construction. The designer is usually paid based on a prearranged fee or on a percentage of the construction contract. The contractor is paid based on a lump-sum amount.

Since design is completed before bidding, the owner has the opportunity to know what the project will look like before proceeding into construction, when the biggest costs will be incurred. The contractor also has a clear understanding of the project requirements and is thereby able to estimate the cost of construction with a high degree of accuracy. This allows the owner to know the project cost before committing to sign construction contracts. In D/B/B the responsibility, risk, and involvement of all parties are well defined. The owner has a relatively high level of involvement and control during design, but low involvement during construction because the contract documents clearly define what the contractor must do.

The biggest disadvantage of the D/B/B project delivery method is the extended time that may be required for completing the design and bidding the project before

starting actual construction. Changes made after the award of construction contracts can be costly to the owner.

Design/Build Method of Project Delivery

The Design/Build (D/B) project delivery method is often chosen to compress the time to complete the project. The completion time usually is reduced because construction can start before all the design is completed. The owner has considerable control and level of involvement throughout the project. This provides flexibility to the owner for revision of the design during construction. The D/B project delivery method is usually selected for projects when the schedule is primary, the cost is secondary, and the scope is not well defined.

The D/B method of project delivery is a two-party arrangement, involving the owner and the D/B company. A contract is signed between the owner and the D/B firm to perform both design and construction services. All design, including construction drawings, are done by the D/B contractor. All construction is done by the D/B contractor, although the D/B contractor may hire one or many subcontractors. The D/B firm typically has an in-house design staff as well as experienced construction personnel. This arrangement can reduce the conflicts between the designer and contractor that often occur in the D/B/B delivery method. Sometimes a construction contractor will team with a design firm, or a design company will team with a construction contractor to provide D/B work for the owner.

It is common to choose the D/B firm by a Qualifications-Based Selection (QBS) procedure. The owner solicits proposals from a prequalified or prescreened list of firms. An evaluation process is used to assess quality, safety record, schedule, cost performance on past jobs, and other factors

from each prospective D/B firm. Thus, selection is based on qualification rather than price. The cost of the D/B services is usually based on some type of cost-reimbursable arrangement, either cost plus a fixed amount or cost plus a percentage.

For projects that have a reasonably defined scope, the D/B firm is sometimes selected based on price. For incentives, the contract may be based on a guaranteed maximum amount, with bonuses when the final cost is less than the guaranteed amount and penalties when the final cost is more than the guaranteed amount.

Although the total project cost is a major consideration, the total cost is not well known at the beginning of a D/B project because the design has not been prepared. Handling inspection is an issue that must be addressed early in the project because the designer is also the builder. If qualified individuals are available in the owner's organization, the owner may perform inspection. In some situations, an independent third party is used for inspection services.

Construction Management Method of Project Delivery

There are many variations of the Construction Management (CM) method of project delivery. One variation of CM is called *agency CM*, sometimes referred to as pure CM in the engineering and construction industry. In this arrangement the CM is a firm outside the owner's organization that acts as the agent for the owner. The agency CM firm performs no design or construction but assists the owner in selecting one or more design firms and one or more construction contractors to build the project. The agency CM firm assumes no risks because all contracts are signed between the owner and the designers and/or contractors. Generally, the agency CM works for a fee.

Corporate CM is similar to agency CM, except the CM services are provided by personnel inside the owner's organization. The design and construction are performed by firms outside the owner's organization with the corporate CM staff managing and coordinating overall effort.

CM at risk (CM@Risk) is another variation of CM. The term CM@Risk is used because the CM firm will actually perform some of the project work, thereby exposing themselves to risks associated with quality, cost, and schedule. The work may include some or all of the design as well as some or all of the construction. There are two subvariations in CM@Risk, primarily construction firms that become involved in CM and primarily design firms that become involved in CM. Construction contractors that do CM@Risk work typically focus on the construction aspects of the project and hire the design work necessary to support the construction effort. Sometimes this variation of CM is referred to as *contractor* CM. Design firms that do CM@Risk are more closely affiliated with design than construction. Typically, they focus on the design aspects of the project and hire the construction work. Sometimes this variation of CM is referred to as *designer CM.* The CM@Risk firm may work on a lump-sum, cost-reimbursable, or a guaranteed maximum price basis.

Regardless of the variation of CM methods that is used for project delivery, CM is a single-source management of the project that allows the owner to control his or her level of involvement. To be successful, the CM must be involved at the beginning of the project. Performing some of the design work without involvement of the CM prevents taking advantage of CM services. Selection of the CM early in the project increases the potential for reductions in costs by eliminating contract administration costs from designers and contractors. There can also be potential savings in time by integrating all parties from the start to the end of the

project. This allows the owner to concentrate on overall aspects of the project rather than on day-to-day problems.

The CM must carefully monitor multiple construction contracts to ensure there are no gaps or overlaps in work. Tracking the costs of multiple construction contracts also requires careful attention. There also must be careful monitoring of the project to prevent delays that can occur due to interference of contractor's work at the jobsite.

Bridging Project Delivery Method

Bridging is a hybrid method of project delivery for building-type projects. The contract documents are prepared by the owner's designer. These documents define functional use and appearance requirements of the project. Performance specifications are used to specify the construction technology. The details of construction are developed by the construction contractor. Final design, consisting of the construction drawings, is done by an engineering/construction contractor, who performs final design and provides construction services using subcontractors. For more information, refer to the references at the end of the chapter.

Build-Operate-Transfer

Build-Operate-Transfer (BOT) involves a partnering relationship between entities in the private sector and the public sector. It is a type of arrangement where a firm in the private sector builds the project, operates it for a certain period of time, and eventually transfers ownership of the project to an entity in the public sector, typically a federal or state agency of government. This arrangement is used primarily for long-term infrastructure projects, such as toll-road highways, power plants, or water treatment facilities.

The private sector designs and builds the project, then operates it for sufficient time to recoup the cost of construction plus a reasonable return on investment. During operation of the completed project, the private-sector firm receives revenues from fee charges to use the project. The transfer of ownership is specified in the concession date of the BOT contract agreement between the private-sector firm and the public-sector agency of government.

Fast-Track Projects

Fast-track is the term commonly used for projects that must be completed in the earliest possible time. Construction work overlaps design. As soon as a portion of the design is completed, then construction work is started. Fast-track projects can be performed under the D/B or CM methods of project delivery. Fast-track applies to projects that are schedule driven at the request of the owner. For example, the owner may want to complete a process plant at the earliest possible date in order to produce and market a product before a competitor. Or a business may want to complete a building by a specific date to accommodate a special event.

Turn-Key Projects

Turn-key is the term commonly used for projects that are designed, built, and put into operation before the project is turned over to the owner. The company providing the turn-key services may secure the land for the project, perform or coordinate all aspects of the design, arrange and administer construction contracts, manage construction of the project, staff and train the personnel to operate the facility, and then turn the project over to the owner. Turn-key projects

typically are manufacturing or process plant-type facilities in remote locations.

Partnering

The competitive environment and the rigid requirements of contracts have, at times, caused adverse relationships in the construction industry. Traditionally, contractors and vendors have been selected on a competitive-bid basis to provide construction services, under formal contracts, to meet the requirements specified in the drawings and specifications. A short-time commitment is made for the duration of the project. Thus, contractors and vendors work themselves out of a job.

The concept of *partnering* is an approach that focuses on making long-term commitments, with mutual goals for all parties involved, to achieve mutual success. The Construction Industry Institute (CII) established a task force on partnering to evaluate the feasibility of this method of doing business in the construction industry. CII Publication 17-1, entitled *In Search of Partnering Excellence*, is a report that discusses the research findings on partnering practices. The following paragraphs are excerpts from the report.

Partnering is a business strategy that offers many advantages to the parties involved; however, its success depends on the conduct of the parties and their ability to overcome barriers related to doing business differently than in the past. Companies agree to share resources in a long-term commitment of trust and shared vision, with an agreement to cooperate to an unusually high degree to achieve separate yet complementary objectives. Partnering is not to be construed as a legal “partnership” with the associated joint liabilities.

The first known partnering relationship in the construction industry was between an oil company and a contractor. The

owner approached the contractor and proposed that some of the existing engineering blanket work be accomplished using a new set of relationships and accountabilities. Hence, both agreed to enter into a “partnering relationship” to perform multiple projects in different locations. The services provided by the contractor included project execution–related services, while the owner provided technical assurance and approved only primary funding documents and scoping documents developed by the contractor. Twenty-five different projects were performed with this relationship.

From a contractual point of view, this first partnering relationship differed from traditional contracts because the bureaucratic procedures were removed, and all issues were open for negotiations. In this relationship, the owner agreed to carry the financial burden of any risks that might occur during the duration of the relationship. The parties agreed to set performance evaluation criteria for major areas that were important to the projects. An incentive system based on the performance criteria was utilized, including monetary awards given by the owner to the contractor for doing a good job. Contractor incentives to employees included both monetary and nonmonetary incentives.

A cultural change is required by all parties in a partnering relationship. The three key elements of any successful partnering relationship are trust, long-term commitment, and shared vision. As these three elements are developed, other subelements are achieved and the benefits to all parties are maximized. Both customer and supplier can profit from reduced overhead and workload stability. Competitive advantage is enhanced through improved cost, quality, and schedule. Growth and balance are important to the continual improvement of the partnering agreement. For example, in developing a long-term commitment, a partnering agreement may grow from single to multiple

projects. Likewise, trust may evolve from competitive bidding through complete disclosure of project costs in a cost-plus relationship. Shared vision can expand to open sharing and mutual development of business objectives.

The CII publication discusses applications of partnering to small businesses and projects, guidelines on selecting partners, and guidelines for implementing a partnering relationship.

Design Development and Performance Specifications

Owner organizations that have some design capabilities, but not enough to design the complete project, will solicit bids based on preliminary design development drawings that are created during detailed scope phase. For example, the design development drawings may only be developed to the 30% to 50% level of detail of the final drawings. Then, performance specifications are written to describe what the systems must do in the project rather than how the systems will perform. The construction drawings are completed by a D/B contractor that has special expertise related to the project. Owner organizations in the process industry sometimes handle projects in this manner.

Key Decisions for Project Delivery

The following issues can have a significant impact on the success of any project and should be considered in selecting the project delivery method:

1. Number of contracts
2. Selection criteria
3. Relationship of owner to contractor

4. Terms of payment

Number of Contracts



As illustrated above, the number of contracts can vary from one to many, depending on the chosen method of project delivery. For D/B/B projects, the owner awards contracts to two parties: one to a designer, who may contract some of the design work to other design firms, and one to the construction contractor, who may contract to numerous subcontractors who perform special construction work.

For D/B projects, the owner awards a contract to one party: the D/B firm, who may in turn subcontract to many contractors. For CM projects, the owner awards contracts to three parties: the construction manager, designer, and construction contractor. Under this scenario, there may be many subcontracts awarded under each of these three principal parties.

Selection Criteria



As illustrated above, contractors may be selected on the basis of price or qualification. Traditionally, designers are selected based on qualification and contractors based on price. However, the trend in recent years has been to select designers based on price. The selection criteria depend on the services that are being procured. Typically, price is used for selection of products that are easily defined or services that are easily evaluated. Qualifications are used for unusual products, proprietary work, or services that require special expertise, knowledge, and judgement.

Contractual Relationship



A contractor may be viewed as an agent or vendor. An agent represents the owner's interest, works for a fee, and usually is selected based on qualifications. A vendor delivers a specified product or service, works for a price, and generally is selected based on price. Traditionally, designers are at the agency end of the spectrum and contractors are at the vendor end of the spectrum. Some owners ask contractors to act as agents in procuring and managing construction and treat designers as vendors of plans and specifications. When owners need advice or guidance, they typically choose an agent relationship, whereas when owners know exactly what is required, they may choose a vendor relationship.

Terms of Payment



As illustrated above, the terms of payment can vary from fixed price to cost reimbursable. Fixed price is used when the details of the work are well understood. Cost reimbursable is used when the scope of work is unknown or not clearly defined. There are ranges of terms of payment from fixed to cost reimbursable.

Under a lump-sum arrangement for payment, the contractor is paid a fixed sum for the work based on executing the contract documents. For unit-price payments, the contractor is paid based on a predetermined amount for each unit of material that is installed.

For a cost-plus fee with a Guaranteed Maximum Price (GMP), the contractor is paid the actual cost plus a fee. If the cost exceeds the GMP, the contractor incurs the extra cost. If the cost is under the GMP, the contractor shares in the savings.

For a cost-plus fee with a target price, the contractor is paid actual costs plus a fee. As an incentive to meet the target price, arrangements can be made for various bonuses and a penalty if the final cost deviates from the target price. For example, the contractor may incur 80% and the owner 20% of all costs over the target price. Or the contractor may receive 70% and the owner 30% of the savings if the final cost is under the target price. Thus, the contractor shares in the savings under the target price and pays part of the overrun if the cost is over the target price. The target price can be modified by the change order process.

For cost-plus projects, the contractor is paid actual costs plus a fixed or percentage fee. The percentage fee can be a sliding scale, depending on the arrangements that are agreed to between the owner and the contractors.

The above payment terms may be combined into one contract, for example, fixed-price, lump-sum with a unit price for ordinary soil excavation and cost-plus fee for rock excavation. The terms of payment should be commensurate with the amount of risk assumed by each party.

Prospective Bidders and Bidding

The selection of the contractor is important because the successful completion of the project is highly dependent on the contractor. The owner and/or designer must depend on the contractor to provide labor, equipment, material, and know-how to build the project in accordance with the plans and specifications. If the contractor has problems, everyone has problems.

For competitive-bid projects, at least three bids should be received to provide a representative comparison of costs. Generally, a higher number of bidders will generate more competition, resulting in lower bids. However, the quality of the bidders is more important than the quantity of bidders. For private projects, it is possible to control which companies are allowed to submit a bid. In this type of situation, it is better to not allow companies to bid if their capabilities are in question or if the owner simply does not want the contractor to build the project. The bid list should only include bidders that are competent and capable of doing the work and to which the owner will agree to award the work.

Careful consideration should be given to the length of time that is allowed for contractors to submit bids. The proposed due date should be adequate for bidders to prepare a thorough bid. If there is uncertainty regarding what length of time would be adequate, a reputable contractor can be consulted to assist in developing a reasonable time for preparation of bids. If the time is too short, some bidders may decline, or worse, the bid may not be properly prepared. If the bid time is too long, there is an unnecessary delay in construction.

An addendum is a change in the bid package during the bidding process to correct errors, clarify requirements of the project, or make changes before awarding a contract to the contractor. Numerous addenda may discourage reputable, prospective bidders or place the bidders in a precarious “beware” status regarding the quality of the plans and specifications, or the possibility of additional changes the owner may make during construction. These conditions can lead to costly change orders that will adversely affect the final cost of a project.

A prebid conference should be held to clarify any unique aspects of a project and assist the bidders in their

preparation of a good bid. This is an opportune time to clarify scope, explain special working conditions, and answer questions of contractors. Any item that is clarified at the meeting, that is not in the bid documents, should be confirmed in writing to all parties.

For any project, the party that will administer the contract should prepare a detailed cost estimate (an engineer's estimate) from the same set of bid documents that the contractors are using to bid the project. This will assist in the evaluation of contractors' bids because the process of preparing an estimate requires a close scrutiny of all aspects of the project. Many problems associated with a project can be detected by thoroughly reviewing the bid documents and going through the process of preparing a detailed cost estimate. There are numerous professional estimating companies that can perform this service if the capability does not exist in the party's organization that will administer the contract.

The owner generally requires prospective contractors to provide a bid bond before a bid is accepted. Before award of a contract, most owners require the contractor to submit a material and labor payment bond, and a performance bond. All bonds are supplied to the owner from the contractor before commencing construction in the field. Although bonds provide some degree of protection to the owner, they do not guarantee that construction will proceed in a smooth operation. In addition to bond requirements, prospective bidders should be screened by a prequalification process that evaluates their record of experience including claims and legal disputes, financial capability, safety record, key staff, company owned and rented equipment, and general character and reputation in the industry.

Qualification-Based Selection

For lump-sum, fixed-price projects, construction contractors typically are selected based on the lowest and best-qualified bidder. Determining the lowest price is relatively simple since each contractor is required to submit a bid price. To ensure qualification, often the contractors are required to submit a prequalification form prior to bidding. The form typically requests information regarding the contractor's reputation, financial stability, and capacity to perform the work. In addition, most bid documents require a bid bond when the bid is submitted to the owner. Qualification for bid bonds typically assures the owner that the contractor will also qualify for the payment and performance bonds after the contract is signed.

For cost-reimbursable projects or negotiated contracts, contractors are often chosen based on Qualification-Based Selection (QBS), because the price of the project is unknown at the time the contractor is being selected. The owner typically selects a short list of contractors, each of whom would likely be selected for the work. Meetings are held to give each prospective contractor the opportunity to ask questions and receive clarifications regarding the extent of the proposed contract and the desired project outcome by the owner. The meetings are informative in nature and may involve a visitation to the project site. Then, formal Requests for Proposals (RFPs) are solicited from contractors. Typically, the RFPs request information regarding overall project management and technical ability, records of relevant past jobs and performance, and the approach to be taken in handling the project, including a cost proposal. A fixed format for the RFP is provided to each contractor to allow the owner to compare proposals on a common basis.

Upon receipt of all RFPs, the owner performs an evaluation. An assessment is made of each cost proposal. Since the actual cost is not known, the owner must determine if each contractor's cost proposal is realistic. The

cost proposal may involve a fee schedule for all labor, equipment, and indirect charges that would apply to the job. Typically, the owner is not looking for the least cost, but a competitive cost range. Costs are considered, but the final selection is based on the best and final offer.

To determine the best and final offer, a weighted evaluation system is used to provide a quantitative measure of each RFP. For example, the RFP is divided into categories, with a weight given to each category depending on its importance. Some categories may be given the same weight, whereas others are given different weights. Below is an illustrative example of categories for evaluation.

- Management information system
- Project schedule
- Personnel
- Contractor quality control
- Management of subcontractors
- Resource utilization
- Health and safety approach
- Financial capacity
- Experience and references

The management information system may include software for Computer-Aided Drafting and Design (CADD), scheduling, cost estimating, accounting, submittal reporting systems, and other relevant data. The level of development of an effective management information system is a measure of a firm’s ability to maintain a project budget during both design and construction. An appropriate project schedule, either a bar chart or network, that shows major milestones required to complete the project should be provided. A cost estimate should be required because price is a consideration in selecting contractors. Although the final

cost is not known at the time a contractor is chosen, the cost estimate does give an indication of the final cost.

The caliber of personnel is extremely important in choosing contractors by QBS. Resumes of key personnel should demonstrate a team composition that is capable of performing the work required in the project. Formal education, project experience, and professional registration of key team personnel are indicators of their ability to perform the work. Each proposal should contain a list of personnel, resources, and major subcontractors to be utilized for the project.

Engineering and construction projects require management of multiple subcontractors. Solicitation of RFPs for choosing contractors by QBS should include a plan for acquiring material, equipment, services, and subcontractors. The owner should provide a list of their preferred vendors before requesting RFPs from prospective contractors. Any QBS process should also provide information about resource utilization, including a detailed description of the staffing plan to accommodate normal fluctuating workload to ensure an experienced work force throughout the project, including periods of work buildup and decline.

A Quality Assurance and Quality Control (QA/QC) program should be fully documented in the RFP for choosing contractors by the QBS process. The system should include quality control during development of design drawings and specifications and throughout the construction process including testing, inspection, and safety.

The factors to be considered in evaluating proposals for QBS of contractors should be tailored to each project. Generally, final selection is based on a combination of safety, quality, technical merits, schedule, and cost. Quality may be expressed in terms of technical excellence, management capability, personnel qualifications, prior

experience, past performance, and schedule compliance. Although the lowest price is appropriate for deciding on a contractor, the final selection may be based on the proposal that offers the greatest value to the owner in terms of performance.

For cost-reimbursable contracts, the cost proposal should not be the controlling factor since advance estimates of cost may not be a valid indicator of final actual costs. Typically, cost-reimbursable contracts are not awarded based on the lowest proposed cost or lowest total proposed cost plus a fee. The award of cost-reimbursable contracts primarily on the basis of estimated costs may encourage the submission of unrealistically low estimates and increase the likelihood of cost overruns. The primary consideration should be which firm has the proposal to perform the contract in a manner most advantageous to the owner, as determined by evaluation of proposals according to the established evaluation criteria.

Numerical weights are applied to each factor in consideration by the owner. Typically, the value of the weights is not disclosed to the firms submitting proposals. However, the RFP may inform prospective contractors of the minimum requirements that apply to particular evaluation factors or subfactors. During the evaluation process, the owner assigns a score to each factor, based on the weight of the factor. The selection of the contractor is based on which RFP receives the best score. The contractor is then notified, and an advance agreement is made. After final arrangements are made, a contract is signed.

Checklist for Bidding

Table 12-2 provides a checklist of duties for the bidding and award phase of a project that is handled by the CM type of contract. For projects other than the CM type of contract,

the duties of the CM are distributed between the owner and designer, depending on the contract arrangement.

Bidding & Award Phase	Owner	CM	Designer*	Contractor
1. Procedures—Contracting	Approve as required	Formulate, issue	Advise, comply	X
2. Bidders list	Approve	Prepare	Assist, approve	X
3. Bid documents estimate	Approve	Prepare	Review, advise	X
4. Bid division descriptions	Review, approve	Prepare	Review, approve	X
5. Proposal forms	Approve	Prepare	Review, advise	Complete
6. Specifications—Advertisement for bids	Approve	Prepare	Review, advise	Respond
7. Preparation of bid documents	Pay printing & dist. cost	Provide required forms & bidders list	Print & distribute	Receive
8. Meetings—Prebid	Participate as required	Organize, conduct	Participate	Participate
9. Addenda	Approve	Recommend, review	Recommend, draft & issue	Acknowledge
10. Bid Openings	Attend as required	Organize, conduct	Attend	X
11. Meetings—Postbid	Attend as required	Organize, conduct	Attend	Attend
12. Letter of intent to award	Approve, sign	Prepare, issue	Recommend, approve	Respond
13. Bonds—Performance, labor & material	Review, file	Review & approve	Review & advise	Provide
14. Insurance—Liability & property damage	Specify & approve	Advise, monitor & file certificates	Include requirements in bid documents	Provide
15. Notice to proceed	Approve, sign	Prepare, issue	Recommend, approve	Respond
16. Award of contracts	Award	Recommend	Recommend	Receive

Source: NSPE/PEC Reporter, Vol. VII, No. 2.

*The referenced NSPE/PEC publication cited "architect"; however, the term "designer" is used here to imply the architect may be the principal design professional for building projects, whereas the engineer may be the principal design professional for heavy/industrial projects.

TABLE 12-2 Checklist of Duties for Bidding and Award Phase

Keys to a Successful Project

There are several factors that are important in order to achieve a successful project during construction. A good field construction representative must be present to represent the interests of the owner and designer. He or she must know the requirements of the project and be readily available to answer questions and respond to situations as they arise. The field construction representative's authority and responsibility must be clearly defined to all parties including the owner, designer, and contractor. It should be recognized that this individual is an asset available to all the

parties involved in the project: the owner, designer, and contractor.

Another important factor is a good, detailed construction schedule that is developed and used by the contractor who is performing the work, not the owner or designer. The owner should only define the start and/or end date of the project. Contractors know their capabilities, resources, and how they plan to coordinate the many activities required to build the project in the field. Thus, they are best qualified to develop a schedule to guide the numerous construction operations.

A good project control system must be developed to monitor, measure, and evaluate the cost, schedule, labor-hours, and quality of work. Chapter 13 provides a detailed discussion of project monitoring and control.

The most important factor in a successful project is good communication. Most experienced project managers readily agree that the source of most problems can be traced to poor communications. People don’t intend to do poor work or make mistakes. These types of problems are a result of misunderstanding of what is to be done and when it is to be done because of poor communications. There must be open lines of communication, so the right people are available to respond when they are needed.

A project organizational chart normally shows vertical lines of authority. However, strictly following vertical lines of authority sometimes is not responsive to dissemination of information in a timely manner. Thus, there is a need for communications that flow horizontally between people who are actually involved in the work.

Figure 12-2 shows a project organizational chart with dotted lines that represent the horizontal communications that are necessary for a project during the construction phase. The horizontal communications between the various organizations are the most difficult to monitor and control

because they are primarily verbal and are often not documented, which can result in misunderstandings and possible lawsuits. Therefore, horizontal communications should be restricted to sharing of information, but no decision making. Although these horizontal communications are necessary, it is the responsibility of all individuals to keep their immediate supervisor informed.

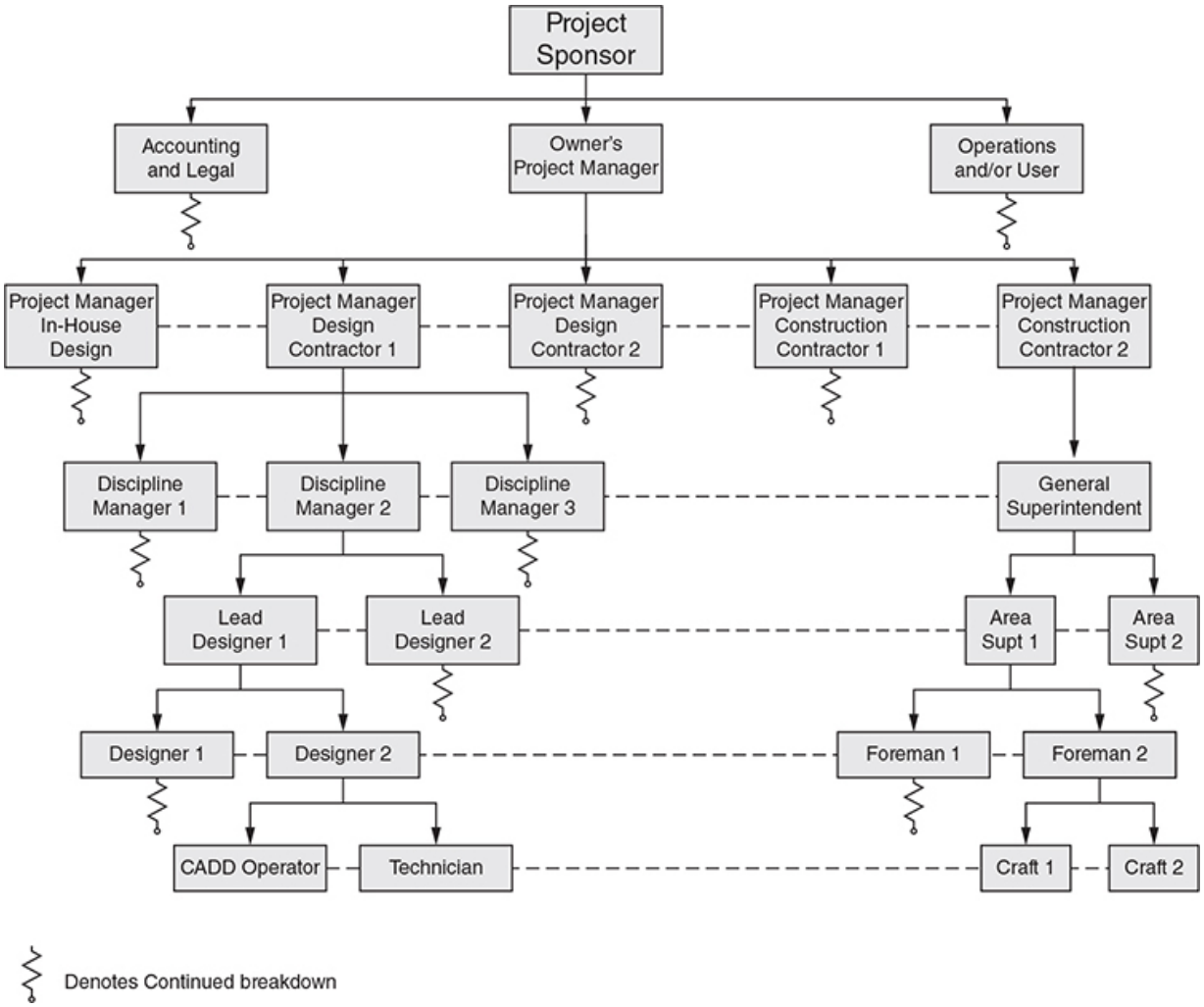


FIGURE 12-2 Effective horizontal communication channels necessary during construction. (Note: Horizontal dashed lines denote exchange of information only, and vertical solid lines denote decision-making authority.)

Construction Schedules

The purpose of scheduling a construction project is to ensure adequate planning of the work so it can be effectively and efficiently managed. A schedule must show all the activities required to complete the work, organized in a logical sequence, and generally presented in a time scale for easy interpretation. The purpose is to ensure that all activities necessary to complete the work are properly planned and coordinated. Adjustments in the schedule must be made as changes occur. The construction contractor must plan the work, and work the plan.

It is imperative for the jobsite superintendent to be involved in preparing the schedule. The superintendent will be involved in the day-to-day supervision of the work, so he or she has a better idea as to how the work will be put in place. If the superintendent is involved in preparing the schedule, the schedule will be used to manage the work because the superintendent will have bought into the schedule. Schedules that are prepared without the superintendent are seldom successful. The person that estimated the job and the contractor’s project manager are valuable resources for providing information and assisting the jobsite superintendent in preparing schedules, but the superintendent is the person who must plan the sequence of activities the way he or she plans to work the project.

A good construction schedule is in the best interest of all parties: the owner, designer, and contractors. First and foremost, the construction schedule must be readable and easily understood by the field personnel who are involved in supervising the work. Too often, construction schedules are developed with excessive details that are of little value to the workers in the field. The schedule should only contain enough detail to enable the field supervisors to know what is expected of them. Then, area foremen in the field can develop a daily or weekly work schedule for their respective

work. For example, the schedule can show an activity of “second floor painting”; then the foreman of the paint crew can develop a daily work schedule that shows the specific rooms to be painted for the week specified in the construction schedule.

Material and equipment delivery dates are extremely important during construction because late delivery is often the cause of delays. Delivery dates for critical activities must be closely monitored to ensure arrival of materials and equipment when needed at the jobsite.

Problems with Construction Schedules

In some situations, a contractor may avoid giving any schedule to the owner with the concept that without a schedule, the owner cannot demonstrate that the contractor failed to properly plan or coordinate the work. An ancillary theory is that an absence of a schedule on the job allows the contractor to build an as-planned versus an actual schedule at the end of the job to serve the interest of the contractor for any disputes or claims.

One method of enticing the contractor to develop an appropriate construction schedule is to include the construction schedule as a specific pay item in the contract documents. Then, the contractor would be entitled to bill for this pay item only after submittal of the baseline schedule and each monthly schedule update. For example, submission of the construction schedule can be tied to the mobilization payment. Thus, the contractor would not be paid mobilization costs until the construction schedule is submitted. This is easy to incorporate in the construction contract because most contracts provide for mobilization payments to the contractor.

Unfortunately, in recent years there has been a trend toward using construction schedules to help build claims against the owner for additional time and cost. Some contractors prepare a schedule only because it is required in the contract. It is common practice in construction contracts to tie the costs to the schedule, which impacts the monthly payment to the contractor. Some contractors prepare a schedule based on the concept that it will help their chances of recovering more money and/or time from the owner in change orders and claims. Thus, the schedule is sometimes not used solely as a planning tool to manage the project, but as a tool to obtain additional time or money.

There are risks involved in requiring, reviewing, and accepting schedules from contractors. Approved or accepted schedules can produce legal implications to the owner. For example, the owner can be placed at risk when he or she accepts a schedule, because the schedule can later be used as documentation of claims against the owner. However, there is also a risk in not requiring construction schedules. When no schedule exists, the contractor may not plan the job properly and the owner has no way of measuring progress or checking on coordination. Most experienced construction managers agree that there are fewer risks when construction schedules are required.

Whoever is assigned the responsibility of reviewing or approving construction schedules should exercise caution because a number of problems can arise with respect to construction scheduling. Some of these precautions are presented in the following paragraphs.

Precautions for Construction Submittals

Submittals are documents that are transmitted from the contractor to the owner or designer for their review and/or

approval. Sometimes the contract documents specify that the engineer will review contractor submittals within a reasonable period of time so as not to delay progress on the work. Contractors usually show submittal review times in the schedule as 3 or 5 days. If the schedule is accepted, the time shown in the schedule establishes the definition of “reasonable period of time.” Any review that takes more time is then considered as “unreasonable” by definition, thus establishing a case for delay or impact claims.

In other situations, there may be no submittal dates shown in the schedule. Instead, the submittals are considered to start on the same day, or next day, of the construction activity. Then, the contractor can raise a delay claim for any time the start of an activity is delayed while the engineer reviews the submittal for that construction activity.

To avoid problems associated with submittal review times, a provision can be written in the contract documents that states the allowable time for submittal review. For example, a paragraph can be included that states the engineer shall have a minimum of 20 calendar days, from receipt of a submittal, to review and respond to a contractor’s submittal. Additionally, the contract documents can stipulate that resubmittal of the contractor’s submittals shall have the same review time as the initial submittal. This clarifies entirely the issue of whether the owner and engineer should have a single time frame in which to review the submittal and all resubmittals, or whether the starting time for submittal review should start over again with each resubmittal. This is an equitable assignment of the risk of providing unacceptable submittals.

A contract requiring submittal reviews be included in the construction schedule can help avoid many problems related to submittal reviews and the impact of review times. A provision can be included in the contract that stipulates

that the contractor prepare a construction schedule of all submittals required on the project, including when each submittal will be provided for review. This helps to ensure that the contractor has a plan for all submittals. It also allows the owner and engineer to plan their staffing and workload appropriately for the review process. A master list of all required submittals, provided by the designer, will assist in incorporating submittals in the schedule.

Delivery Dates of Owner-Furnished Equipment or Materials

It is common in the construction industry for owners to procure and furnish long lead-time equipment or materials. This is done to save time and money for the owner. The delivery dates of owner-furnished equipment or material are typically shown on the construction schedule. If the owner-furnished equipment or material delivery dates are shown on the schedule and the schedule is accepted by the owner, then this establishes an informal warranty that the items will be delivered no later than the date shown on the schedule. If the owner is unable to meet the previously scheduled and agreed-on delivery dates, then the contractor may file a claim for extra cost due to delay of work and impact claims.

Another problem can arise when the construction schedule shows very early delivery dates for all owner-furnished items. This provides more opportunities for a delay claim against the owner if the owner-furnished items arrive late. To help avoid this type of problem, the contract documents can stipulate the earliest possible delivery dates for all owner-furnished items. These dates can be based on delivery dates established by the manufacturer, plus an appropriate contingency for time. Another approach to addressing the issue of claims related to owner-furnished items is to make provisions in the contract documents that

states owner-furnished items will be delivered not earlier than a certain date but not later than another date. In this manner, the contractor is given some assurance of when to expect the items on the jobsite. Providing a window of expected delivery dates reduces risk related to owner-furnished items.

Scheduling Contractor Procured and Installed Equipment

The construction schedule that simply shows installation of equipment as one activity in the schedule does not provide an adequate description of the work necessary to procure and install the equipment. Major equipment that is procured and installed by the construction contractor should show fabrication, delivery, and installation as separate activities. This ensures adequate planning by the contractor and reduces confusion regarding fabrication and delivery times. It also clarifies the pay request from the contractor related to the equipment because the pay request for purchasing equipment will likely occur much earlier than the pay request for installing the equipment. The designer should specify in the bid documents which items of equipment are considered major.

Another method of assisting the proper planning and scheduling of contractor-furnished equipment is to include a provision in the contract that requires the contractor to provide a separate schedule that shows anticipated order and delivery dates of each piece of equipment on the project. The contract documents should specify which pieces of equipment are considered major, to prevent any misunderstandings. The payment terms for each piece of major equipment can be broken into parts aligning with the purchase and with the installation of each piece.

Contract Schedule Constraints

During the detailed design phase of a project, the construction contract documents may be written to include certain schedule constraints that require construction activities to be completed before other activities can start, or sequences that must be followed to prevent disruption of other activities. This type of situation is more prevalent in renovation-type projects than construction of new facilities. The contractor's initial schedule submittal may ignore these requirements. If the owner accepts the schedule without the constraints and then later attempts to enforce the contract requirements, the contractor may argue that the owner "waived the contract requirements" by acceptance of the schedule and therefore now owes an equitable adjustment in order to reestablish these constraints.

The owner and designer should carefully review all constraints to assess their impact on the contractor's operations. This must be done during the detailed design phase to ensure that a complete list of constraints is written into the contract documents. Constraints on the contractor usually result in additional costs and time for the contractor to complete the work.

Sequestering Float

Sequestering float is a technique of developing a construction schedule so there is little or no float for most activities. This results in a schedule with multiple critical paths or one single critical path with numerous other paths that are near critical because the noncritical paths have very small float, such as less than 5 or 10 days. Construction schedules with extensive sequestering float are sensitive to delays. Any interference with the contractor's operations by the owner increases the

opportunity for the contractor to bring claims for additional costs to the owner.

The construction schedule may also contain preferential sequencing, where activities that could be performed concurrently instead are shown as sequential. Showing activities sequentially instead of concurrently reduces float in the network, thereby causing more critical activities.

A careful review of the construction schedule should be performed to evaluate artificial activity durations. For example, an activity that is shown with a 20-day duration may actually only require 10 days, which would result in reduced float in the network.

To decrease problems related to sequestering float, the contract documents can include a nonsequestering float clause. Such a clause may read as, “Pursuant to the float sharing requirement of the contract documents the use of float suppression techniques such as preferential sequencing or logic, special lead/lag logic restraints, and extended activity times are prohibited, and the use of float time disclosed or implied by the use of alternative float suppression techniques shall be shared to the proportionate benefit of the owner and contractor.”

Schedule Updates

Too often, a good schedule at the beginning of a project becomes a schedule that is unmanageable due to poorly prepared updates. As changes occur during construction, there is a tendency to use constraints to model the actual work. The use of activity constraints such as start-to-start and finish-to-finish almost invariably cause logic that is difficult to understand and often leads to confusion and distrust of the schedule.

It can be helpful to involve the owner, designer, contractor, and all major subcontractors to review the

update process. A joint discussion between all parties will enhance communications and reduce surprises when the schedule updates are provided. The discussions can often eliminate the activity constraints. The best approach is to not use activity constraints in developing the original schedule or in preparing schedule updates.

Relations with Contractors

Construction contractors have the lead role during the construction phase; however, the owner and designer have an important role as well. A cooperative environment of teamwork must be developed so all parties can work together as a unit to achieve the project.

The construction industry is unique compared to other industries. Because each construction project is different, the work force is transient, multiple crafts are involved, projects are planned and worked in short time frames, and there is a tremendous variety of material and equipment that must be installed. Also, much of the work is exposed to weather and construction workers are continually working themselves out of a job. Due to these conditions, the management of construction is a challenge, and cooperation of participants is imperative.

In all situations, the relations with contractors must be fair, consistent, polite, and firm. A person must conduct his or her affairs in a professional manner to gain the respect of others and to get others to do what must be done. There are times when a person must be assertive, but not obnoxious, and other times when a person must be reserved, but not a pushover. The ability to work with people and to know how to react in each situation must be developed in order to work in a construction environment.

Due to the nature of construction projects, there are times when disagreements and conflicts between

individuals arise. One must realize that disagreements and conflicts are not necessarily all bad because many good ideas have been developed as a result of disagreements. The attitude that should prevail is that disagreements can be changed to agreements with diplomacy. There are times when it may be desirable to take a neutral position.

Contractors are independent business organizations and are only required to produce the end product of the contract. There are times when a contractor and an owner may not agree; however, achievement of the end product should always remain a priority. Good owner/contractor relationships make the best use of the contractor's expertise, labor, and equipment.

Checklist of Duties

Table 12-3 provides a comprehensive checklist of duties for the construction phase of a project that is handled by the CM type of contract. For projects other than the CM type of contract, the duties of the CM are distributed between the owner and the designer, depending on the contract arrangement.

Construction Phase		Owner	CM	Designer*	Contractor
1	Contracts: Construction	Approve, execute, enforce as required	Prepare documents, enforce	Review, approve	Approve, execute, conform
2	Meetings: Pre-construction	Participate as required	Organize, conduct, record	Participate	Participate
3	Meetings: Monthly project	Participate	Organize, conduct, record	Participate	Participate
4	Meetings: Monthly team	Participate	Organize, conduct, record	Participate	X
5	Insurance: Workers compensation	Specify, approve	Advise, monitor, file certificates	Include requirement in bid documents	Provide
6	Submittals: Shop drawings & samples	Approve as required	Coordinate, expedite, & review	Specify submittals required, review & approve	Provide
7	Scheduling: Short-term construction activities plan	Approve as required, comply	Prepare, monitor, enforce, comply	Participate, comply	Participate, comply
8	Schedule enforcement	Participate as required	Provide	Assist	Comply
9	Construction support items	Approve as required & pay	Recommend & arrange	Advise	Cooperate
10	Security: Site	Advise, review, approve, pay	Advise & arrange for	Facilitate	Facilitate
11	Field layout	Observe	Coordinate, check where practical	Design, observe	Provide & be responsible
12	Temporary: Power, water, roads, etc.	Approve, pay	Determine need, arrange & coordinate	Provide specifications as required	Use
13	Meetings: Weekly construction	Participate as required	Organize, conduct, record	Participate as necessary	Participate
14	Construction methods, procedures	Observe	Observe	Observe	Originate
15	Contractor coordination	Observe	Provide	Advise	Facilitate
16	Field reporting	Review	Provide, review	Provide, review	Cooperate
17	Jobsite safety	Enforce through CM	Observe, report	Observe, report	Responsible
18	Payment requests	Approve, respond	Review, approve, assemble	Review, approve, endorse	Submit
19	Waivers of lien	Review & file	Coordinate, review, & assemble	Review	Provide
20	Change orders	Approve, execute	Request, review, approve, distribute	Request, prepare, approve	Execute, respond
21	Quality control	Observe	Observe, evaluate, report	Observe, evaluate	Provide, be responsible
22	Field testing	Approve, pay	Arrange, coordinate	Recommend, approve	Cooperate
23	Expediting: Construction	Participate as required	Originate, monitor, motivate	Advise, assist	Responsible
24	Equipment: Owner purchased	Specify, purchase, expedite	Coordinate scheduling, installation & start-up	Incorporate requirements into design	Hook-up
25	Expediting: Owner purchased equipment	Provide	Coordinate scheduling requirements, assist	Advise	X
26	Receiving equipment	Inspect & approve	Coordinate on-site delivery & storage requirements	X	Assist
27	Drawings: As-builts	Receive & file	Coordinate, monitor	Check, draft	Provide as-built

Source: NSPE/PEC Reporter, Vol. VII, No. 2.

*The referenced NSPE/PEC publication cited "architect"; however, the term "designer" is used here to imply the architect may be the principal design professional for building projects, whereas the engineer may be the principal design professional for heavy/industrial projects.

TABLE 12-3 Checklist of Duties during Construction Phase

Quality Control

Quality is achieved by people who take pride in their work and have the necessary skills and experience to do the work. The actual quality of construction depends largely on the control of construction itself, which is the principal responsibility of the contractor. What is referred to today as “quality control,” which is a part of a quality assurance program, is a function that has for years been recognized as the inspection and testing of materials and workmanship to see that the work meets the requirements of the drawings and specifications.

Quality is the responsibility of all participants in a project. Too often, the attitude is “what can we do to pass quality control?” or “what can we do to get past inspection?” Instead, the attitude should be, “what can we do to finish the project that we can be proud of that meets the specifications and satisfies the owner?” Without the right attitude, even the best planned quality-control program cannot be successful.

In the past, the traditional acceptance of construction work by the owner, or owner’s representative, involved 100% visual inspection of the construction work. In addition, a so-called representative sample, which often consists of a single specimen, is used to determine the true quality of the material. If the test result is within the stated tolerance, the material passes and is accepted, otherwise the material or construction fails to pass and is unacceptable. In the latter case, engineering judgement is then applied to reach a decision as to whether the material should be retested or whether it may be said to substantially comply, because the deviation will not cause a serious impairment to performance. This places the inspector in a difficult situation and can cause delays, disputes, and numerous problems for both the owner and contractor.

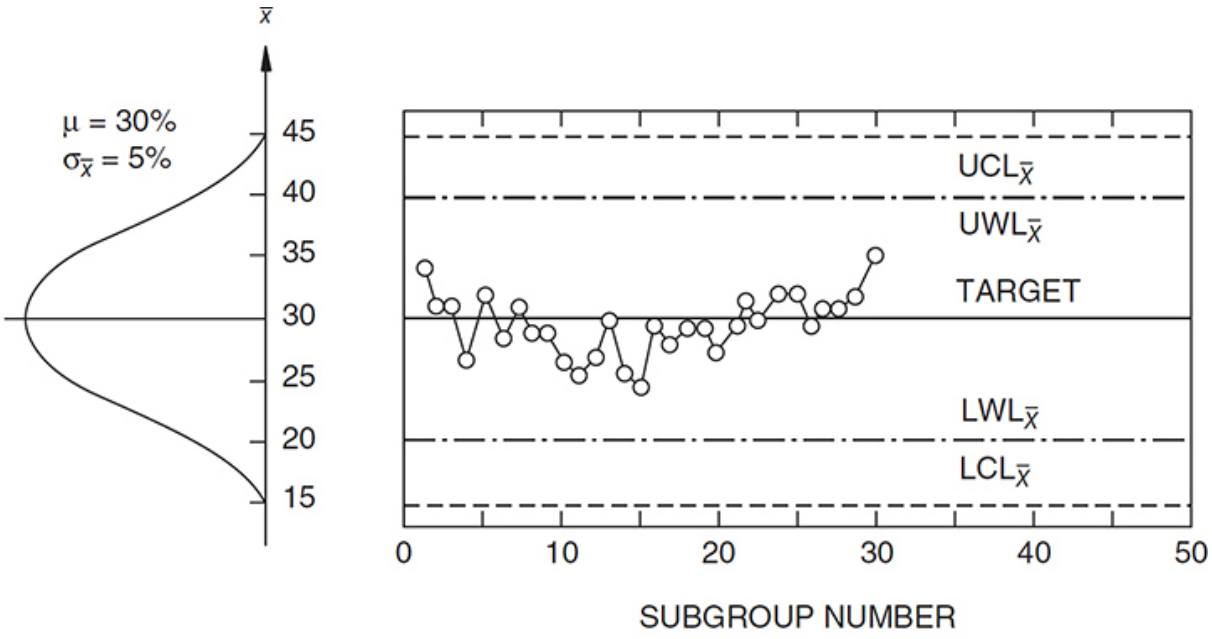
The purpose of quality control during construction is to ensure that the work is accomplished in accordance with the requirements specified in the contract. A program of quality control can be administered by the owner, designer, contractor, or an independent consultant. In recent years, the trend by many owners is to require prime contractors to take a more active role in the control of project quality by making them manage their own quality-control programs. The contractor is required to establish a quality-control plan to maintain a job surveillance system of its own, to perform tests and keep records to ensure the work conforms to contract requirements. The owner then monitors the contractor’s quality-control plan and makes spot-check inspections during the construction process, which constitutes a quality-assurance program.

In modern quality-assurance programs, traditional specifications are being replaced by statistically based specifications that reflect both the variability in construction materials and the true capabilities of construction processes. Quality requirements are expressed as target values which contractors are to accomplish, and compliance requirements are specified as plus or minus limits. Statistically based acceptance plans call for random samples, with each sample consisting of a number of specimens taken at random in order to eliminate bias. Acceptance procedures are more detailed and the risks to both the owner and contractor are made known to reduce uncertainty.

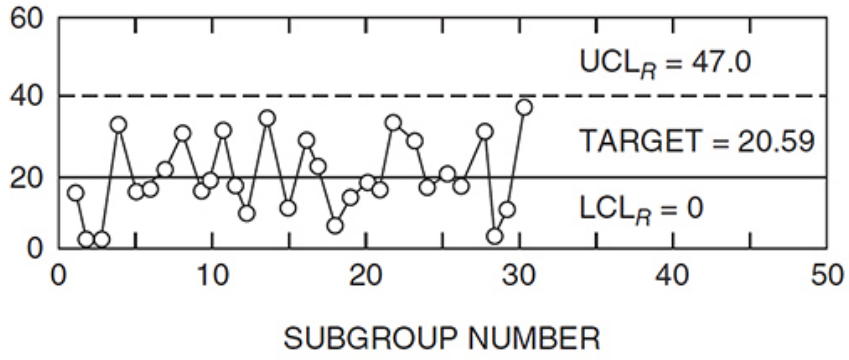
Each contractor is expected to have a process control program that will ensure they are meeting the acceptance requirements of the owner. Control charts, which are simple line graphs of the target quality level and of the allowable variations from this level, are used as tools in the process control. They provide early detection of trouble before rejections occur, which can result in savings to the

contractor by reducing penalties and rework costs. Thus, control charts present the results in a form that enables everyone concerned to observe trends or patterns that may affect quality.

An example of a control chart for a percent passing gradation is given in Figure 12-3. Figure 12-3*a* is referred to as an *X*-chart and is used to monitor the average value of the process, that is, whether the process average has remained at a constant level or has shifted. The horizontal axis identifies the number of observations; that is, the number 1 is the first inspection, and the number 30 is the last inspection. The vertical axis represents the quality characteristic under consideration, which in this case is the percent passing a given sieve size. Each small circle represents the average value of that sample, or subgroup. The two dashed outer lines are the Upper Control Limit (UCL) and Lower Control Limit (LCL), which are used to judge the significance of a change in the process. It is also possible to place Upper and Lower Warning Limits, (UWL) and (LWL). Warning limits are typically placed at two standard deviations from the target value. The second control chart, Figure 12-3*b*, is called the *R*-chart (range) and is used to detect changes in the process variability.



a. $\bar{X}$ CONTROL CHART FOR PERCENT PASSING



b. *R* CONTROL CHART FOR PERCENT PASSING

FIGURE 12-3 Control charts for (a) $\bar{X}$ and (b) *R*.

Dispute Resolutions

Due to the nature of construction projects, it is almost certain that contractors, owners, and designers will be involved in disputes. The resolution of a dispute may be by several methods: negotiation, mediation, arbitration, or litigation.

Direct negotiations between parties in the dispute can be held to openly discuss and resolve the conflict to the satisfaction of each party. Usually, no other parties are involved. Mediation allows disputing parties to use an independent, objective person to assist in resolving the dispute. The mediator has no authority to issue a final decision. Arbitration is similar to mediation except the arbitrator has the authority to issue a final binding decision that cannot be appealed by the disputing parties. For some disputes, there may be a panel of arbitrators to resolve the dispute. Litigation is a resolution of disputes by lawsuits that are resolved through legal formality in the court system. Generally, this technique requires a long period of time and significantly higher legal costs than the other techniques.

The resolution of disputes by negotiations is usually the quickest and most economical technique because factual matters are discussed without the formality of legal formats. Direct negotiations are held on a voluntary informal basis by the parties involved, at a mutually agreed on time and location. The negotiator for each party must have the authority to act for his or her company. The size of the negotiating teams varies depending on the complexity of the issue; however, the efficiency is generally higher if there are fewer individuals involved. The success of the negotiations depends on the willingness of both parties to negotiate in good faith, the extent the contract definitively addresses the issues in the dispute, and the amount of preparation prior to negotiation. Direct negotiations can enhance good business relationships between the parties.

In the event that direct negotiations cannot result in a settlement, mediation is often the next most suitable method. Similar to negotiation, mediation is voluntary, so there must be a mutual agreement between both parties to have the mediator to serve as a catalyst to explore alternate solutions, to gather facts and clarify discrepancies, and to

persuade the parties to adopt flexibility in their stances so a final settlement can be reached. During the process, the mediator may have joint or private meetings with the disputing parties. The mediator is mutually agreed upon by both parties in the dispute. The American Arbitration Association (AAA) is a public-service, nonprofit organization that has established guidelines and rules for mediation.

Arbitration is the submission of a dispute to a mutually agreed upon impartial third party whose decision is legally binding and enforceable. To use this method, an arbitration clause is normally included in the general conditions of a contract, so when the contract is signed, the parties mutually agree to settle all disputes through arbitration. The Construction Industry Arbitration Rules, established by the AAA, contains 57 articles that have become the most widely recognized arbitration procedures in the construction industry. The procedures follow a five-step process: agreement to arbitrate, selection of arbitrator, preparation for hearing, hearing of the dispute, and the award. The decision by the arbitrator is usually made within 30 days from the close of the hearing. Thus, decisions are made much faster than through litigation.

Most parties strive to resolve conflicts before proceeding to litigation because it is the costliest, time-consuming, and complex method for the resolution of disputes. Legal counsels, who follow the formalities of the legal judicial system, are used to represent the interest of the parties. The final resolution of the dispute is determined by a court of law. Often, a settlement of the dispute is reached just prior to entering court proceedings.

The American Society of Civil Engineers has produced a booklet entitled *Avoiding and Resolving Disputes During Construction*, which presents a method of developing cooperative, problem-solving attitudes on projects, through a basic risk-sharing philosophy between the owner and

contractor. It explains special contracting provisions and practices that have been used successfully on hundreds of projects to avoid or to resolve disputes without resorting to litigation. There are three provisions: Dispute Review Boards (DRB), Escrow Bid Documents (EBD), and Geotechnical Design Summary Reports (GDSR), which are described in detail and recommended on all projects subject to potential major disputes.

Formation of a three-member DRB at the beginning of construction assists in avoiding disputes and, if necessary, provides timely and equitable recommendations for nonbinding resolutions. Escrowing of the contractor's bid documents provides a reliable database for use in negotiating price adjustments and resolving disputes. Inclusion of the Federal Differing Site Conditions clause and a GDSR in the contract acknowledges the contractor's right to compensation for materially differing site conditions and establishes a concise geotechnical baseline to clearly identify differing site conditions. These provisions are discussed in the booklet, together with guideline specifications for implementation.

Jobsite Safety

Safety is an important part of project management just as are planning, scheduling, estimating, cost control, and other project work. The concern for safety must be shown at all levels and in each phase of the project. Accidents not only affect workers, but also their families. The economic costs, liability consequences, regulatory requirements, and the image of a company all show the importance of safety related to a project.

Many of the basic principles and approaches that have been previously presented to manage a project can also be applied to safety. The element of safety is a factor that

should be considered in each phase of the design and construction of a project. Safety is not included in a project by accident; it must be designed into the project and monitored just like scope, budget, and schedule.

Construction, by the nature of the work, involves many potential hazards to workers and equipment, such as heat, noise, wind, dust, vibrations, and toxic chemicals. The Occupational Safety and Health Administration (OSHA) was enacted by the federal government as a regulatory agency to ensure safety for workers. It applies to all parties involved in a project: designers, owners, workers, and contractors. Although OSHA and other legislation has been enacted for safety, the responsibility rests with management.

The project manager must work closely with his or her team members to include safety in every aspect of the project: planning, design, budget, and construction. Safety should start at the top level of an organization and, by words and actions, be infused in each level of management through to the crews and workers at the jobsite.

Although the current practice places final responsibility for construction safety with the contractor, there should be a united teamwork approach to understanding and implementing a safety philosophy that improves construction jobsite safety.

Accident costs include medical costs, premiums for compensation benefits, liability, and property loss. These costs have been escalating in recent years. However, there are other significant costs attributed to accidents. These include the cost of lost time of the injured employee, the cost of work stoppage of other employees due to an accident, and the lost supervisory time. Safety requires everyone’s full attention. Research has shown that safer jobsite managers are also the better producers.

They are better at keeping down job costs and better at keeping jobs on schedule. These facts contradict two

reasons that managers sometimes give as excuses for a poor safety record: accidents are inevitable in a dangerous industry like construction, and the first priority has to be getting the job done. Such managers are misled by myths that can cost the project and the company a great deal of money. Jobsite safety management should treat productivity and safety as two related parts of high job performance. A successful jobsite manager has been quoted as “You don’t have to sacrifice productivity for safety. The safer the crew, the quicker they work. The more safety you have, the more productivity you have.”

The prequalification of contractors is usually based on bonding capacity and past experience. The selection of the construction contractor usually is based on the lowest bid price of all prequalified contractors. A contractor’s safety record should also be considered as a necessary part of construction bids so an unsatisfactory safety record could be one possible basis for rejection of a bid.

Management of Changes

Every project requires some changes during construction in order to complete the project. The source of changes may be the owner, designer, or contractor. An owner may wish to make a change to better achieve his or her intended use of the project after construction is complete. A designer may make a change in the original plans or specifications, or the contractor may wish to make a change, because it is not always possible to accurately predict all the events that will arise during the construction process. Thus, changes during construction are almost inevitable.

The mechanism for making changes during construction is the change-order, a written document that describes the modification in the work. This mechanism should be clearly described in the contract. All approved change-orders are

incorporated into the original bid documents to form the binding contract documents for the project. Although a change-order may increase or decrease the cost and/or schedule of a project, most change-orders add cost to a project and impact the schedule. Thus, every project manager must be cautious in dealing with changes during construction because a change in the work almost always adversely affects the cost and schedule of the project.

The management of changes is greatly enhanced if the changes can be predicted in advance. There are some factors that can be determined, prior to commencing construction, that are early warning signs of future changes in a project. Research has shown that lump-sum projects that have a large difference between the low bid and next higher bid amount tend to have significant increases in project costs. In the construction industry, the term *money-left-on-the-table* is commonly referred to as the difference between the bid amount of the low bidder and the next higher bidder. Thus, a project manager should expend more effort in monitoring and controlling a project if there is high money-left-on-the-table, because it is an indicator of potential cost growth.

One approach to the management of changes during construction is to request a list of anticipated change-orders on a monthly basis. The project manager, or his or her assistant, then works with the party anticipating the change, to evaluate the need and/or value of the change. Sometimes a candid discussion of the merits of a change can result in a decision that the change is not necessary once the full impact of the change is compared to the true value of the change.

There must be a thorough evaluation of all aspects of a change because a change in any part of a project often affects other parts of a project. Sometimes the full impact on other parts of a project is not known until some later

date, which can adversely affect the cost later in the project. The term *ripple-effect* is commonly used to describe a change that occurs late in the project as a result of a change made earlier in the project.

A project manager should avoid changes during construction unless they are absolutely necessary. If a change is necessary, it should be thoroughly evaluated, clearly defined, agreed on by all parties, and implemented in the most efficient and economical manner.

Resource Management

Many resources are needed to accomplish the construction phase of a project. Resources include people, equipment, materials, and subcontractors. Each resource must be managed in the most efficient manner to keep costs to a minimum during construction.

The crafts that install material and operate equipment are the most important resource on the project. These individuals gain their skills through training and experience. They have the ability to accomplish the work, provided adequate instruction, tools, and materials are available when they are needed. Too often, the skilled workers are criticized for not producing good work on a project. However, it is not a trait of people to intentionally do poor work. The cause of poor work is usually from poor instructions, late delivery of material, unavailable tools, or lack of leadership and supervision. These sources of problems are the responsibility of management on the project. Thus, there must be a well-defined work plan for the project that clearly defines the work that must be accomplished today and the work that is planned ahead. This plan must be communicated to the teams of crafts on the project.

The type and number of equipment used on a project depends on the nature of the project. For example, construction of a large earthen dam may require a large spread of scrapers, dozers, water wagons, compactors, and motor patrol graders. However, the construction of a strip shopping center may only need a small front end loader, truck, and small portable crane. The selection and utilization of equipment on a project must be an integral part of the total construction plan and schedule, just as there must be a plan for the workers on the project. It is the responsibility of the construction project manager and his or her field superintendent to develop an equipment plan for the project. Adequate consideration should be given to the down-time and maintenance of equipment because the unavailability of equipment can have a significant impact on the schedule of a project.

A major cost of many construction projects is the acquisition and installation of materials. A materials management system includes the major functions of identifying, acquiring, storing, distributing, and disposing of materials needed in a construction project. The effective utilization of people can be greatly enhanced by ensuring that quality materials are available when and where required. A material plan will vary depending on the project size, location, cash flow requirements, and the procedure for purchasing and inspection. The timing of material delivery to the jobsite is extremely important because the cause of delays during construction is often late delivery of material, incomplete delivery of material, or delivery of the wrong type of material. Materials requiring a long lead time must be included in the construction project schedule. It is the responsibility of the contractor to ensure that a well-defined materials management system and materials management plan are developed for the project.

For most projects, the owner assigns one contract to a prime contractor, usually called the general contractor, to accomplish the construction phase of a project. In turn, the general contractor assigns contracts to numerous subcontractors, usually called specialty contractors or subs, to perform the construction work that requires special skills or equipment. Thus, much of the work required on many construction projects is performed by numerous subcontractors who work for the general contractor. This multiple-contract arrangement requires careful planning, scheduling, and coordinating by the general contractor to integrate the work of all subcontractors on the job. This is necessary because the work of any subcontractor usually affects one or more other subcontractors on the project. The owner may use multiple prime contractors for a large project that extends over a long period of time.

The management of subcontractors should be accomplished using the same management principles presented throughout this book. There must be a well-defined scope of work, cost, and schedule for each subcontractor on the project. In addition, there must be a clear interfacing of the work of all subcontractors on the project. It is the responsibility of the general contractor to effectively manage his or her subcontractors.

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CHAPTER 13
Monitoring and Reporting

Control Planning

Effective project management requires planning, measuring, evaluating, forecasting, and controlling all aspects of a project: quality and quantity of work, costs, and schedules. Project control begins at the start of the phase. For example, planning for project control during Detailed Scope phase begins in the Alternative Analysis/Conceptualization phase. Control planning for Detailed Design and Construction phases is done during Detailed Scope and is part of the project execution plan (PEP). Project control is an extensive and detailed function within project management. The material presented in this chapter explains the basic principles of project control as it relates to performance analysis.

An all-encompassing project execution plan (PEP) including a project control plan must be part of the project authorization package. Without a project plan, no basis for control exists. Project tracking cannot be accomplished without a well-defined work plan, budget, and schedule as discussed in the previous chapters of this book. The project control plan is an essential section in the PEP. The project control plan contains the approach and processes to be used for controlling the project. It provides the control accounts that integrate cost, schedule, resources, risk, and procurement. It includes the Work Breakdown Structure

(WBS) directory and describes to what level work will be managed. It lists control reports, progress measurement periods, and baselines for cost and schedule. The project control plan should define the process for identifying, logging, and approving changes to the project.

Since the project plan is developed with input from people who will be performing the work, and communicated to those participants, the control components should make sense to them. The tasks, costs, and schedules of the project plan establish the benchmarks and checkpoints that are necessary for comparing actual accomplishments to planned accomplishments, so the progress of a project can be measured, evaluated, and controlled. The project control plan must strike a balance on the level of detail for monitoring and control.

At the end of any reporting period (N), a project is expected to have achieved an amount of work (X) with a level of quality (Q) at a predicted cost (C). The objective of project control is to measure the actual values of these variables and determine if the project is meeting the targets of the work plan, and to make any necessary adjustments to meet project objectives. Project control is difficult because it involves a quantitative and qualitative evaluation of a project that is in a continuous state of change. Project control requires forethought, detailed plans, and discipline.

To be effective, a project control system (set of processes) must be simple to administer and easily understood by all participants in a project. Control systems tend to fall into two categories; they are either so complex that no one can collect and update the progress information much less interpret the results that are obtained; or they are too limited or meaningless because they apply to only costs or schedules rather than integrating costs, schedules, and work accomplished. A control system must be developed so information can be routinely collected, verified, evaluated,

and communicated in a timely fashion to all participants in a project; so, it will serve as a tool for project guidance and correction rather than reporting flaws that irritate people.

A well-defined Work Breakdown Structure (WBS) forms the essential nucleus of an effective project control plan. The smallest unit in the WBS is a work package, which defines the work in sufficient detail so it can be measured, budgeted, scheduled, and controlled. The project control account ties directly to the work package and integrates the project control components of cost, schedule, resources, procurement, and risk. After developing a thorough and comprehensive WBS that describes 100% of the work, the project manager and project controls lead should develop the control accounts for the project.

The Critical Path Method (CPM) is used to develop the overall project schedule from the WBS by integrating and sequencing the activities contained in the work packages. To control costs, the WBS is linked to the Cost Breakdown Structure (CBS) by the control accounts. Likewise, the WBS is linked to the Organizational Breakdown Structure (OBS) to coordinate personnel to keep the project on schedule. Control accounts allow sorting of information to produce a variety of reports that are subsets of the entire project.

This general concept of project control was presented by the Department of Energy for federal and energy projects. Since that time, several modifications have been suggested to simplify the process of transferring information from the WBS to the CPM, linking the WBS and OBS to the coding system, and measurement of work accomplished.

Linking the WBS and CPM

The work packages of the WBS provide the information necessary to develop a CPM logic network diagram. With a well-defined detailed WBS, a single work package often

becomes one activity on the diagram. However, sometimes it is necessary to combine several work packages into a single activity or to divide a single work package into several activities. The process of developing the CPM diagram requires good judgement with extensive involvement of key participants in the project. Although the level of detail should be kept to a minimum, all activities that may influence the project completion date must be included in the diagram.

A CPM diagram for project scheduling and control can be classified as one of three types: design, construction, or engineering/procurement/construction (EPC). For each, the WBS defines the project framework for planning, scheduling, and control of the work. The level of detail of the CPM diagram depends on the completeness of the WBS.

The products of design are calculations, production drawings, and specifications. As discussed in Chapter 10, a bar chart is frequently preferred for scheduling individual design activities. However, for effective scheduling control of the whole project, a composite of the individual bar charts must be integrated into a CPM diagram that shows the interrelationship and sequencing of related work. Thus, a CPM diagram for design is often a summary level schedule. CII Publication 6-1, *Project Control for Engineering*, provides a good description of current industry practice of scheduling and control of design.

CPM logic diagrams have been successfully used for scheduling and control of construction for many years. A detailed WBS can be developed as a cooperative effort of the estimating, project control, and field operations management personnel. The estimate must be prepared so that costs, durations, and resources can be assigned to work packages in the WBS. The work packages then become activities on the CPM diagram. The purchase and delivery of long lead-time material must also be included in the

diagram. In addition, the work performed by subcontractors on the job must be integrated with other work to form a complete integrated CPM diagram. For large projects, a separate CPM diagram can be prepared for each individual area of the project; then a master CPM diagram can be developed that links the individual area diagrams.

The CPM diagram for an EPC project must interface the design work packages with the procurement and construction activities. It is often best to develop separate individual working schedules for design, procurement, and construction. Then link the individual schedules into a summary EPC schedule that integrates the total system. It is imperative to sequence all related activities that may influence the completion date of the project.

To illustrate the linking of the WBS to the CPM, the WBS shown in Figure 13-1 is used to develop the CPM diagram in Figure 13-2. This EPC project is an expansion of the design project presented in Chapter 10, to now include the procurement and construction activities. It is a service facility for maintenance operations and consists of site work, on-site utilities, an employee's office building, and a maintenance building. To handle this project, the contracting strategy is to use in-house personnel to design the on-site utilities, site work, and the maintenance building. A separate contract is assigned for design of the employee's building. The maintenance building is denoted as Building A and the office building as Building B on the WBS and CPM.

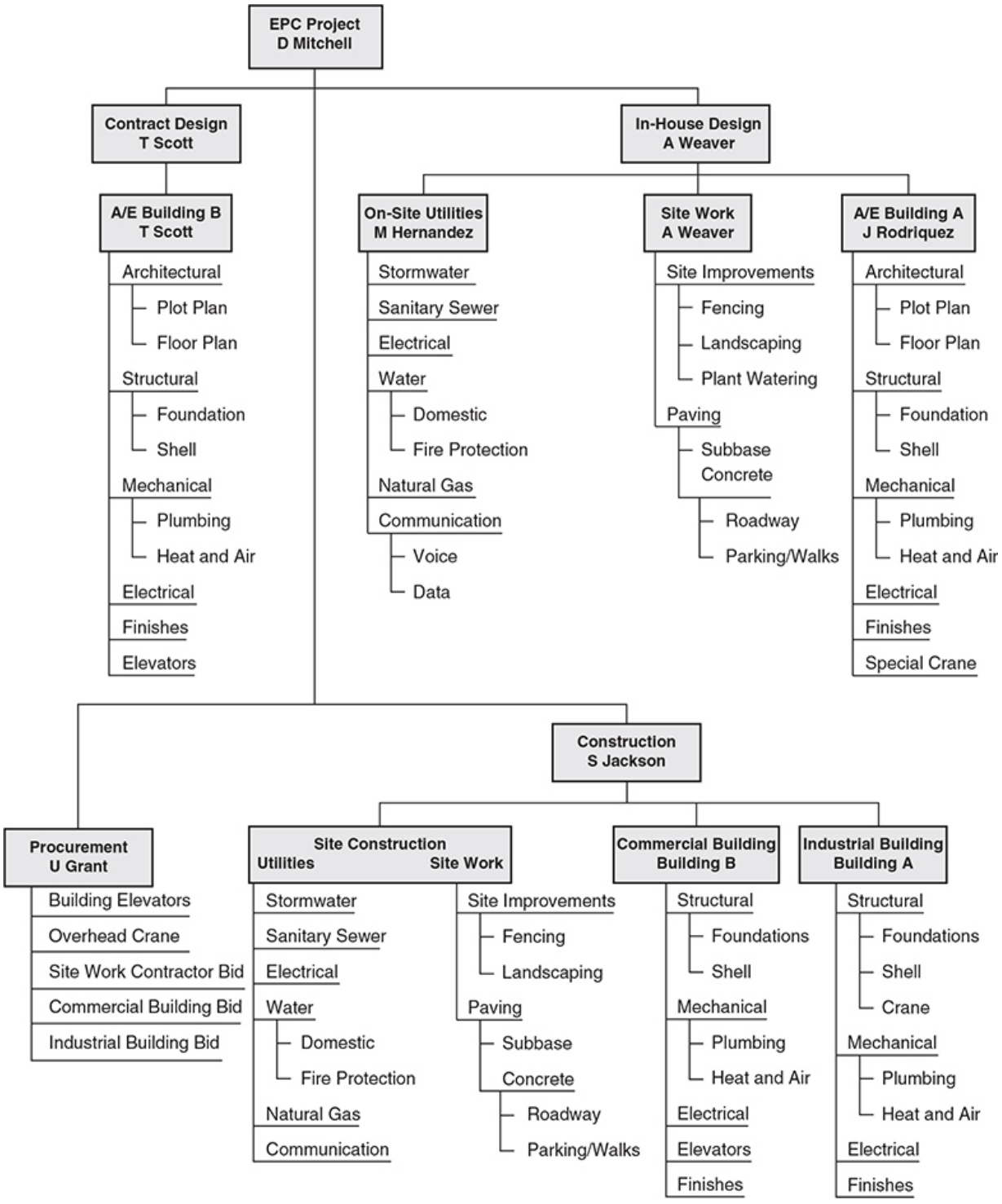


FIGURE 13-1 WBS for EPC of service facility project.

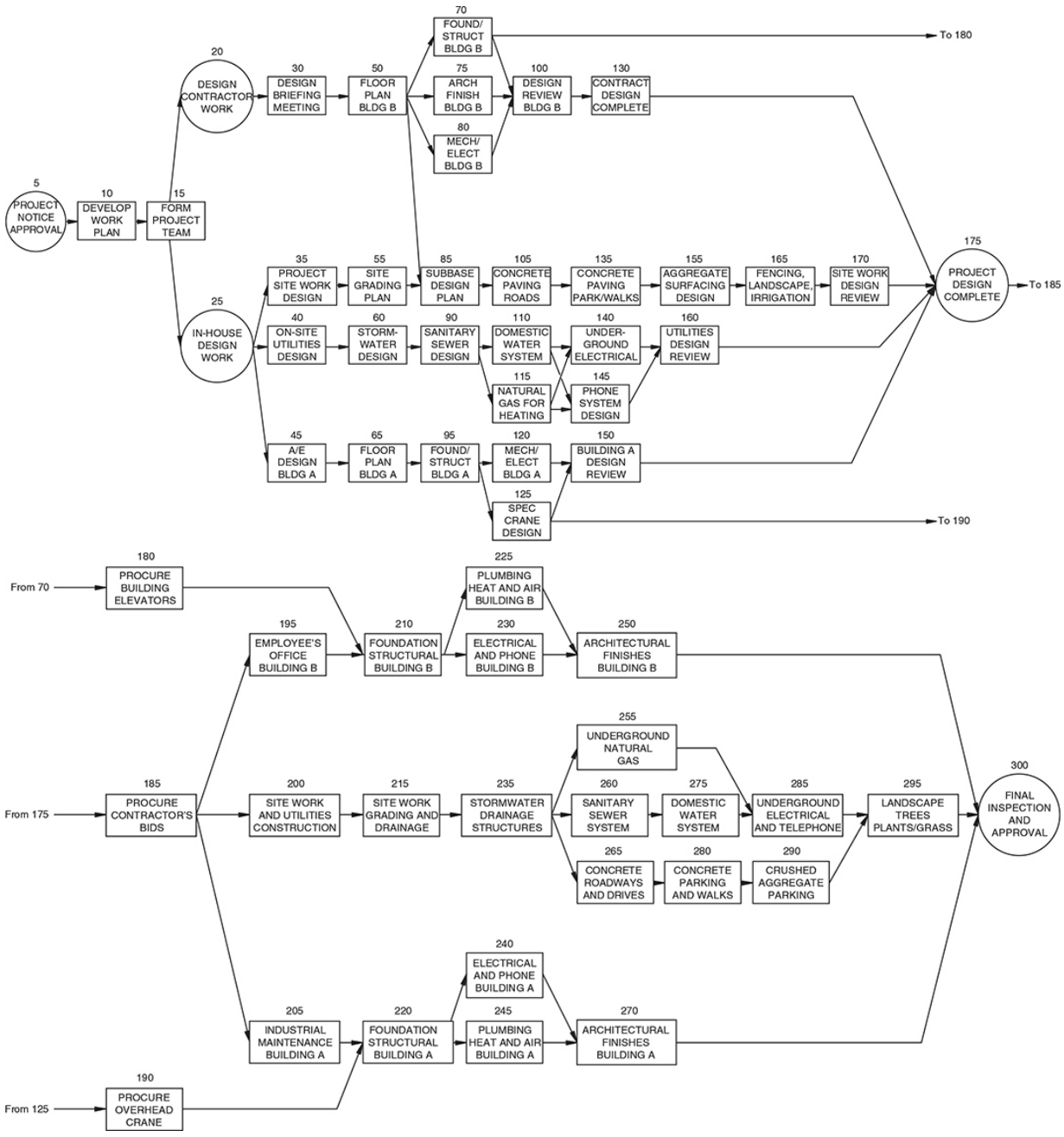


FIGURE 13-2 CPM diagram for EPC project.

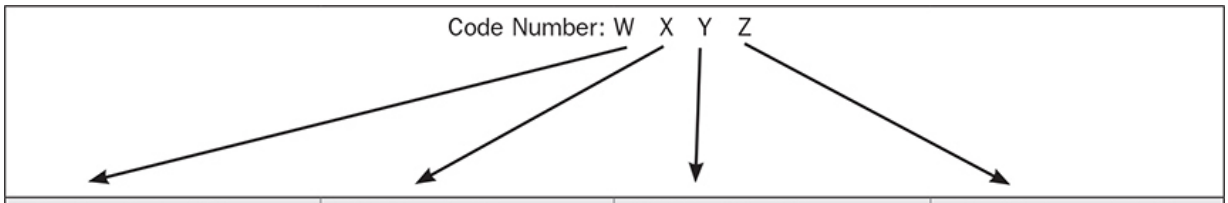
The contracting strategy for construction is to assign one contract to a heavy construction contractor to build all on-site utilities and site work activities. Two building contractors will be used: one for the office building and the other for the industrial maintenance building. The construction activities are limited on the EPC schedule but will be expanded into

more detail by each construction contractor as a part of his or her contractual requirements.

As shown in Figure 13-2, the appropriate design activities are directly linked to the procurement activities for materials and equipment. For example, the design of the overhead crane for Building A is followed by procurement and then construction. Likewise, design of the elevator for Building B is linked to the respective procurement and construction activities.

Coding System for Project Reports

The coding system developed for the project should be appropriate for the size and scope of the project. It should be able to identify each controlled component of the project to allow for sorting of information in order to produce a variety of reports for project monitoring and control. For example, a code number can be assigned to each work item that identifies a variety of information, such as, phase of project, type of work, responsible person, or facility of which the work item is a part. Table 13-1 illustrates this with a simple four-digit coding system for the project shown in Figure 13-2.



Digit 1—Project Phase	Digit 2—Facility	Digit 3—Discipline	Digit 4—Team Member
0—Unassigned	0—Unassigned	0—Unassigned	0—Unassigned
1—Engineering—internal	1—Grading/subbase	1—Architectural	1—D Mitchell
2—Design—contract	2—Concrete paving	2—Civil	2—T Scott
3—Procurement—vendor	3—Aggregate parking	3—Structural	3—A Weaver
4—Procurement—contract	4—Stormwater sewer	4—Mechanical	4—M Hernandez
5—Site work construction	5—Sanitary sewer	5—Electrical/voice & data	5—J Rodriquez
6—Office building	6—Underground utilities	6—Landscape	6—U Grant
7—Industrial building	7—Building A	7—Project engineering	7—S Jackson
8—Unassigned	8—Building B	8—Unassigned	8—Unassigned
9—Unassigned	9—Landscape	9—Unassigned	9—Unassigned
WBS		OBS	

TABLE 13-1 Coding System for the Project in Figure 13-2

Table 13-1 can be used to assign a code number that is unique to each activity in the CPM diagram of Figure 13-2 to link the WBS to the OBS and CPM. For example, Activity 95 (Design of Foundations and Structure for Building A) is assigned the code number of 1735. This code identifies the activity as the in-house structural engineering for Building A involving structural design that is the responsibility of team member J. Rodriquez. Table 13-2 is a list of the code numbers assigned to each activity in the project.

No.	Code	Activity Description	Duration	Cost	Team Member
5	0071	Project notice approval	3	$7,500	D Mitchell
10	0071	Develop work plan	7	$180,000	D Mitchell
15	0071	Form project team	5	$12,750	D Mitchell
20	2872	Design contractor's work	2	$45,000	T Scott
25	1073	Internal design work	3	$22,500	A Weaver
30	2872	Design briefing meeting	1	$18,000	T Scott
35	1073	Project site work design	1	$21,000	A Weaver
40	1624	On-site utilities design	1	$18,000	M Hernandez
45	1715	A/E design building A	1	$22,500	J Rodriquez
50	2812	Floor plan building B	10	$148,500	T Scott
55	1123	Site grading plan	12	$210,000	A Weaver
60	1424	Stormwater design	10	$30,000	M Hernandez
65	1715	Floor plan building A	15	$390,000	J Rodriquez
70	2832	Found/struct building B	45	$468,000	T Scott
75	2812	Arch finishes building B	30	$742,500	T Scott
80	2842	Mech/elect/voice/data building B	45	$559,500	T Scott
85	1123	Subbase design plan	5	$60,000	A Weaver
90	1524	Sanitary sewer design	10	$180,000	M Hernandez
95	1735	Found/struct building A	30	$1,390,500	J Rodriquez
100	2871	Design review building B	10	$120,000	D Mitchell

No.	Code	Activity Description	Duration	Cost	Team Member
105	1223	Concrete paving roads	20	$180,000	A Weaver
110	1624	Domestic water systems	7	$135,000	M Hernandez
115	1624	Natural gas system	8	$90,000	M Hernandez
120	1745	Mech/elect/voice/data building A	30	$333,000	J Rodriquez
125	1735	Special overhead crane	11	$162,000	J Rodriquez
130	2872	Contract design complete	1	$15,000	T Scott
135	1223	Concrete paving parking/walkways	10	$105,000	A Weaver
140	1654	Underground electrical	14	$180,000	M Hernandez
145	1654	Underground voice and data	4	$45,000	M Hernandez
150	1771	Design review building A	3	$75,000	D Mitchell
155	1323	Aggregate surfacing design	8	$90,000	A Weaver
160	1677	Utilities design review	1	$16,500	D Mitchell
165	1963	Fencing/landscape/irrigation	14	$420,000	A Weaver
170	1071	Site work design review	5	$105,000	D Mitchell
175	0071	Project design complete	1	$15,000	D Mitchell
180	3876	Procure building elevators	25	$1,425,000	U Grant
185	4076	Tender for bids	20	$105,000	U Grant
190	3776	Procure overhead crane	40	$825,000	U Grant

195	6887	Employee offices building B	3	$15,000	S Jackson
200	5087	Site work/utilities construction	4	$22,500	S Jackson
205	7787	Industrial/maintenance building A	2	$21,000	S Jackson
210	6882	Foundation/struct building B	45	$2,925,000	T Scott
215	5083	Site work/grading/drainage	18	$1,275,000	A Weaver
220	7785	Foundation/struct building A	110	$5,850,000	J Rodriquez
225	6882	Plumbing/HVAC building B	75	$4,275,000	T Scott
230	6882	Electrical, voice, data building B	60	$3,225,000	T Scott
235	5484	Stormwater/drainage structures	15	$330,000	M Hernandez
240	7785	Electrical, voice, data building A	65	$2,505,000	J Rodriquez
245	7785	Plumbing/HVAC building A	85	$2,880,000	J Rodriquez
250	6882	Arch finishes building B	50	$3,900,000	T Scott
255	5684	Underground natural gas	5	$157,500	M Hernandez
260	5584	Sanitary sewer system	21	$498,000	M Hernandez
265	5283	Concrete paving roads & driveways	60	$2,775,000	A Weaver
270	7785	Arch finishes building A	30	$2,625,000	J Rodriquez
275	5684	Domestic water system	7	$198,000	M Hernandez
280	5283	Concrete parking & walkways	15	$525,000	A Weaver
285	5684	Underground electrical, voice, data	14	$705,000	M Hernandez
290	5383	Crushed aggregate parking	40	$1,140,000	A Weaver
295	5983	Landscape/trees/plants/grass	20	$930,000	A Weaver
300	9977	Final inspection & approval	3	$52,500	D Mitchell

TABLE 13-2 EPC Project Activity List—Example EPC Maintenance Facility Project

Using the coding system of Table 13-1, a schedule report can be obtained for all structural work by selecting activities that have a 3 in the third digit of their code number. Similarly, all activities related to Building B can be obtained by selecting activities that have an 8 in the second digit of their code number.

Multiple sorting of code numbers enables a project manager to obtain various levels of reports for project control. This can be accomplished even with a simple four-digit coding system as just described. For example, a report for all structural work for Buildings A and B can be obtained by sorting activity code numbers that have a code digit 3

equal to 3, and code digit 2 greater than 6 and less than 9. Thus, many types of sorts can be obtained by selecting combinations of code digits that are greater than, equal to, or less than a number.

A coding system can also be designed using letters, rather than numbers. Using letters there are 26 characters that can be designated (one for each letter in the alphabet) for each location in the code, instead of 10 numbers that can be designated for each digit in a pure numeric system. However, for computer applications it is more difficult to sort letters on a greater than, equal to, and less than basis, than it is for a numeric coding system. A combination alphanumeric coding system can be designed using numbers in locations of the code that require sorting multiple capabilities and letters in locations where sorting is not required.

When developing the coding system for project controls, the project manager should work with the project controls lead to understand the following:

- Who needs project progress information
- What progress information they need and in what format
- Why they need the progress information
- How they will use the progress information
- When or how frequently they will need the progress information

Control Schedules for Time and Cost

The CPM network diagram shows the sequencing of activities that represents the work packages identified by the WBS. The expected time and cost that is required to perform each activity can be obtained from the work

packages of the WBS in order to establish the parameters for control of cost and time. For each activity of the EPC project shown in Figure 13-2, Table 13-2 provides the cost and duration along with the team member who is responsible for the activity. These costs and durations are directly related to the WBS, and their expenditure is directly related to the work that is produced. To measure the progress of the project, the actual costs and durations are compared to these control or baseline costs and durations.

The total cost for the project includes the direct costs plus indirect costs, contingency, and profit. A CBS for the project includes all these costs. However, only the direct costs that are tied to the WBS are used for project control purposes to manage the accomplishment of work. Indirect costs include support personnel, equipment, and supplies that are not directly chargeable to the project. The cost of insurance, bonds, general office overhead, etc., are also excluded from the project control system for monitoring costs and managing work because these items are fixed at the beginning of the project, and they are independent of the work accomplished. The management of these costs is generally a function of the accounting department because the project manager and his or her team usually do not have control of these costs. These costs are typically distributed over a specified period of time and will expand or contract with the schedule.

A good description of the relationship between engineering CBS and WBS is provided in CII Publication 6-1, *Project Control for Engineering*. Figure 13-3 is an example from the publication that illustrates a total engineering budget matrix. The CBS includes all elements in the budget matrix that have been given a dollar amount. The total dollar value of all the elements is the total engineering budget. The WBS for the project consists of budget items

from the CBS for tasks that produce deliverables: design calculations, drawings, and specifications.

Engineering Budget Matrix

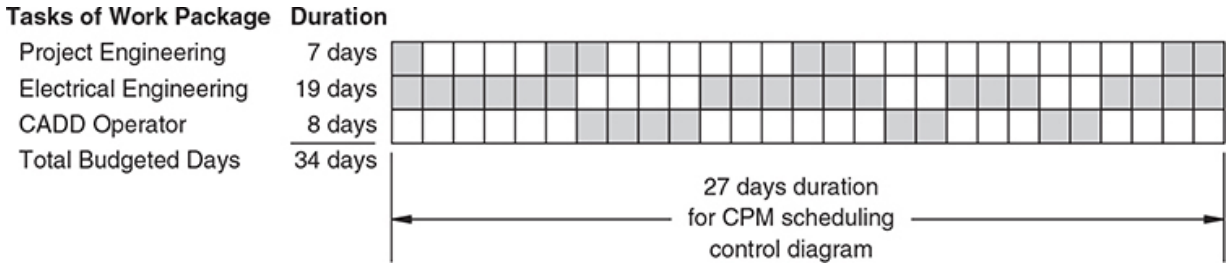
ACTIVITY OR COST ELEMENT / FUNCTION		DESIGN AND DRAWINGS	SPECS	PROCUREMENT SUPPORT	FIELD SUPPORT	SUPERVISION AND CONTROL	TRAVEL	SUPPLIES AND SERVICES
MANAGEMENT						WH & $		
PROCUREMENT				WH & $	WH & $		$	$
DISCIPLINES	CIVIL	WH & $	WH & $	WH & $	WH & $	WH & $		
	ELECTRICAL	WH & $	WH & $	WH & $	WH & $	WH & $		
	ETC.	WH & $	WH & $	WH & $	WH & $	WH & $		

FIGURE 13-3 Engineering cost breakdown structure and work breakdown structure. (*Source:* Construction Industry Institute, Publication No. 6-1.)

For the example of Figure 13-3, the functions that are chosen for work control are shaded in the matrix and are design and drawings, specifications, procurement support, and field support. The detailed WBS would be expanded from these budget items into areas, systems, and subsystems that define the total project. For example, the deliverable to be produced by the electrical discipline would be a drawing list that included all drawings for electrical work. The number of work-hours for each drawing and the number of work-hours (WH) of calculations that are required to produce the drawings would represent the budget.

The schedule for the work is the total time to produce the final drawings, including the overlap of design calculations and design drafting. As discussed in Chapter 10, most engineers prefer a bar chart for scheduling individual design tasks. However, for project control the individual bar charts

must be developed into activities on the CPM diagram for the total project schedule. The start and finish of each activity of the CPM engineering design schedule is a composite of all tasks of the work package. The following illustrates the evaluation of overlapping tasks of the work package to determine the duration of an activity on the CPM diagram.



CII Publication 6-4, *Contractor Planning for Fixed-Price Construction*, provides a good description of the relationship of the CBS and WBS for construction. Figure 13-4 is an example from the publication that shows the WBS is the direct cost portion of the CBS. The WBS includes work that is budgeted, scheduled, and controlled. The estimate should be prepared in the same organizational format as the WBS. The quantity takeoff from the plans and specifications is used as the basis for direct labor, material, and equipment costs. The cost estimate should also consider the method of construction and the sequencing of work for development of the project schedule.

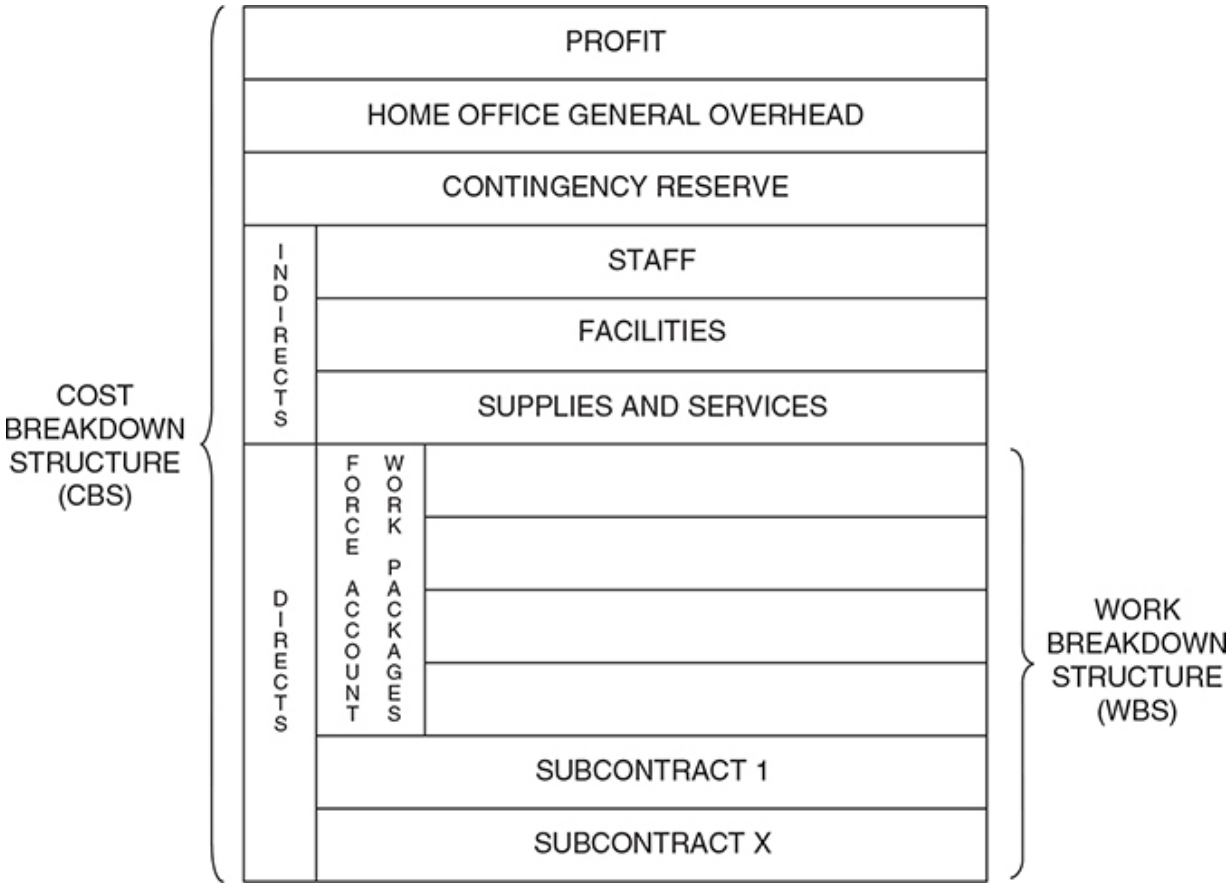


FIGURE 13-4 WBS versus CBS. (*Source*: Construction Industry Institute, Publication No. 6-4.)

The general superintendent who will be responsible for the project on the construction jobsite must be involved in developing the detailed construction schedule. However, during the early stages of project development, it is often necessary to develop a construction schedule before the construction contractor has been identified. For this type of situation, the initial CPM diagram for construction must be developed without excessive constraints in the sequencing of activities. The CPM schedule should show the sequencing of major areas of the project and identify the general flow of work. Then, prior to construction, a detailed CPM diagram can be developed by the construction personnel who will actually perform the work.

A construction contractor usually performs some work with direct-hire (force account) personnel and contracts portions of the work to one or more subcontractors. Since many subcontractors do not have an elaborate project control system, the assignment of work to a subcontractor should be a work package that has a scope of work, budget, and schedule that is defined in sufficient detail, so the subcontractor's responsibilities and duties are clearly understood. The subcontract work package must be compatible with the WBS; otherwise, there is no basis for control.

Milestone dates that are required for the start and completion of each subcontractor's work should be clearly defined, including any hold in work that may be necessary in order to schedule the work of other subcontractors. Each subcontractor is an independent company and not an employee of the general contractor. However, each subcontractor's work must be included in the total project schedule since the work of any one contractor usually affects the work of other contractors on the job, which can impact the completion date of the project.

The unsuccessful procurement of materials is a common source of delays during construction. A procurement plan must be included in the project schedule to guide the purchase of contractor furnished materials. Although the contractor generally obtains most of the material as a part of his or her construction contract, many projects require the procurement of special material and equipment that is unique to the project. Also, the owner may procure equipment or bulk materials that will be installed by the construction contractor. The project schedule should identify and sequence all activities that can impact the delivery of special equipment and material.

The previous sections presented the list of activities, costs, durations, and coding system for the EPC project

shown in Figure 13-2. The preparation of this data provides the base for a project monitoring and control system. For example, to evaluate the engineering design phase of the project, a cumulative cost curve or S-curve, see Figure 13-5, can be produced that shows the distribution of costs for all design work. This curve is obtained using the coding system of Table 13-1, by selecting all activities in which the first digit of their code is 1 or 2.

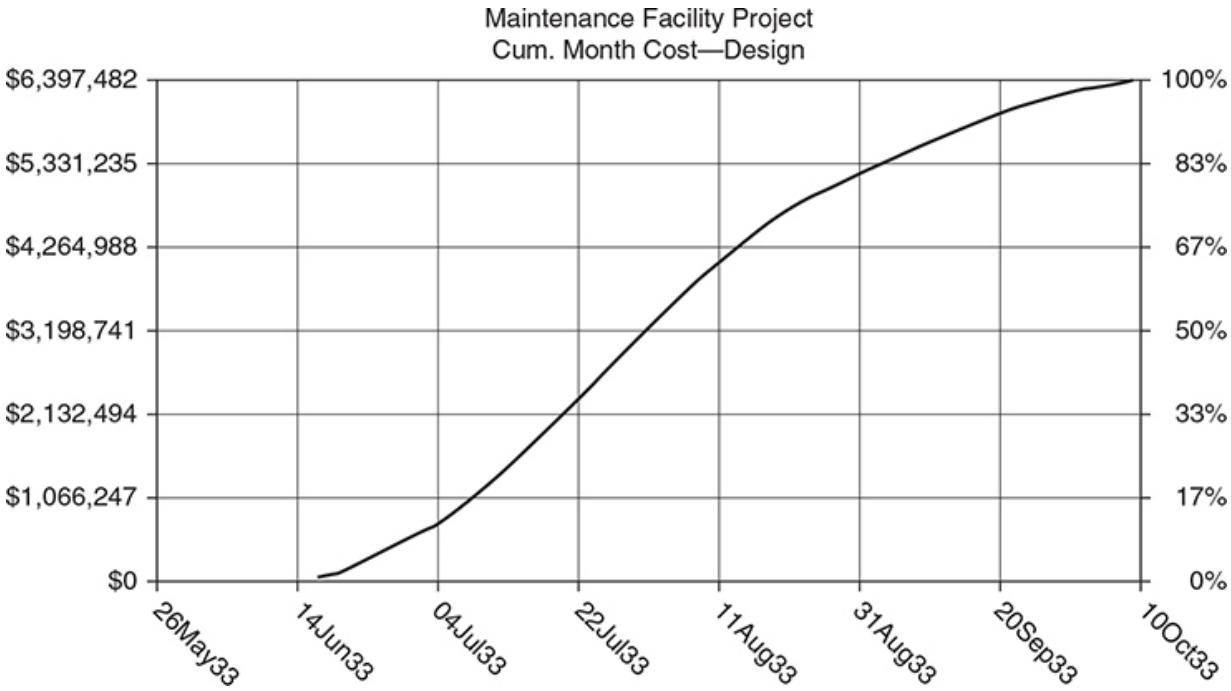


FIGURE 13-5 S-Curve for all design work (code digit 1 = 1 & 2).

Additional reports can be generated as discussed in Chapter 10. For example, Figure 13-6 shows the graph of daily cost for all internal engineering design. It can be obtained by selecting all activities that have a 1 in the first digit of their code number. A similar curve can be obtained for work-hours which would show the personnel requirements needed to perform the work.

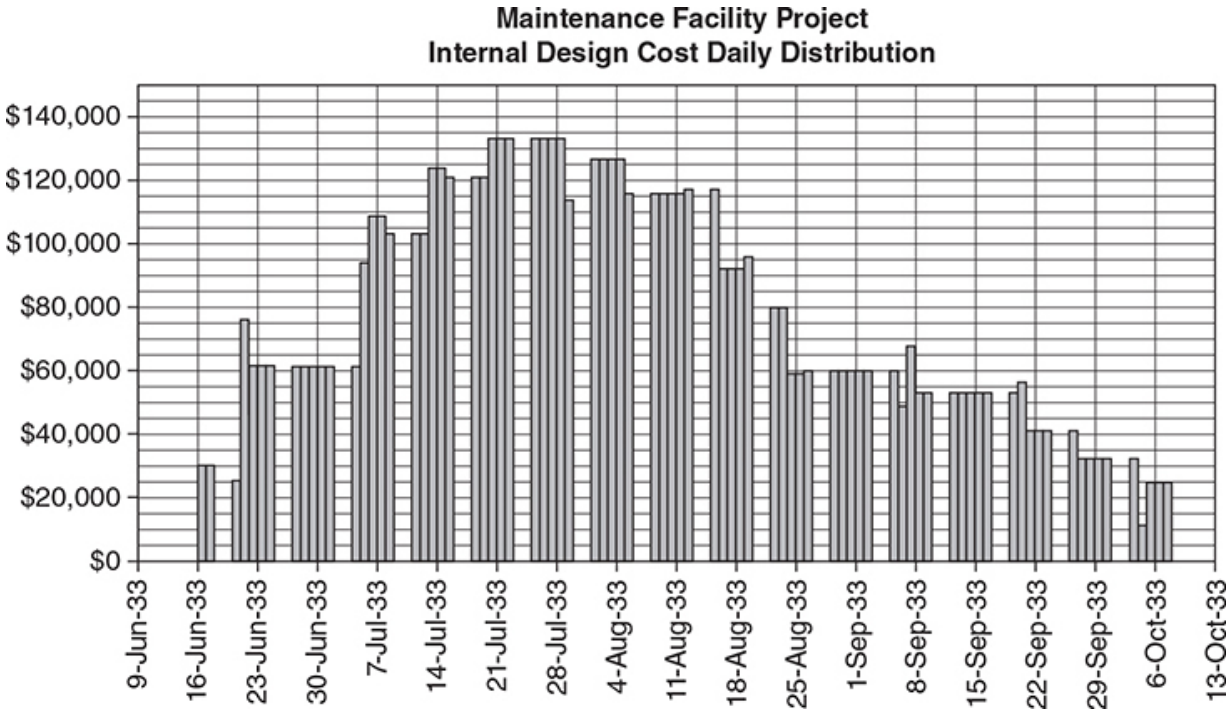


FIGURE 13-6 Daily cost distribution for all internal design work (code digit 1 = 1).

Table 13-3 is a partial listing of the project control workday schedule for all activities in the project. Only the first and last portion of the total schedule is shown to illustrate the type of information that can be obtained for all the 60 activities in the total project. Critical activities are those activities that have zero float time and are denoted by ***bold italic*** font. Major milestone events are also noted on the schedule. This schedule is a summary-level schedule report that integrates engineering, procurement, and construction.

Activity Schedule

Project: Service Maintenance Facility **Project ID**: 22-739-04

Project Manager: D. Mitchell

Activity No.	Activity Description	Duration	Early Start Work Day	Early Finish Work Day	Late Start Work Day	Late Finish Work Day	Total Float	Free Float
5	***Project Notice Approval***	***3***	***1***	***3***	***1***	***3***	***0***	***0***
10	***Develop Work Plan***	***7***	***4***	***10***	***4***	***10***	***0***	***0***
15	***Form Project Team***	***5***	***11***	***15***	***11***	***15***	***0***	***0***
20	Design Contractor's Work	2	16	17	23	24	7	0
25	***Internal Design Work***	***3***	***16***	***18***	***16***	***18***	***0***	***0***
30	Design Briefing Meeting	1	18	18	25	25	7	0
35	Project Site Work Design	1	19	19	23	23	4	0
40	On-site Utilities Design	1	19	19	54	54	35	0
45	***A/E Design Building A***	***1***	***19***	***19***	***19***	***19***	***0***	***0***
50	Floor Plan Building B	10	19	28	26	35	7	3
55	Site Grading Plan	12	20	31	24	35	4	0
60	Storm-water Design	10	20	29	55	64	35	0
↓	↓	↓	↓	↓	↓	↓	↓	↓
260	Sanitary Sewer System	21	156	176	284	304	128	0
265	Concrete Paving Roads & Driveways	60	156	215	211	270	55	0
225	Plumbing, HVAC Building B	75	167	241	221	295	54	0
230	Electrical, Voice, Data Building B	60	167	226	236	295	69	15
275	Domestic Water System	7	177	183	305	311	128	0
285	Underground Electric, Voice, Data	14	184	197	312	325	128	73
280	Concrete Parking & Walkways	15	216	230	271	285	55	0
240	Electrical, Voice, Data Building A	65	231	295	251	315	20	20
245	***Plumbing, HVAC Building A***	***85***	***231***	***315***	***231***	***315***	***0***	***0***
290	Crushed Aggregate Parking	40	231	270	286	325	55	0
250	Architectual Finishes Building B	50	242	291	296	345	54	54
295	Landscape, Trees, Plants, Grass	20	271	290	326	345	55	55
270	***Architectual Finishes Building A***	***30***	***316***	***345***	***316***	***345***	***0***	***0***
300	***Final Inspection & Approval***	***3***	***346***	***348***	***346***	***348***	***0***	***0***

TABLE 13-3 Schedule of All Activities (critical activities are ***bold italic***)

Table 13-4 is a monthly cost schedule for the entire project. The distribution of costs is shown on an early start, late start, and target basis. The percentage-time and percentage-cost distribution are shown in the two rightmost columns. There is a nonlinear distribution between costs and time. For example, at the end of the sixth month, which represents 33% of the time of completion, only 17.9% of the costs are anticipated to be expended. However, at the end of the 11th month, 64.1% of the time, 54.3% of the costs are expected to be expended.

Monthly Cost Schedule

Project: Service Maintenance Facility **Project ID**: 22-739-04

Project Manager: D. Mitchell

Start Date: 26-May-2033 **Finish Date:** 25-Sep-2034

		Early Start		Late Start		Target Schedule			
No.	Month	Cost/Month	Cumulative Cost	Cost/Month	Cumulative Cost	Cost/Month	Cumulative Cost	% Time	% Cost
1	May	$58,935	$58,935	$58,935	$58,935	$58,935	$58,935	1.2%	0.1%
2	Jun	$732,615	$791,550	$519,675	$578,610	$626,145	$685,080	7.5%	1.5%
3	Jul	$2,658,915	$3,450,465	$1,518,060	$2,096,670	$2,088,495	$2,773,575	13.5%	6.1%
4	Aug	$1,958,745	$5,409,210	$1,962,570	$4,059,240	$1,960,665	$4,734,240	20.1%	10.3%
5	Sep	$2,503,965	$7,913,175	$2,407,875	$6,467,115	$2,455,920	$7,190,160	26.4%	15.7%
6	Oct	$1,038,825	$8,952,000	$956,760	$7,423,875	$997,785	$8,187,945	32.4%	17.9%
7	Nov	$2,702,805	$11,654,805	$937,605	$8,361,480	$1,820,205	$10,008,150	38.7%	21.9%
8	Dec	$3,706,740	$15,361,545	$1,679,175	$10,040,655	$2,692,965	$12,701,115	45.0%	27.7%
9	Jan	$4,861,005	$20,222,550	$2,713,995	$12,754,650	$3,787,500	$16,488,615	51.3%	36.0%
10	Feb	$4,993,500	$25,216,050	$3,536,130	$16,290,780	$4,264,815	$20,753,430	57.1%	45.3%
11	Mar	$4,744,185	$29,960,235	$3,515,430	$19,806,210	$4,129,800	$24,883,230	63.7%	54.3%
12	Apr	$3,630,330	$33,590,565	$3,689,505	$23,495,715	$3,659,925	$28,543,155	69.5%	62.3%
13	May	$3,757,335	$37,347,900	$4,625,145	$28,120,860	$4,191,240	$32,734,395	76.1%	71.5%
14	Jun	$4,260,255	$41,608,155	$4,943,835	$33,064,695	$4,602,045	$37,336,440	82.4%	81.5%
15	Jul	$1,342,185	$42,950,340	$4,840,650	$37,905,345	$3,091,410	$40,427,850	88.4%	88.3%
16	Aug	$1,656,915	$44,607,255	$5,083,395	$42,988,740	$3,370,155	$43,798,005	95.0%	95.6%
17	Sep	$1,189,995	$45,797,250	$2,808,510	$45,797,250	$1,999,245	$45,797,250	100.0%	100.0%

TABLE 13-4 Monthly Cost Distribution for All Activities in the Project

Relationships between Time and Work

Measurement of design work is difficult because design is a creative process that involves ideas, calculations, evaluation of alternatives, and other tasks that are not physically measurable quantities. Considerable time and cost can be expended in performing these tasks before end results such as drawings, specifications, reports, etc., which are measurable quantities of work, are ever seen.

The measurement of design is further complicated because of the diversity of work. For example, all the design calculations may be complete, half of the drawings may be produced, and yet only one-fourth of the specifications may be written. For this situation, it is difficult to determine how much work has been accomplished because the work that is produced does not have a common unit of measure. Because of this, a percentage of completion is commonly used as a unit of measure of design work. The criteria for determining the percent complete for measuring work must be developed and confirmed in writing with the project team members prior to commencing design. This provides a common basis for the monthly evaluation of progress.

A weighting multiplier can be assigned to design tasks to define the magnitude of effort that is required to achieve each task. The sum of the weighting factors is 1.0, which represents 100% of the total design effort. The determination of each weight should be a joint effort between the project manager and the designer who is responsible for performing the work. This should be done before starting work.

A significant amount of overlap work is necessary during the design process. For example, initial drafting normally starts before the design calculations are finished. Likewise, final calculations are often not complete before the final

production drawings are started. The project manager and his or her team members can jointly define the overlap of related work to show the timing of tasks throughout the duration of a project. Table 13-5 is an illustrative example that lists work items, weight multiplier, and estimated timing for each task required in a design effort. Further division of weight multipliers within each category may also be necessary.

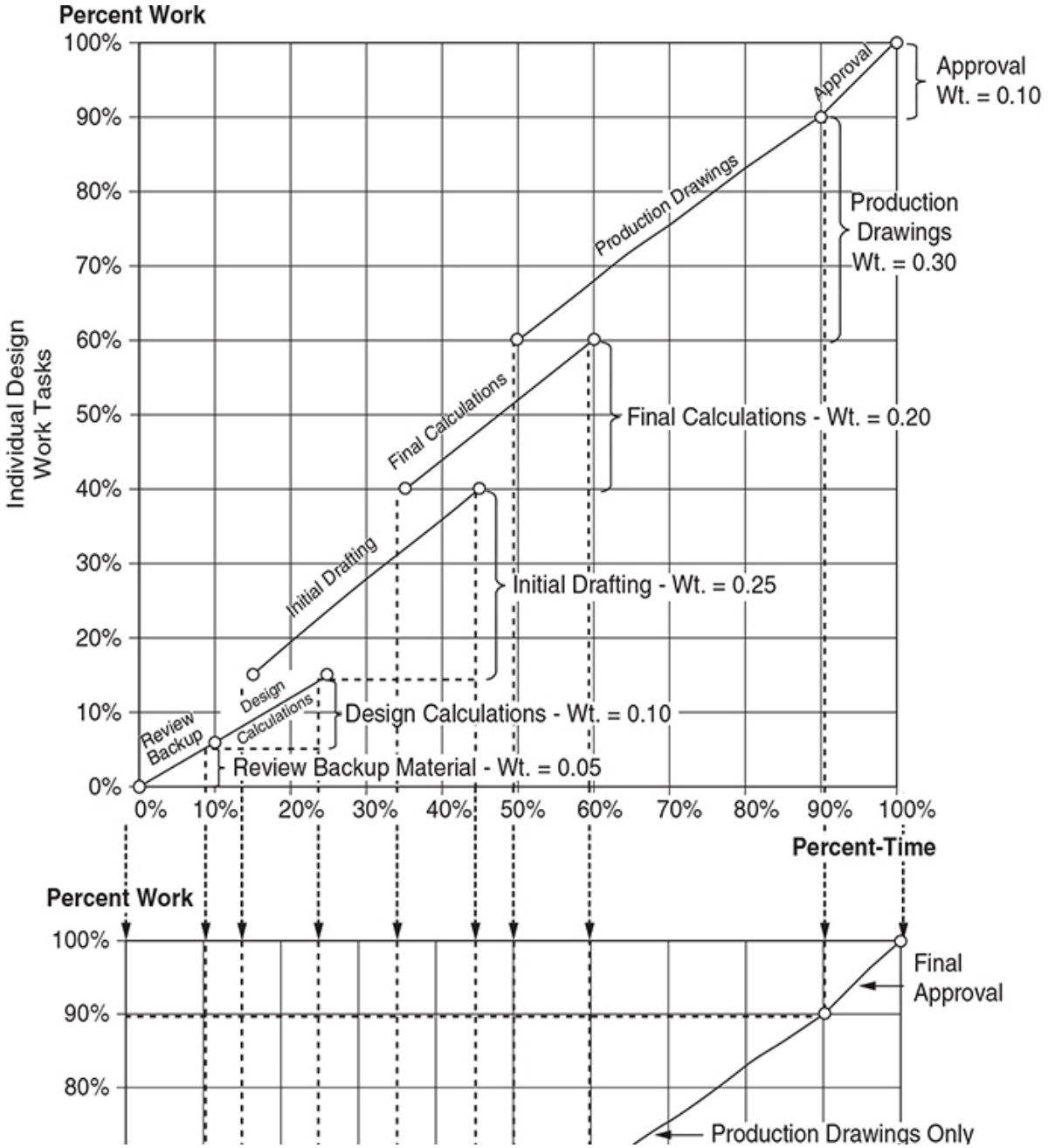
The information in Table 13-5 is provided for illustrative purposes only. Because each project is unique, it is necessary to define the weight multipliers that are appropriate for each individual project. The timing of design work depends on the availability of personnel. This information can be compiled from a summary of the individual design work packages.

Design Work	Weight Multiplier	Project Timing
Review backup material	0.05	0%–10%
Design calculations	0.10	10%–25%
Initial drafting	0.25	15%–45%
Final calculations	0.20	35%–60%
Production drawings	0.30	50%–90%
Drawing approval	0.10	90%–100%
	1.00	

TABLE 13-5 Illustrative Weight Multipliers for Design Work

To manage the overall design effort, a work/time curve can be developed from the information in Table 13-5, see Figure 13-7. The upper portion of Figure 13-7 is a series of graphs that represent each design task individually, arranged in the order of occurrence. The slope of each graph is the ratio of the weight multiplier to the time required for the work to be performed. The lower portion of Figure 13-7 is the work/time curve for the entire design

effort and is obtained by a composite, superposition of the individual graphs. This curve represents the planned accomplishment of work and serves as a basis of control for comparison of actual work accomplished. It can be superimposed onto the time/cost S-curve that was discussed in the preceding section. This forms the overall integrated cost/schedule/work curve that is discussed later in subsequent sections of this chapter.



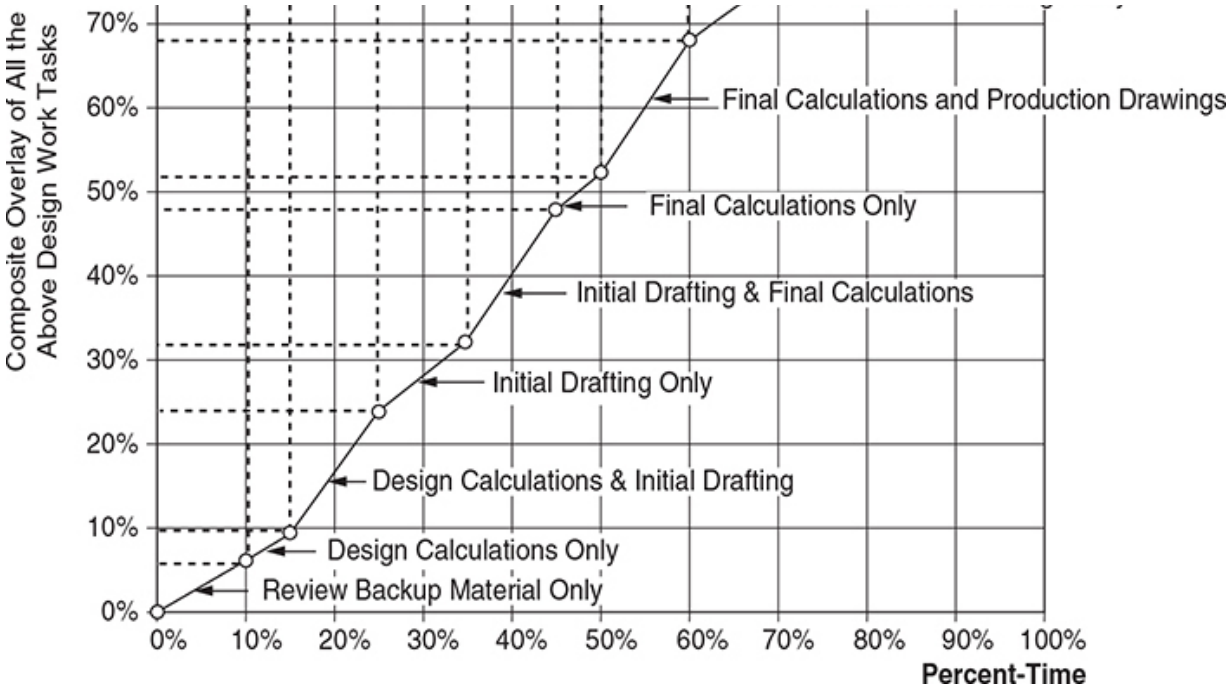


FIGURE 13-7 Work/time relationship for all design work.

Construction involves many types of different work that have different units of measure, such as, cubic yards, square feet, pounds, or each. Thus, it is convenient to use percentage as a unit of measure for management and control of overall construction.

The procedure used for measurement of design can also be applied to construction. For example, a project may consist of three major facilities: site work, a concrete office building, and a pre-engineered metal building. A weight multiplier can be applied to each of the three major facilities, along with their planned sequence of occurrence (reference Table 13-6).

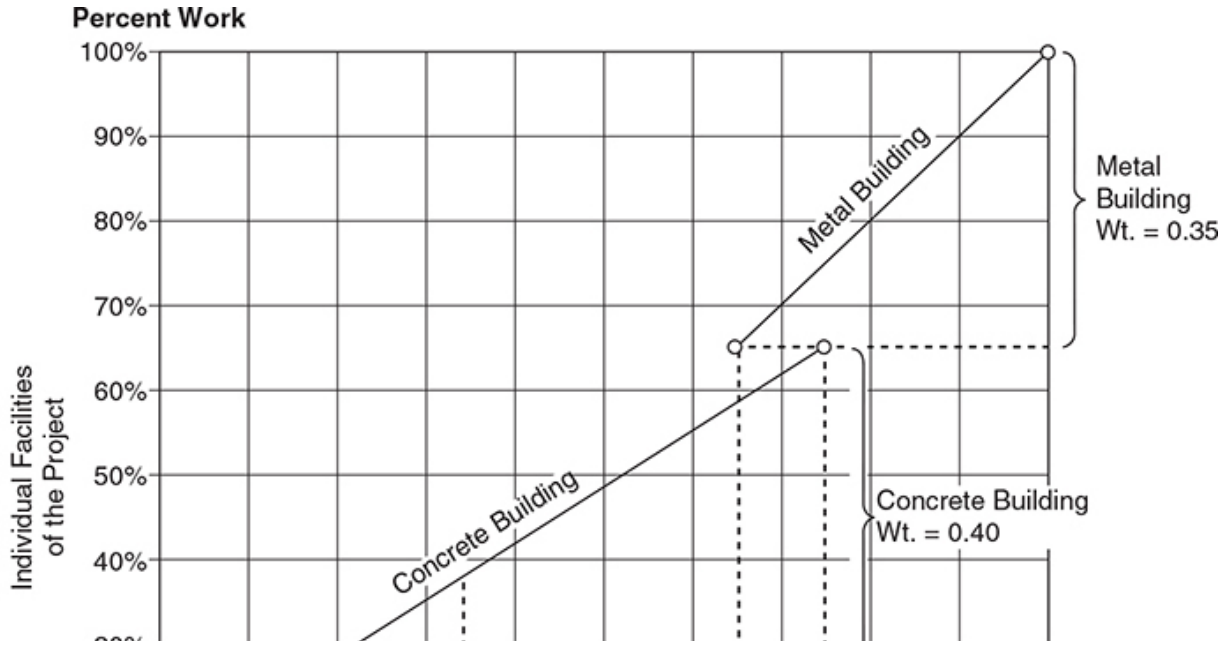
Table 13-6 only lists three major parts of the project. A more accurate definition of the planned work can be achieved by dividing each of the major facilities into smaller components. For example, site work can be divided into grading, drainage, paving, landscaping, etc. Likewise, each of the two buildings can be divided into smaller components. Regardless of the level of detail of the project,

the sum of all the weight multipliers would be equal to 1.0, to represent 100% of the project. The weight and timing of each major facility is established by key participants of the project team, before starting construction, to serve as a basis of control during construction.

Facility	Weight Multiplier	Project Timing
Site work	0.25	0%–35%
Concrete building	0.40	15%–75%
Metal building	0.35	65%–100%
	1.00	

TABLE 13-6 Illustrative Weight Multiplier for Construction

Figure 13-8 shows the composite of the planned accomplishment of work. The upper portion of Figure 13-8 is a graphical display of the overlap and sequence of each of the three major facilities. The lower portion is the integrated work/time curve for the entire project and is obtained by a composite superposition of the three individual graphs of each major facility.



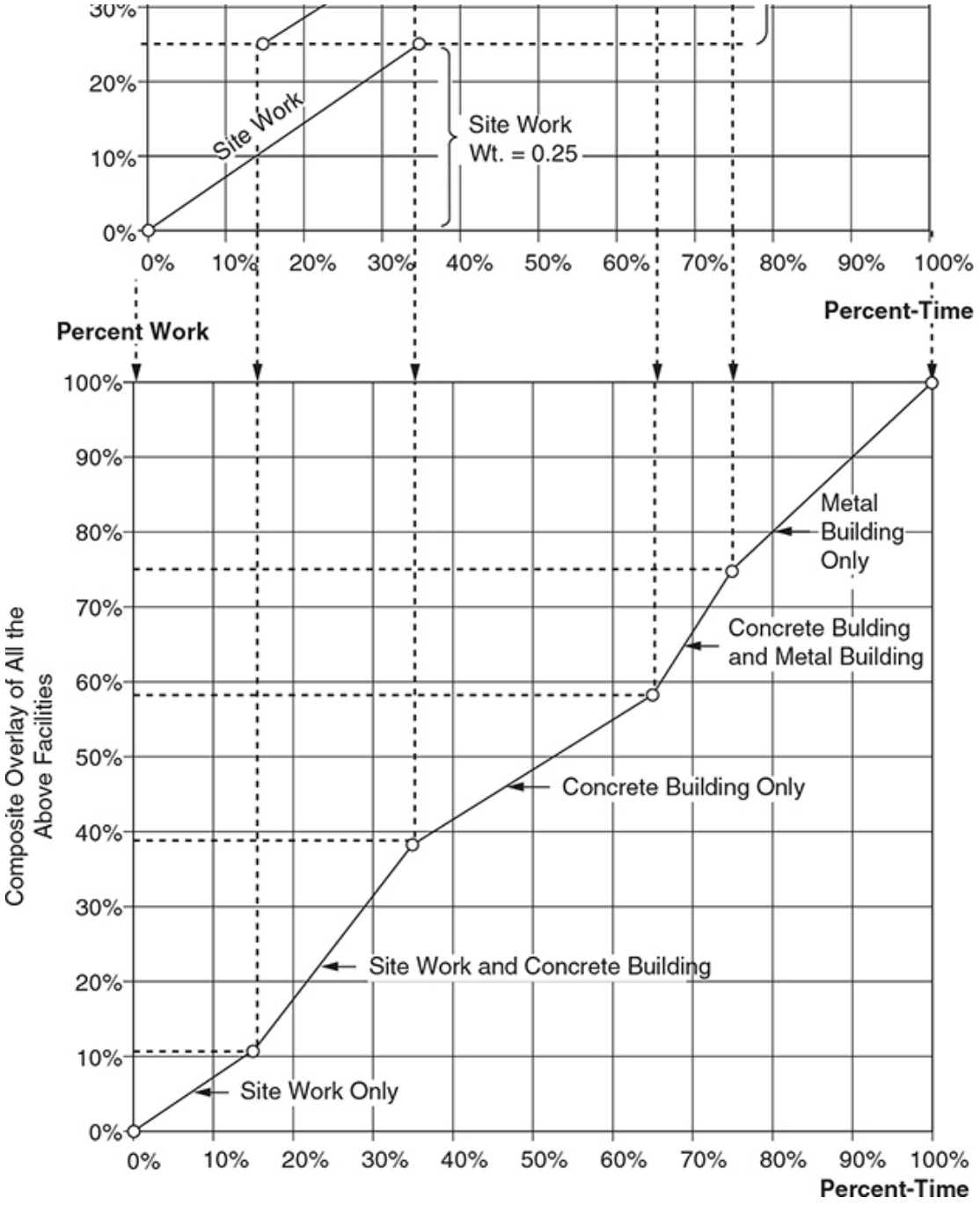


FIGURE 13-8 Work/time relationship for construction of the entire project.

The procedure is a top-level summary of all facilities in the total project. This same procedure can be used for each facility, or parts of a facility, depending on the complexity of

the project and the level of control that is desired by the project manager.

At the lowest level, it may be possible to use a unit of measure of work that can be physically measured at the jobsite, rather than using a percentage. For example, “wire pulling” can be easily measured in linear feet or “concrete piers” can be measured in cubic yards. However, some precautions must be used when physical quantities are used to represent work in place of a percentage. To illustrate, the construction of concrete piers involves drilling, setting steel, and placement of concrete. For a project that has 18 piers, a progress report may show all piers drilled, steel set in 9 piers, and concrete placed in 3 piers. If cubic yards are the only measure of control, only 3 of the 18 piers would be reported as complete, which would not include the drilling and steel work that is accomplished. For this situation, a weight multiplier system must be developed to account for each task that is required to construct the piers. As previously discussed, the sum of all weights must equal 1.0 to represent 100% of the work.

Integrated Cost/Schedule/Work

Experienced project managers are familiar with the problems of using only partial information, such as only costs or time to track the status of a project. To illustrate, half of a project budget may be expended by the midpoint of the scheduled duration, but only 20% of the work may be accomplished. A monitoring of only time and cost would indicate the project is going well; however, upon completion of the project, there would likely be a cost overrun and a delay in schedule because the measurement of work was not included in the project control system. Thus, a project manager must develop an integrated cost/schedule/work system which provides meaningful feedback during the

project rather than afterward. The status of a project can then be determined, and prompt corrective actions taken to minimize the cost impacts to the project.

The preceding sections presented the relationships of cost/time and work/time for project control. However, evaluating these relationships separately does not provide an accurate status of a project. A cost/schedule/work graph can be prepared that shows the integrated relationship of the three basic components of a project: scope (work), budget (cost), and schedule (time). Figure 13-9 is a graph that links costs on the left-hand ordinate, time on the abscissa, and work on the right-hand ordinate. The upper curve is simply the cost/time S-curve that has been discussed in previous sections of this book. The lower work/time curve shows the relationship between work and time throughout the duration of the project. Thus, the graph is simply a composite overlay of the information previously presented.

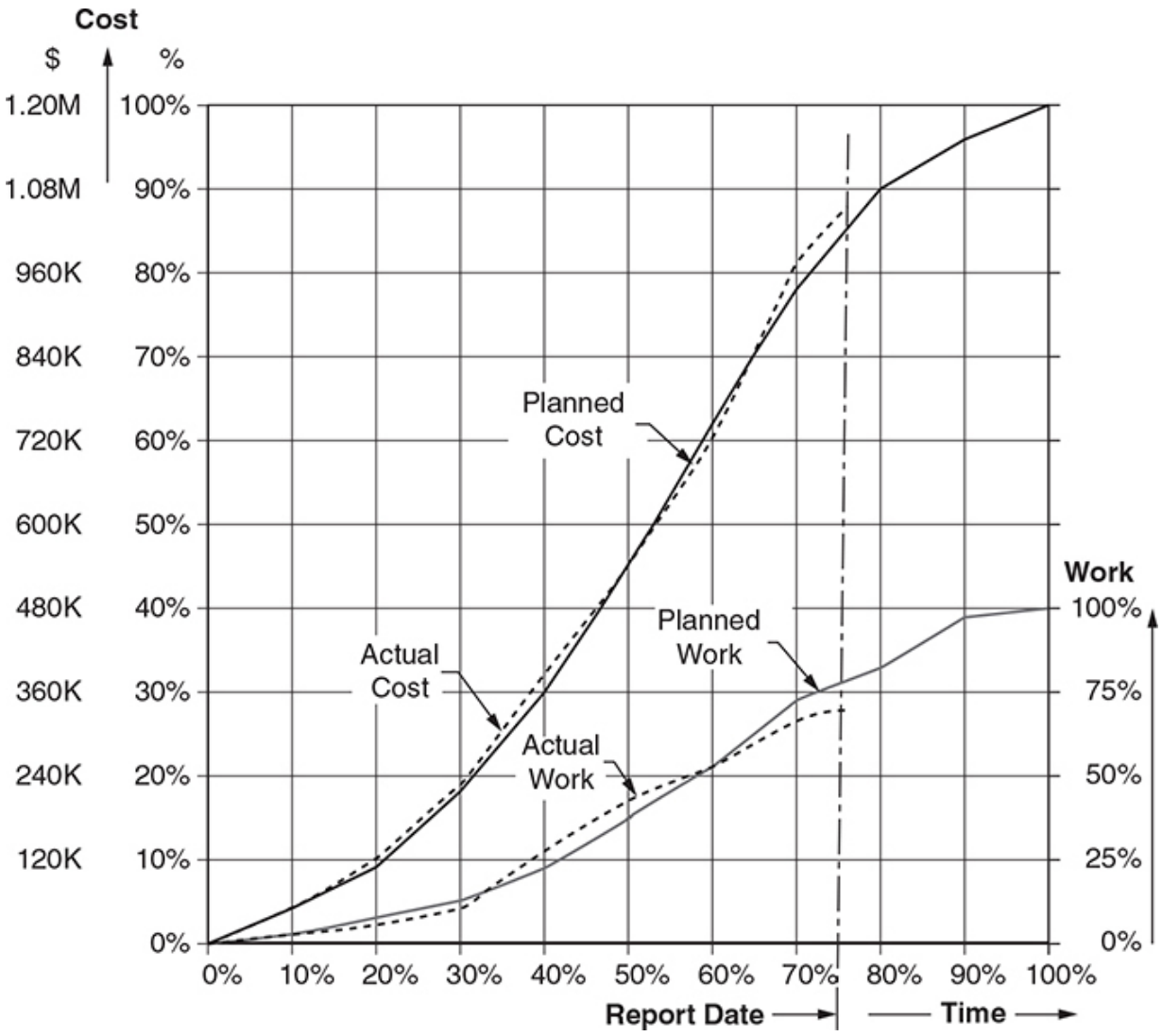


FIGURE 13-9 Integrated cost/schedule/work graph.

The unit for costs is dollars and the unit for schedule is days, which are easily determined units of measure for any type of project. The unit of measure for work is represented as a percentage which provides a common base for all parts of the project. As previously discussed, a project may have three types of buildings: concrete, steel, and wood frame. An appropriate unit of measure for work would be cubic yards for the concrete building, pounds of steel for the steel building, and board feet of lumber for the wood frame building. However, since it is not possible to add cubic yards

to pounds or board feet, percent is a dimensionless unit of measure that can conveniently be used to represent work.

Although percentage provides a common unit of measure for work, a multiplier is necessary to define the distribution of work for each part of the project. For example, the project with three buildings of the previous paragraph may use a multiplier of 45% for the concrete structure, 35% for the steel structure, and 20% for the wood structure, which when combined represents 100% for the total project. Factors that may be considered for determining the multiplier include work-hours, costs, and/or the time to complete the work. The multiplier that is selected involves both a quantitative and qualitative evaluation of the project, based on good judgement, and should be determined as a joint effort by key participants of the project team.

The actual cost and work accomplished can be superimposed onto the curves to compare with the planned cost and work in order to determine the status of the project; see Figure 13-10a. For this example, the actual accomplished work curve is below the planned work curve, which shows a schedule slippage. For the same reporting period, there is a cost overrun as noted on the upper curve of the graph. Thus, there is a schedule slippage and cost overrun for the reporting period. Other scenarios are possible as illustrated in Figure 13-10b to 13-10d.

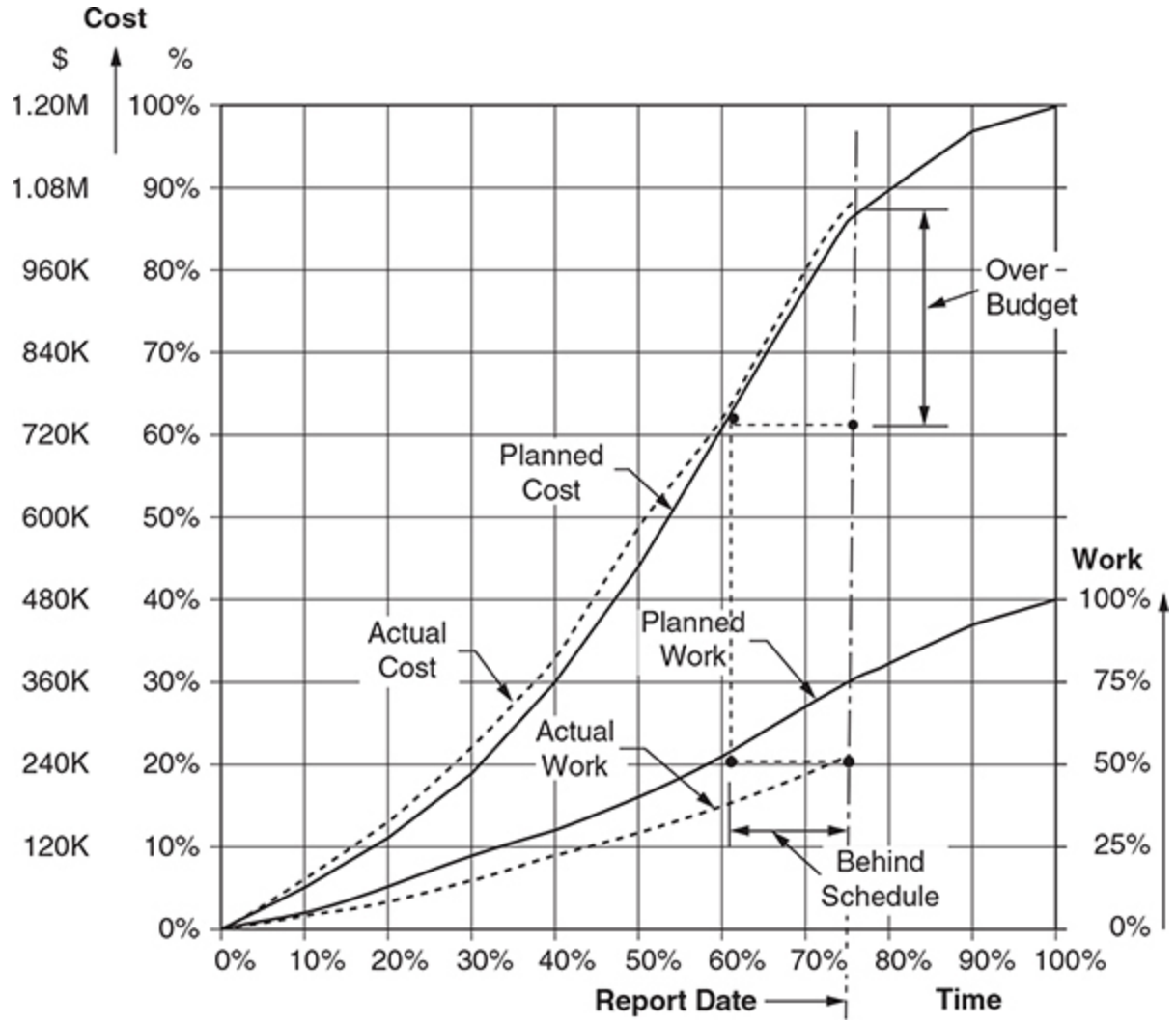


FIGURE 13-10a Over budget and behind schedule.

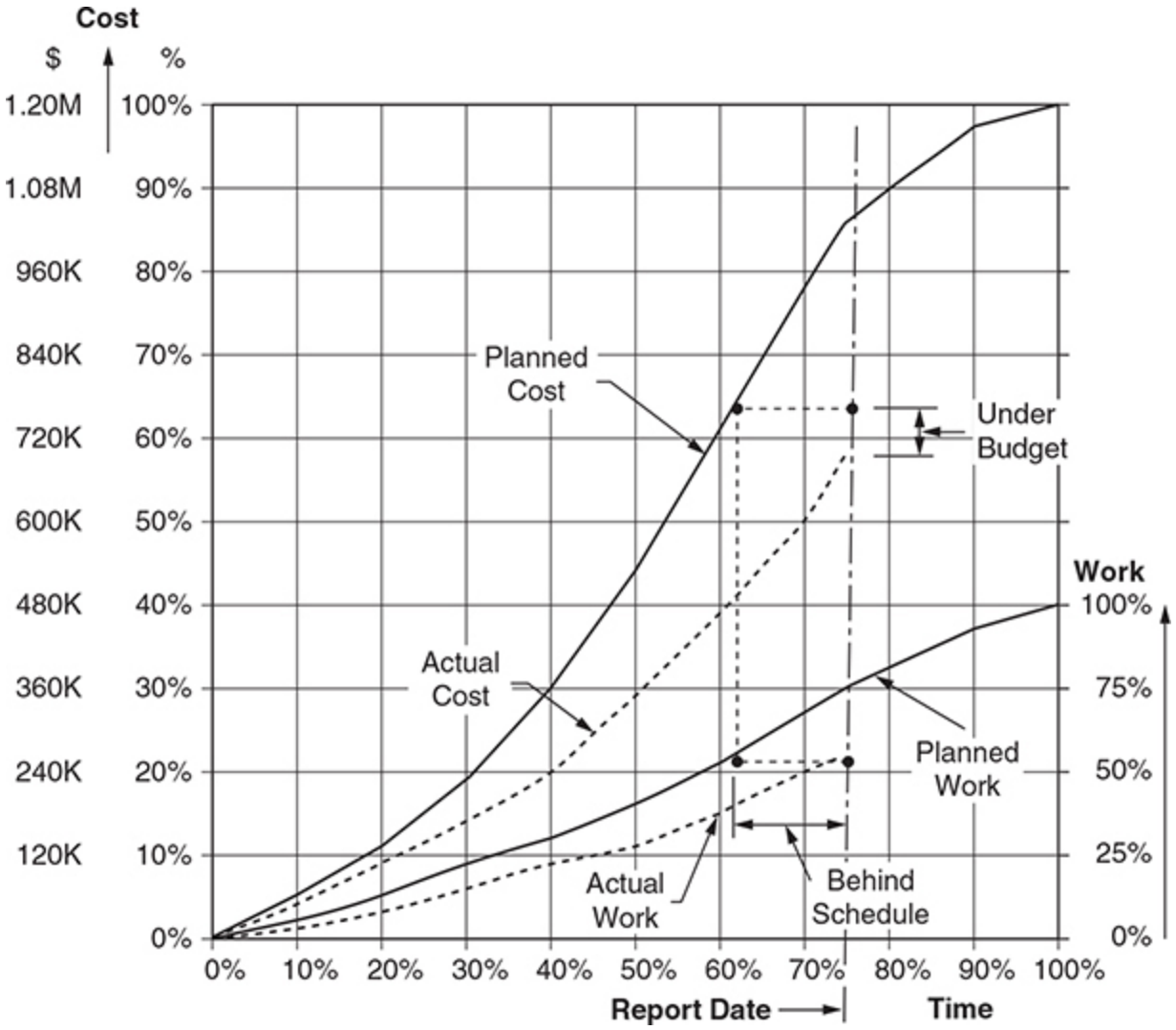


FIGURE 13-10b Under budget and behind schedule.

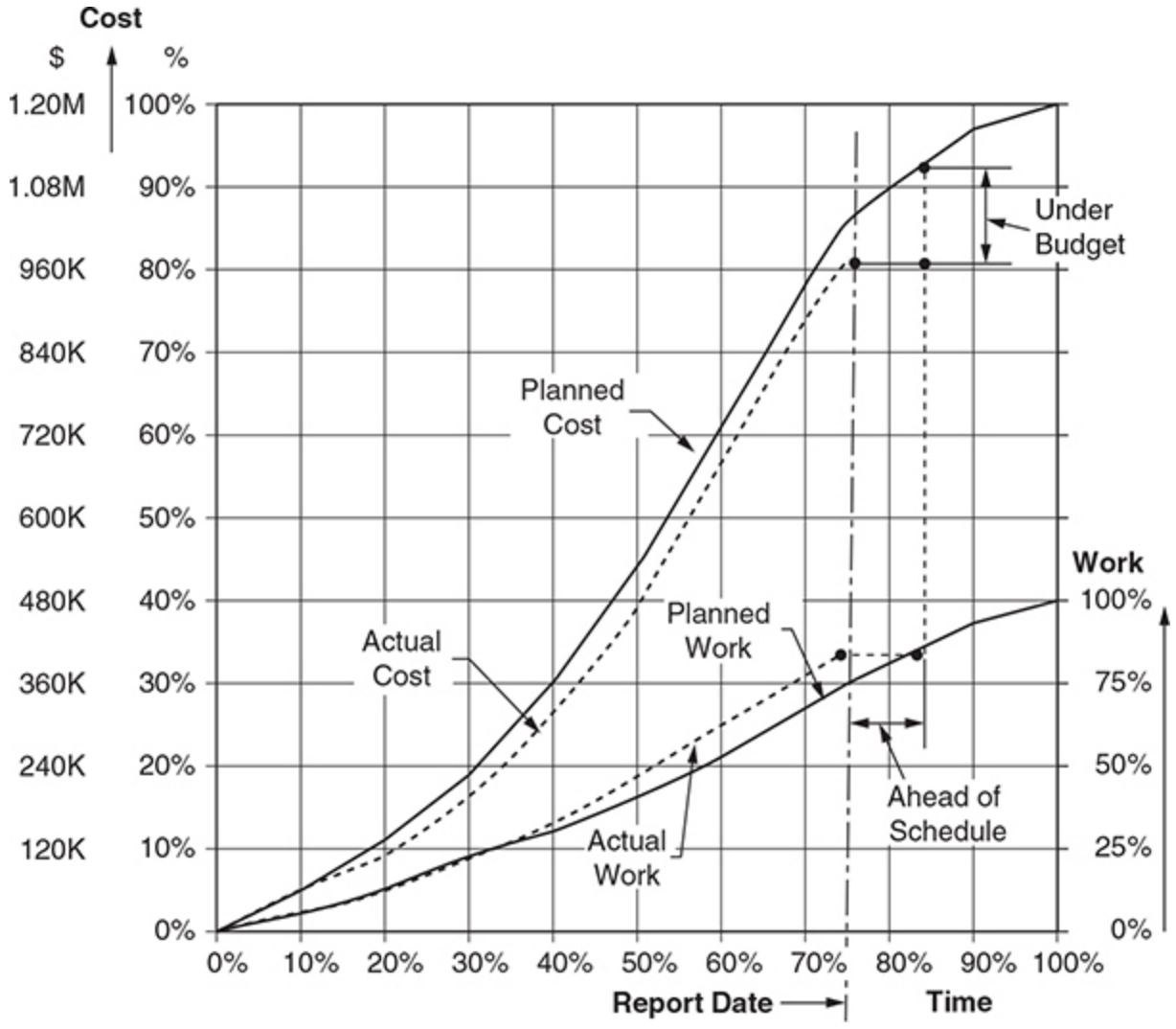


FIGURE 13-10c Under budget and ahead of schedule.

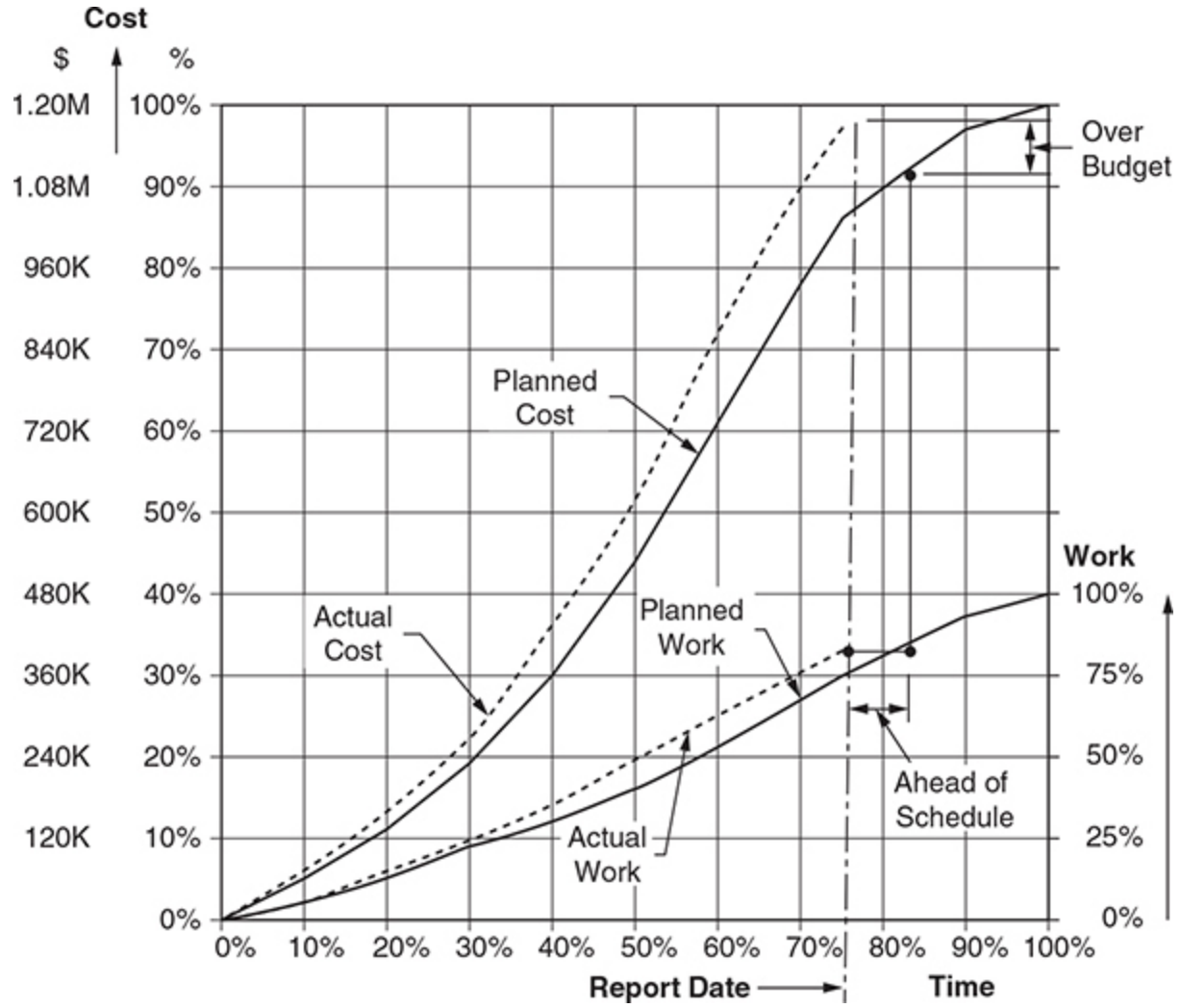


FIGURE 13-10d Over budget and ahead of schedule.

An integrated cost/schedule/work graph provides a good summary level report for the status of the overall project. Lower-level graphs, that is, the concrete building only, can be prepared to evaluate the status of a part of the total project. Thus, multiple graphs can be developed, depending on the complexity of the project and the level of control desired by the project manager.

The integrated cost/schedule/work method is especially useful for tracking design work because design work is typically measured in percent complete. For example, a design review may be held at 25% design complete. For

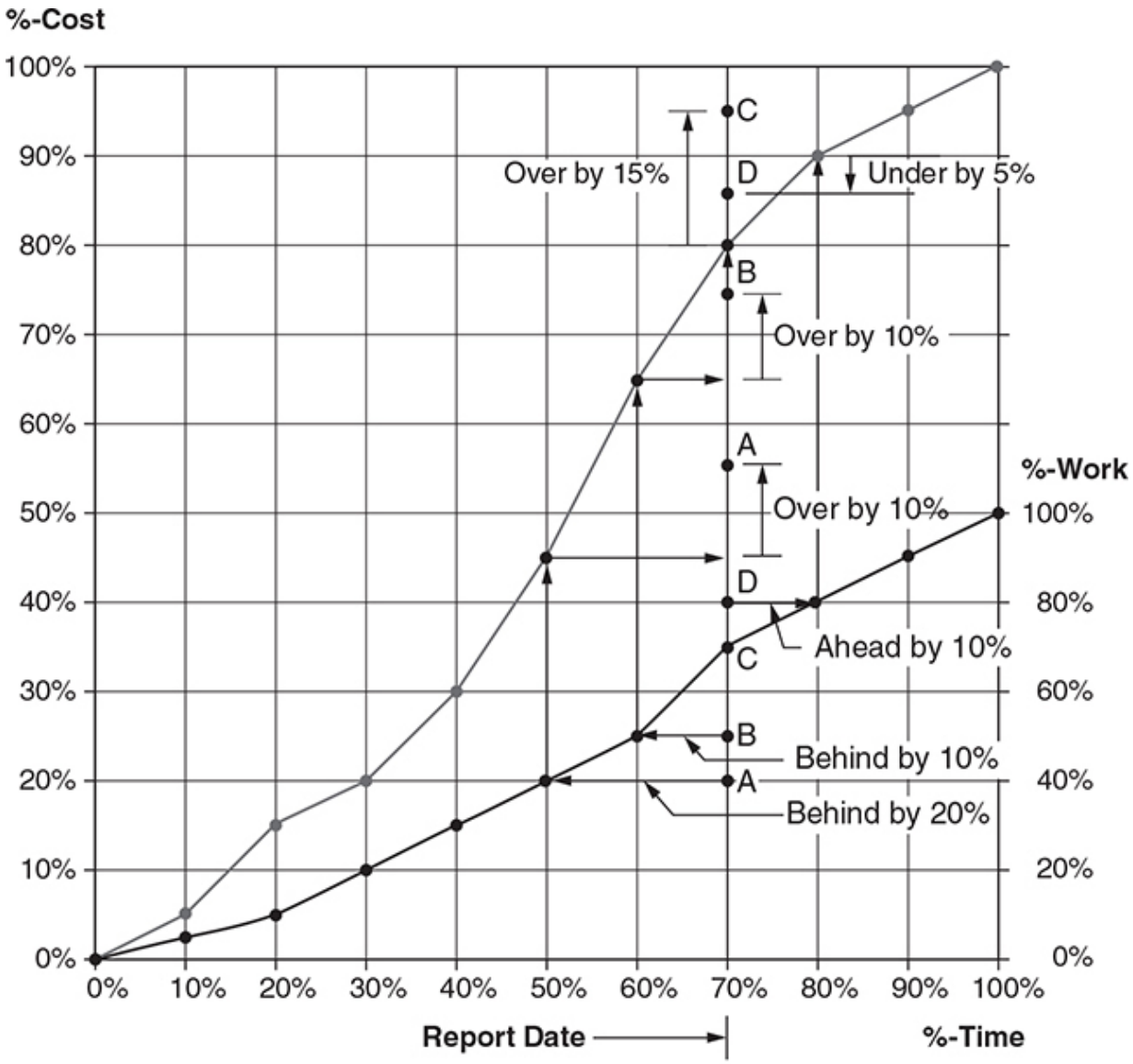
architectural design work, the design may represent 40% of the design effort, and 60% of the work may represent development of drawings, reference Tables 9-1 and 13-5. Also, the cost of design is sometimes measured in design-hours or CADD-hours.

Example 13-1 The following data represent the information that has been jointly compiled by the various disciplines of the design team for a project. These data represent the planned cost and work anticipated during the design phase. Prepare an integrated planned cost/time/work graph for the project.

Expected Time	Anticipated Cost	Planned Work
0%	0%	0%
10%	5%	5%
20%	15%	10%
30%	20%	20%
40%	30%	30%
50%	45%	40%
60%	65%	50%
70%	80%	70%
80%	90%	80%
90%	95%	90%
100%	100%	100%

Evaluate the status report for the project for the following scenarios, assuming the status report is issued at 70% of the project duration. For each scenario, determine if the project is behind or ahead of schedule. Is there a cost overrun or underrun, and if so, by how much? A graphical evaluation of the four scenarios is shown below, followed by a summary table.

Scenario	Status report at 70% of the project duration
A	Reported cost to date is 55% and work accomplished is reported as 40%
B	Reported cost to date is 75% and work accomplished is reported as 50%
C	Reported cost to date is 95% and work accomplished is reported as 70%
D	Reported cost to date is 85% and work accomplished is reported as 80%



Scenario	Schedule	Cost
A	Behind by 20%	Over by 10%
B	Behind by 10%	Over by 10%
C	On schedule	Over by 15%
D	Ahead by 10%	Under by 5%

Percent Complete Matrix Method

A basic technique for determining the overall status of a project is the percent complete matrix method. It can be

used for any size project and only requires a minimal amount of information that is readily available in the work packages. The overall status can be measured as a percent complete matrix, based on the budget for each work package in a project. The budget can be measured as any one of three variables: cost, work-hours, or physical quantity of work. To describe this method, only cost is used in the following paragraphs; however, the method can be just as easily applied to work-hours or physical quantities of work. There may be times when a project manager may wish to use all three measures to determine the status of a project.

The percent complete matrix method requires only two input variables for each work package: estimated cost and percent complete. This report is easily created in a spreadsheet using six pieces of information from the work package for a given area as shown in Figure 13-11.

Work Package	
Estimated Cost* (EC)	Percent Unit (%Unit)
Percent Complete* (%Complete)	Percent Project (%Project)
Cost to Date (CTD)	% Complete Project (%CP)
Spreadsheet Formulas	
Input from Estimate (EC)*	Estimated Cost/Total Unit Cost
Variable Input by User (%Complete)*	Estimated Cost/Total Project Cost
Percent Complete × Estimated Cost	Cost to Date/Total Project Cost

*Required Input Data by User

FIGURE 13-11 Work package information and spreadsheet formulas for % complete matrix.

Figure 13-12 is a spreadsheet that illustrates the percent complete matrix method for a project that consists of five buildings. Each building is defined by four summary-level components: foundation/structural, mechanical/electrical, finishes/furnishings, and special equipment. The “total cost” and “percent of project” for each building are shown in the

right-hand two columns of the spreadsheet. The total cost of all buildings in the project represents the total project budget, $240,000. Formulas in the spreadsheet calculate the "total cost" of each component in the project. For example, $81,000 represents the budget costs for all structural work.

	Foundation/Structural		Mechanical/Electrical		Finishes/Furnishings		Special/Equipment			
	EC	%Unit	EC	%Unit	EC	%Unit	EC	%Unit		
	%Complete	%Project	%Complete	%Project	%Complete	%Project	%Complete	%Project		
Facility	CTD	%CP	CTD	%CP	CTD	%CP	CTD	%CP	**Total Cost**	**Percent Total**
Building A	$15,000	30%	$8,000	16%	$10,000	20%	$17,000	34%	$50,000	21%
	70%	6%	35%	3%	0%	4%	0%	7%		
	$10,500	4%	$2,800	1%	$0	0%	$0	0%		
Building B	$25,000	28%	$9,000	10%	$23,000	26%	$33,000	37%	$90,000	38%
	10%	10%	0%	4%	0%	10%	0%	14%		
	$2,500	1%	$0	0%	$0	0%	$0	0%		
Building C	$8,000	40%	$3,000	15%	$4,000	20%	$5,000	25%	$20,000	8%
	100%	3%	80%	1%	0%	2%	0%	2%		
	$8,000	3%	$2,400	1%	$0	0%	$0	0%		
Building D	$2,000	20%	$1,000	10%	$0	0%	$7,000	70%	$10,000	4%
	100%	1%	100%	0%	0%	0%	0%	3%		
	$2,000	1%	$1,000	0%	$0	0%	$0	0%		
Building E	$31,000	44%	$18,000	26%	$21,000	30%	$0	0%	$70,000	29%
	5%	13%	0%	8%	0%	9%	0%	0%		
	$1,550	1%	$0	0%	$0	0%	$0	0%		
Sum Est. & %Project	$81,000	34%	$39,000	16%	$58,000	24%	$62,000	26%	$240,000	100%
Sum CTD & Sum %Complete	$24,550	10%	$6,200	3%	$0	0%	$0	0%	$30,750	13%

FIGURE 13-12 Percent complete matrix for a project composed of five buildings.

The summary-level components of each building contain the six pieces of information from the work package discussed in Figure 13-11. For example, the work packages for Building A structural is $15,000, which represents 30% of Building A and 6% of the total $240,000 project budget. Upon entry in the spreadsheet of 70% complete for Building A, the formulas automatically calculate the $10,500 "cost to date" and the 4%, which represents the percent complete for the total project. The only entry required to obtain the project status is the cell of "% complete," the entry

highlighted and underlined in the spreadsheet illustrated in Figure 13-12.

As entries are made for each work package in the matrix, the total values for each component in the project are calculated at the bottom of the spreadsheet. For example, all the “cost to date” values in the vertical column under the heading of structural work sums to $24,550, which represents 10% of the total project. Similarly, formulas in the spreadsheet sum all the total cost values of each component in the bottom horizontal row to calculate the total project cost to date of $30,750, which represents 13% complete for the entire project. This percentage can be used for the evaluation of the integrated cost/time/work graphs that were discussed in the preceding section.

Progress Measurement of Design

The primary objectives of a progress measurement method during design are to (1) support project management in establishing a realistic plan for execution of the project, (2) provide the project manager and client with a consistent analysis of project performance, and (3) provide an early warning system to identify deviations from the project plan and scope growth.

The drawing list and specification list are typical deliverables of the design effort. However, for some projects there may be additional deliverables. For example, deliverables for projects in the process industry typically include an equipment list and instrument list. Sometimes procurement of long lead-time equipment or procurement of special materials are included in the design contract. For this situation, a list of procurement activities becomes a part of deliverables of the design effort.

The percentage completion of a single activity can usually be determined by one of four systems: Units Completed,

Incremental Milestone, Start/Finish Percentages, or Ratio. The Units Completed method may be suitable for writing specifications, provided that each part of the specifications can be considered as having equal effort of work. The measurement of work can be determined as a percentage that is calculated by dividing the number of specifications completed by the total number of specifications that are to be produced.

The Incremental Milestone method is appropriate for measurement of production drawings or procurement activities that consist of easily recognized milestones. The following percentages are typical examples of progress measurement for development of production drawings and procurement.

Production Drawings	
Start drafting	0%
Drawn, not checked	20%
Complete for office check	30%
To owner for approval	70%
First issue	95%
Final issue	100%
Procurement	
Bidders list developed	5%
Inquiry documents complete	10%
Bids analyzed	20%
Contract awarded	25%
Vendor drawings submitted	45%
Vendor drawings approved	50%
Equipment shipped	90%
Equipment received	100%

The start/finish percentage method is applicable to those activities that lack readily definable intermediate milestones, or the effort and time required is difficult to estimate. For these tasks, 20% to 50% is given when the activity is started and 100% when finished. A percentage is assigned for starting to account for the long time between the start and finish when no credit is being given. This method is appropriate for work such as planning, designing, model building, and studies. It can also be used for specification writing.

The ratio method is applicable to tasks such as project management or project control that are involved throughout the duration of the project. Such tasks have no particular end product and are estimated and budgeted on a bulk allocation basis, rather than on some measure of production. It can also be used on tasks that are appropriate for the start/finish method. The percent complete at any point in time is found by dividing hours (or costs) spent to date by the current estimate of hours (or costs) at completion.

Percent complete may be determined by one of the above described methods. It is important to define the progress measurement method in the project execution plan (PEP) and to use it consistently during project execution. Regular and consistent progress measurement helps to identify trends in project performance. If corrective actions based on these trends occur in a timely manner, adverse project outcomes can be avoided.

Earned-value techniques can be used to summarize overall work status. The earned value of any one item being controlled is

$$\text{Earned work-hours} = (\text{Budgeted work-hours}) \times (\text{Percent complete})$$

Budgeted work-hours equal original budget plus approved changes.

Overall percent complete of the project or of a work package can be calculated as

$$\text{Percent complete} = \frac{\text{Sum of earned work-hours of tasks included}}{\text{Sum of budgeted work-hours of tasks included}}$$

Trends can be tracked through various indices, such as the Cost Performance Index (CPI) and the Schedule Performance Index (SPI). The CPI provides a comparison of the number of work-hours being spent on work tasks to the hours budgeted and is an indicator of productivity. The equation for CPI is

$$\text{CPI} = \frac{\text{Sum of earned work-hours of tasks included}}{\text{Sum of actual work-hours of tasks included}}$$

For the above to be a true indicator of productivity, only those tasks for which budgets have been established should be included in summations. If for some reason there is no budget for an item and people are working on that item, the project manager should prepare a change order for out-of-scope work. All actual work-hours need to be properly reported to establish accurate historical records for subsequent projects of a similar nature.

The SPI relates the amount of work performed, or level of effort, to the amount of work scheduled to a point in time. The equation for SPI is

$$\text{SPI} = \frac{\text{Sum of earned work-hours to date}}{\text{Sum of scheduled work-hours to date}}$$

Scheduled work-hours in the above equation are summarized from the task schedules. In both the CPI and SPI equations, an index of 1.0 or greater is favorable. Trends can be noted by plotting both “this period” and

“cumulative” CPI and SPI values on a graph. While the SPI for the total project, or for a work package, is somewhat of an indicator of schedule performance, it only compares volume of work performed to volume of work scheduled. There can be an SPI in excess of 1.0 that can still be in danger of not meeting milestones and final completion dates if managers are expending effort on non-critical activities at the expense of critical activities. The SPI does not show that work is being completed in the proper sequence. Thus, as part of schedule control, the schedules of all included tasks in each work package must be regularly examined so that any items behind schedule can be identified and corrective action taken to bring them back on schedule.

Measurement of Construction Work

A construction project requires completion of numerous tasks, beginning with initial clearing and site work through the final punchlist and cleanup. Throughout the duration of a project, there must be a systematic reporting of the progress of work for each part of the project. The following paragraphs describe six methods for measuring progress during construction: Units Completed, Incremental Milestone, Start/Finish, Supervisor Opinion, Cost Ratio, and Weighted Units. The system that is selected depends on the nature and complexity of the project and the desired level of control by the project manager. Each of the six methods may be used on a given project. As stated before, it is important to define the progress measurement method for construction in the PEP and to use it consistently during project construction. Regular and consistent progress measurement helps to identify trends in construction performance. If corrective actions based on these trends

occur in a timely manner, adverse project outcomes can be avoided.

The U.S. Departments of Defense and Energy have established what is known as the Cost and Schedule Control Systems Criteria (C/SCSC) for control of selected federal projects. While intended primarily for high-value, cost-reimbursable research and development projects, it may be applied to selected construction projects. Various methods for measuring the status of a project that have become common usage in the construction industry are described in C/SCSC.

The Units Completed method of measuring progress during construction is applicable to tasks that are repetitive and require a uniform effort. Generally, the task is the lowest level of control so only one unit of work is necessary to define the work. To illustrate, the percent complete for installation of wire is determined as a percentage, by dividing the number of feet installed by the total number of feet that is required to be installed.

The Incremental Milestone method is applicable to tasks that include subtasks that must be handled in sequence. For example, the installation of a major vessel in an industrial facility may include the sequential tasks as shown below. Completion of any subtask is considered a milestone, which represents a certain percentage of the total installation. The percentage may be established based on the estimated work-hours to accomplish the work.

Received and inspected	15%
Setting complete	35%
Alignment complete	50%
Internals installed	75%
Testing complete	90%
Accepted by owner	100%

The Start/Finish method is applicable to tasks that do not have well-defined intermediate milestones or for which the time required is difficult to estimate. For example, the alignment of a piece of equipment may take a few hours to a few days, depending on the situation. The workers may know when the work will start and when it is finished, but never know the percentage completion in between. For this method, an arbitrary percent complete is assigned at the start of the task and a 100% complete is assigned when it is finished. A starting percentage of 20% to 30% might be assigned for tasks that require a long duration, while 0% may be assigned for tasks with a short duration.

The Supervisor Opinion method is a subjective approach that may be used for minor tasks, such as construction support facilities, where development of a more discrete method cannot be used.

The Cost Ratio method is applicable for administrative tasks, such as project management, quality assurance, contract administration, or project control. These tasks involve a long period of time or are continuous throughout the duration of the project. Generally, these tasks are estimated and budgeted as lump-sum dollars and work-hours, rather than measurable quantities of production work. For this method, the percent complete can be calculated by the following equation.

$$\text{Percent complete} = \frac{\text{Actual cost or work-hours to date}}{\text{Forecast at completion}}$$

The Weighted Units method is applicable for tasks that involve major efforts of work that occur over a long duration of time. Generally, the work requires several overlapping subtasks that each have a different unit of measurement of work. This method is illustrated by the structural steel example shown in Figure 13-13. A common unit of measure for steel is tons. A weight is assigned to each subtask to

represent the estimated level of effort. Work-hours is usually a good measure of the required level of effort. As quantities of work are completed for each subtask, these quantities are converted into equivalent tons and percent complete is calculated as shown in Figure 13-13.

Wt.	Subtask	U/M	Quantity Total	Equivalent Steel Ton	Quantity to-date	Earned Tons*
0.02	Run foundation bolts	each	200	10.4	200	10.4
0.02	Shim	%	100	10.4	100	10.4
0.05	Shakeout	%	100	26.0	100	26.0
0.06	Columns	each	84	31.2	74	27.5
0.10	Beams	each	859	52.0	0	0.0
0.11	Cross-braces	each	837	57.2	0	0.0
0.20	Girts & sag rods	bay	38	104.0	0	0.0
0.09	Plumb & align	%	100	46.8	5	2.3
0.30	Connections	each	2977	156.0	74	3.9
0.05	Punch list	%	100	26.0	0	0.0
1.00	STEEL	TON		520.0		80.5

$$^{*}\text{Earned Tons to Date} = \frac{(\text{Quantity to date}) \times (\text{Relative Weight})}{(\text{Total Quantity})}$$

$$\text{Percent complete} = \frac{80.5 \text{ tons}}{520 \text{ tons}} = 15.5\%$$

FIGURE 13-13 Illustrative example of Weighted Units method for measurement of construction work. (*Source:* Construction Industry Institute, Publication No. 6-5.)

As presented in the previous paragraphs, there are many ways of measuring progress of work for each task in a project. After determining the progress of the different work tasks, the next step is to develop a method that combines the different work tasks to determine the overall percent complete for the project. The earned-value system can be used to define overall percent complete for the entire project. Earned value can be linked to the project budget,

which is expressed as work-hours or dollars. For a single account, the earned value can be calculated by the following equation.

$$\text{Earned value} = (\text{Percent complete}) \times (\text{Budget for that account})$$

A budgeted amount is “earned” as a task is completed, up to the total amount in that account. For example, an account may be budgeted at $10,000 and 60 work-hours. If the account is reported as 25% complete, as measured by one of the previously described methods, then the earned value is defined as $2,500 and 15 work-hours. Thus, progress in all accounts can be reduced to earned work-hours and dollars, which provides a method for summarizing multiple accounts and calculating overall progress for the total project. The equation for determining the overall project percent complete is given below.

$$\text{Percent complete} = \frac{(\text{Earned work-hours or dollars all accounts})}{(\text{Budgeted work-hours or dollars all accounts})}$$

The concepts discussed above provide a system for determining the percent complete of a single work task or combinations of tasks. This provides the basis for analyzing the results to determine how well work is proceeding, as compared to what was planned. The earned-value system provides a method for evaluating performance of the project.

Previous paragraphs have only discussed budgeted and earned work-hours and dollars. Actual work-hours and dollars must also be included to evaluate the performance evaluation of the project. The following definitions are provided to describe the procedure for evaluation of cost and schedule performance.

- Budgeted work-hours or dollars to date represent what is planned to do. The C/SCSC defines this as Budgeted Cost for Work Scheduled (BCWS).
- Earned work-hours or dollars to date represent what was done. The C/SCSC defines this as Budgeted Cost for Work Performed (BCWP).
- Actual work-hours or dollars to date represent what has been paid. The C/SCSC defines this as Actual Cost of Work Performed (ACWP).

Performance against schedule is a comparison of what was planned against what was done, that is, a comparison of budgeted and earned work-hours. If the budgeted work-hours are less than the earned work-hours, it means more was done than planned and the project is ahead of schedule. The opposite would indicate the project is behind schedule.

Performance against budget is measured by comparing what was done to what was paid. This compares earned work-hours to actual work-hours or cost. If more was paid than is done, then the project would have a cost overrun of the budget. The following variance and index equations can be used to calculate these values.

$$\mathrm{SV} = \mathrm{BCWP} - \mathrm{BCWS}$$

$$\mathrm{SPI} = \frac{\text{Earned work-hours or dollars to date}}{\text{Budgeted work-hours or dollars to date}}$$

$$\mathrm{SPI} = \frac{\mathrm{BCWP}}{\mathrm{BCWS}}$$

Cost variance (CV) = (Earned work-hours or dollars) − (Actual work-hours or dollars)

$$CV = BCWP - ACWP$$

$$CPI = \frac{\text{Earned work-hours or dollars to date}}{\text{Actual work-hours or dollars to date}}$$

$$CPI = \frac{BCWP}{ACWP}$$

A positive variance and an index of 1.0 or greater is a favorable performance.

Project Measurement and Control

The purpose of the project plan is to successfully control the project to ensure completion within budget and schedule constraints thereby achieving the owner's business and facility objectives. The S-curve, which plots cost (or work-hours) against time, provides a measure of schedule performance. Project elements of labor, materials, and equipment are usually evaluated in common units of dollars. Schedule performance indicates the rate at which these project elements are occurring as budgeted expenses. Performance measurements are based on earned-value concepts and S-curve analysis. The earned-value concept provides a quantitative measure of the scheduled budget value of work compared to the actual budgeted value of the work accomplished.

Measuring the progress of a project supports management in establishing a realistic plan for execution of a project and provides the project manager and client with a consistent analysis of project performance. Progress measurement also provides an early warning system via trending to identify deviations from the project plan and scope growth. To control engineering work, a drawing list, specification list, equipment list, instrument list, progress S-curve, and histogram of work-hours are used to determine

the project status and for continued planning. The project manager can use progress curves and work-hour histograms for different levels of the WBS.

Earned-Value System

The earned-value system is used to monitor the progress of work and compare accomplished work with planned work. The BCWS is the amount of money that was planned, or budgeted, at each time period in the project. It is determined by cost loading the CPM diagram to determine the distribution of cost in accordance with the project plan. The S-curve for a project represents the BCWS. The ACWP is the actual amount of money that has been spent at any point in time during the project. It is determined from project accounting records (not financial accounting records) or the responsible party that keeps records of actual expenditure of project funds (i.e., a field project controls analyst). The BCWP is the amount of money earned based on the work that has been completed. It is determined by multiplying the percent completed by the budgeted amount for the work. Below is a summary of the terms used in an earned-value analysis.

Earned-Value Analysis

BCWS = Budgeted cost of work scheduled	Planned
ACWP = Actual cost of work performed	Actual
BCWP = Budgeted cost of work performed	Earned

Variances

CV = BCWP − ACWP	Cost Variance = Earned − Actual
SV = BCWP − BCWS	Schedule Variance = Earned − Planned

Indices

$$CPI = \frac{BCWP}{ACWP} \qquad \text{Cost Performance Index} = \frac{\text{Earned}}{\text{Actual}}$$

$$SPI = \frac{BCWP}{BCWS} \qquad \text{Schedule Performance Index} = \frac{\text{Earned}}{\text{Planned}}$$

Forecasting:

$$BAC = \text{Original project estimate} \qquad \text{Budget at completion}$$

$$ETC = \frac{BAC - BCWP}{CPI} \qquad \text{Estimate to complete}$$

$$EAC = ACWP + ETC \qquad \text{Estimate at completion}$$

Ratios are used in the earned-value system to predict the cost to complete a project. The CPI is used to predict the magnitude of a possible cost overrun or underrun. It adjusts the budget based on past performance. The SPI is used to predict the magnitude of a possible time advance or delay. It adjusts the schedule based on past performance. The following examples illustrate the calculations in an earned-value analysis. The examples provide a progressive analysis of the project with an interpretation of the results based on the earned-value system for assessing project performance.

Example 13-2 The EPC project shown in Appendix A has an original planned schedule of 17 months with a budget of $45,797,250, excluding contingency (see Figure A-3). Figure A-10 shows the monthly distribution of costs for all activities of the project. The costs are shown on an early start, late start, and target schedule basis. The target schedule is used for planned BCWS cost in this earned value analysis. Below are update reports for the first 8 months of the project.

Status report for month	Planned (BCWS)	Earned (BCWP)	Actual (ACWP)
1	$58,935	$58,050	$59,520
2	$685,080	$643,980	$670,815
3	$2,773,560	$2,440,725	$2,871,435
4	$4,734,225	$4,639,545	$5,272,215
5	$7,190,145	$7,621,545	$7,857,270
6	$8,187,945	$8,351,700	$8,030,475
7	$10,008,150	$10,708,725	$9,915,480
8	$12,701,100	$12,193,050	$10,790,310

Perform an earned-value analysis of the project. For each report period, calculate the variances (CV and SV), the performance indices (CPI and SPI), the estimate to complete (ETC), and the estimate at completion (EAC). Prepare a graph similar to Figure 13-15 to show trends in the project performance. Figures 13-16 and 13-17 provide a guide to interpret the CPI and SPI for each reporting period. The first month's analysis is shown below.

Analysis of Month #1:
The status report after Month #1 into the project includes the following information:

$$\begin{aligned} \text{Planned, BCWS} &= \$58{,}935 \\ \text{Earned, BCWP} &= \$58{,}050 \\ \text{Actual, ACWP} &= \$59{,}520 \\ \text{Budget at Completion, BAC} &= \$45{,}797{,}250 \end{aligned}$$

Cost and Schedule Deviations:

$$\begin{aligned} \text{Cost Variance} &= \text{BCWP} - \text{ACWP} \\ &= \$58{,}050 - \$59{,}520 \\ &= -\$1{,}470 \end{aligned}$$

A negative value of CV represents a cost overrun. Based on the status report, the actual cost is greater than earned by $1,470.

$$\begin{aligned} \text{Schedule Variance} &= \text{BCWP} - \text{BCWS} \\ &= \$58{,}050 - \$58{,}935 \\ &= -\$885 \end{aligned}$$

A negative value of SV represents a schedule slippage. The project is behind the planned schedule.

Cost and Schedule Performance:

$$\begin{aligned}\text{Cost Performance Index, CPI} &= \text{BCWP}/\text{ACWP}\\ &= \$58{,}050/\$59{,}520\\ &= 0.98\end{aligned}$$

The CPI is less than 1, which indicates a poor cost performance. The earned value is less than the actual costs.

$$\begin{aligned}\text{Schedule Performance Index, SPI} &= \text{BCWP}/\text{BCWS}\\ &= \$58{,}050/\$58{,}935\\ &= 0.98\end{aligned}$$

The SPI is less than 1, which indicates the schedule performance is worse than planned. The project is behind schedule.

Forecasting Cost at Completion

$$\begin{aligned}\text{Estimate to Complete, ETC} &= (\text{BAC} - \text{BCWP})/\text{CPI}\\ &= (\$45{,}797{,}250 - \$58{,}050)/0.98\\ &= \$46{,}672{,}653\end{aligned}$$

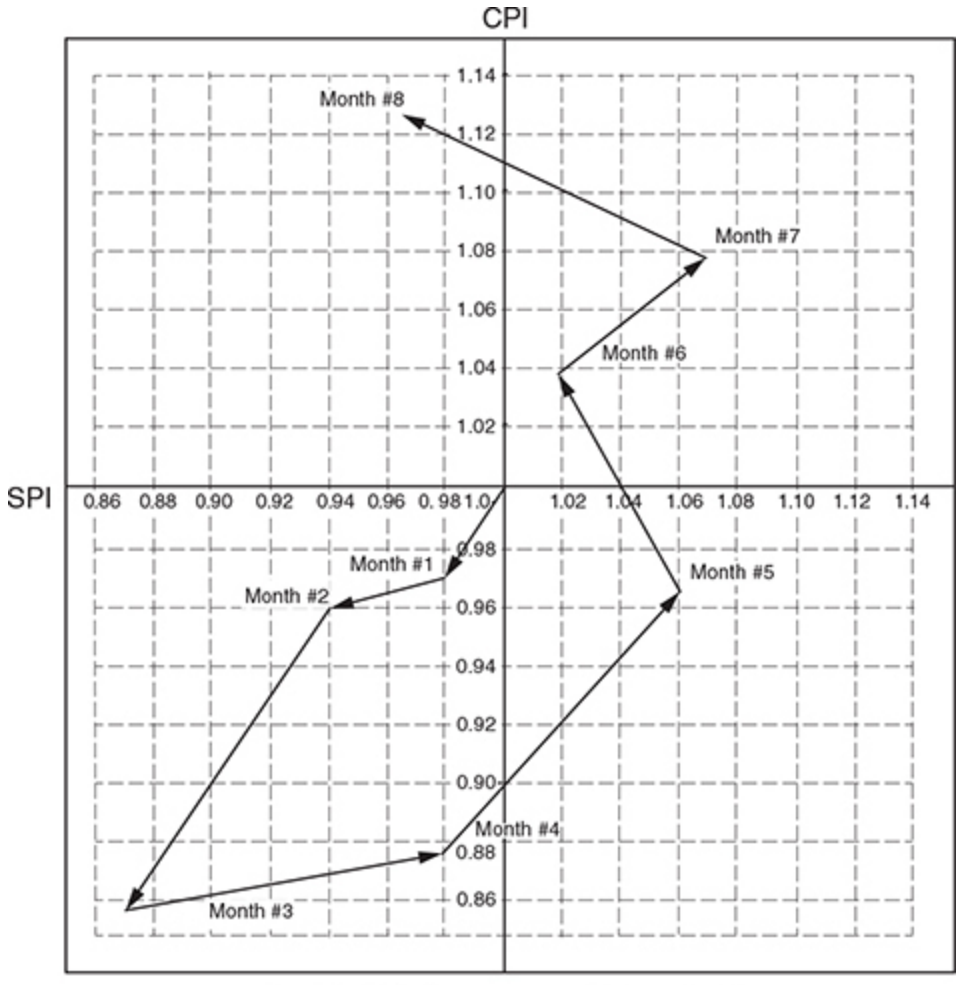
Based on the analysis of the status report, the remaining cost to complete the project is $46,672,653.

$$\begin{aligned}\text{Estimate at Completion, EAC} &= \text{ACWP} + \text{ETC}\\ &= \$59{,}520 + \$46{,}672{,}653\\ &= \$46{,}732{,}173\end{aligned}$$

Based on analysis of the status report, the estimated cost of the project at completion is $46,732,173, which is $934,653 over the original budget of $45,797,520.

Following is a summary of the earned-value analysis and a project performance chart comparing CPI to SPI for the 8 months. SPI is plotted on the horizontal axis; CPI is plotted on the vertical axis.

Earned Value Analysis by Month						
Month	CV = BCWP – ACWP	SV = BCWP – BCWS	CPI = BCWP / ACWP	SPI = BCWP / BCWS	ETC = (BAC – BCWP) / CPI	EAC = ACWP + ETC
Month #1	–$1,470	–$885	0.98	0.98	$46,672,653	$46,732,173
Month #2	–$26,835	–$41,100	0.96	0.94	$47,034,656	$47,705,471
Month #3	–$430,710	–$332,835	0.85	0.88	$51,007,676	$53,879,111
Month #4	–$632,670	–$94,680	0.88	0.98	$46,770,119	$52,042,334
Month #5	–$235,725	$431,400	0.97	1.06	$39,356,397	$47,213,667
Month #6	$321,225	$163,755	1.04	1.02	$36,005,337	$44,035,812
Month #7	$793,245	$700,575	1.08	1.07	$32,489,375	$42,404,855
Month #8	$1,402,740	–$508,050	1.13	0.96	$29,738,230	$40,528,540



Project Performance—CPI and SPI

Example 13-3 Provide an earned-value analysis to evaluate the progress of the sewer and water lines project shown in Figure 10-6. The original budget is $147,500 and the project is scheduled to be completed in 94 working days. A status report after 10 working days into the project includes the following information:

Water & Sewer Line Project Status after 10 working days

BAC: $147,500 **Schedule:** 94 working days

Current Period: 10 working days

Activity ID	% Complete	Schedule	Actual Cost
10	100%	Complete as scheduled	$1,500
20	100%	Complete as scheduled	$2,200
30	100%	Complete as scheduled	$4,000
BCWP	**ACWP**	**BCWS**	
$7,600	$7,700	$7,600	

The BCWS and BCWP shown above are the same values as shown on the 10th working day in Figure 10-12 because Activities 10, 20, and 30 were all completed according to the original planned schedule.

The earned-value analysis is summarized below.

Earned Value Analysis for Sewer & Water Line Project after 10 working days		
CV = BCWP – ACWP	–$100	Negative CV represents a cost overrun. Based on the status report, the actual cost is greater than the earned cost by $100.
SV = BCWP – BCWS	0	SV is 0 which means the project is progressing as planned. The project is not ahead or behind schedule.
CPI = BCWP/ACWP	0.987	CPI is less than 1.0, indicating a poor cost performance. The earned value is less than the actual costs.
SPI = BCWP/BCWS	1.000	SPI is equal to 1.0, indicating the schedule performance is progressing according to plan.
ETC = (BAC – BCWP)/CPI	$141,743	This is the remaining cost, based on performance to date, to complete the project.
EAC = ACWP + ETC	$149,443	Based on the analysis of the status report, the project cost at completion will exceed the project's budgeted cost.
(Over)/Under Budget	–$1,943	

Example 13-4 Provide an earned-value analysis to evaluate the progress of the sewer and water lines project shown in Figure 10-6. The original budget is $147,500 and the project is scheduled to be completed in 94 working days. A status report after 20 working days into the project includes the following information:

Water & Sewer Line Project Status after 20 working days

BAC: $147,500 **Schedule:** 94 working days

Current Period: 20 working days

Activity ID	% Complete	Schedule	Actual Cost
40	100%	2 days delayed	$8,000
50	60%	2 days delayed	$3,200
60	50%	Out of sequence start	$6,300
	BCWP	**ACWP**	**BCWS**
Current status:	$22,720	$25,200	$22,400
Previous status:	$7,600	$7,700	$7,600

The BCWS shown above is different than the value shown on the 20th working day in Figure 10-12 because Activities 40, 50, and 60 have been completed at different times than the original planned schedule. The BCWS of $22,400 shown above is based on an updated schedule for the project. Also, the BCWP is based on the updated schedule.

The earned-value analysis for the project is summarized below.

Earned Value Analysis for Sewer & Water Line Project after 20 working days		
CV = BCWP – ACWP	–$2,480	Negative CV represents a cost overrun. Based on the status report, the actual cost is greater than the earned cost by $2,480.
SV = BCWP – BCWS	$320	SV is $320 which means the earned value is greater than planned. The project has greater than planned effort and may be ahead of schedule.
CPI = BCWP/ACWP	0.902	CPI is less than 1.0, indicating a poor cost performance. The earned value is less than the actual costs.
SPI = BCWP/BCWS	1.014	SPI is greater than 1.0, indicating the schedule performance is progressing better than plan.
ETC = (BAC – BCWP)/CPI	$138,337	This is the remaining cost, based on performance to date, to complete the project.
EAC = ACWP + ETC	$163,537	Based on the analysis of the status report, the project cost at completion will exceed the project's budgeted cost and is significantly worse than the status of Example 13-3.
(Over)/Under Budget	–$16,037	

Example 13-5 Provide an earned-value analysis to evaluate the progress of the sewer and water lines project shown in Figure 10-6. The original budget is $147,500 and the project is scheduled to be completed in 94 working days. A status report after 25 working days into the project includes the following information:

Water & Sewer Line Project Status after 25 working days

BAC: $147,500 **Schedule:** 94 working days

Current Period: 25 working days

Activity ID	% Complete	Schedule	Actual Cost
50	100%	1 more day delay	$6,200
60	100%	No additional delays	$12,600
70	100%	Complete, no delays	$2,100
	BCWP	**ACWP**	**BCWS**
Current status:	$33,000	$36,600*	$31,740
Previous status:	$22,720	$25,200	$22,400

*Includes final actual costs of Activities 10–70

The earned-value analysis for this status report is summarized below.

Earned Value Analysis for Sewer & Water Line Project after 25 working days		
CV = BCWP – ACWP	–$3,600	Negative CV represents a cost overrun. Based on the status report, the actual cost is greater than the earned cost by $3,600.
SV = BCWP – BCWS	$1,260	SV is $1,260 which means the earned value is greater than planned. The project has greater than planned effort and may be ahead of schedule.
CPI = BCWP/ACWP	0.902	CPI is less than 1.0, indicating a poor cost performance. The earned value is less than the actual costs.
SPI = BCWP/BCWS	1.040	SPI is greater than 1.0, indicating the schedule performance is progressing better than plan.
ETC = (BAC – BCWP)/CPI	$126,940	This is the remaining cost, based on performance to date, to complete the project.
EAC = ACWP + ETC	$163,540	Based on the analysis of the status report, the project cost at completion will exceed the project's budgeted cost and is about the same as Example 13-4.
(Over)/Under Budget	–$16,040	

Example 13-6 Provide an earned-value analysis to evaluate the progress of the sewer and water lines project shown in Figure 10-6. The original budget is $147,500 and the project is scheduled to be completed in 94 working days. A status report after 70 working days into the project includes the following information:

Water & Sewer Line Project Status after 70 working days

BAC: $147,500 **Schedule:** 94 working days

Current Period: 70 working days

Activity ID	% Complete	Schedule	Actual Cost
80	100%	Complete, no delays	$14,000
90	100%	Complete, no delays	$800
100	100%	Complete, no delays	$1,400
110	100%	Complete, no delays	$5,000
130	100%	Complete, no delays	$4,500
140	20%	No delays	$680
160	30%	No delays	$2,100
	BCWP	**ACWP**	**BCWS**
Current status:	$56,830	$65,080	$102,800
Previous status:	$33,000	$36,600	$31,740

The earned-value reporting for this project status is provided below.

Earned Value Analysis for Sewer & Water Line Project after 70 working days		
CV = BCWP – ACWP	–$8,250	Negative CV represents a cost overrun. Based on the status report, the actual cost is greater than the earned cost by $3,600.
SV = BCWP – BCWS	–$45,970	SV is a negative value of $45,970 which means the earned value is less than planned. The project has less than planned effort and may be behind schedule.
CPI = BCWP/ACWP	0.873	CPI is less than 1.0, indicating a poor cost performance. The earned value is less than the actual costs.
SPI = BCWP/BCWS	0.553	SPI is greater than 1.0, indicating the schedule performance is progressing better than plan.
ETC = (BAC – BCWP)/CPI	$103,860	This is the remaining cost, based on performance to date, to complete the project.
EAC = ACWP + ETC	$168,940	Based on the analysis of the status report, the project cost at completion will exceed the project's budgeted cost by $21,440 which is a significant cost overrun.
(Over)/Under Budget	–$21,440	

Figure 13-14 shows the variation by reporting period of CPI and SPI for Examples 13-3 through 13-6. CPI and SPI can also be compared similar to Example 2 in order to show project performance.

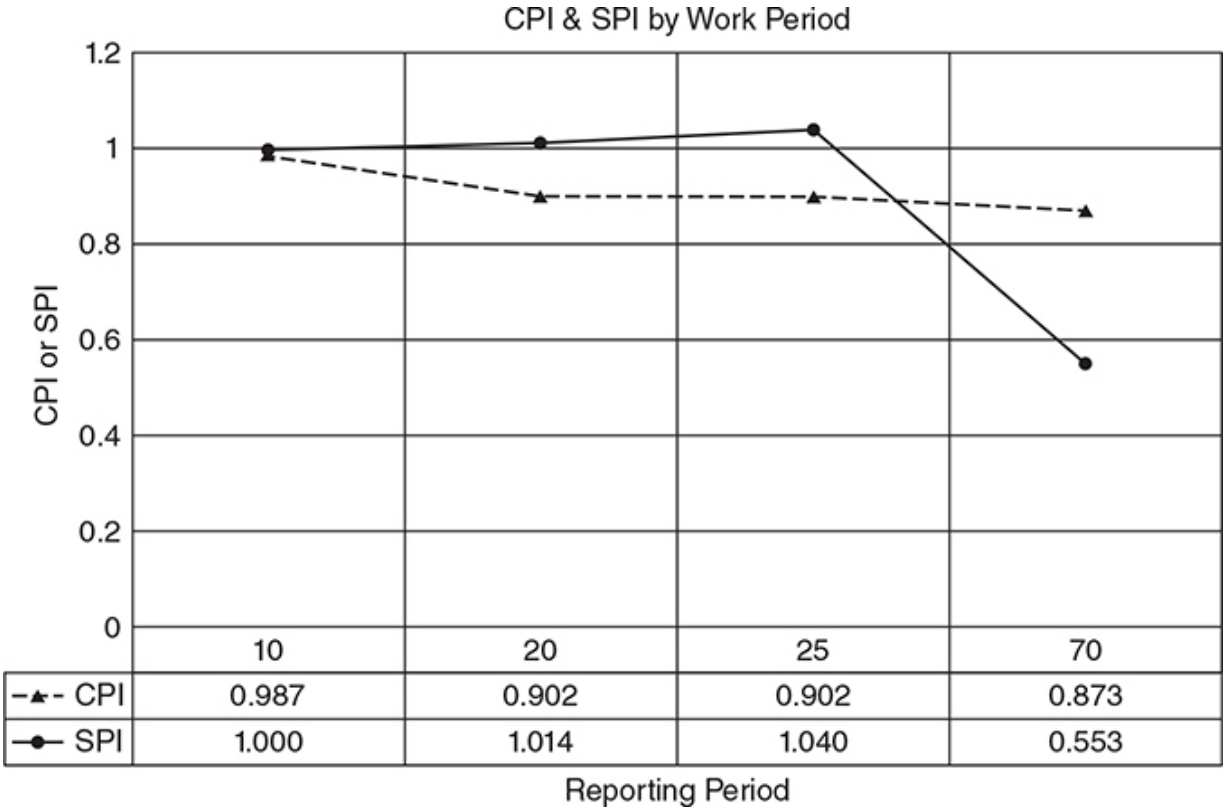


FIGURE 13-14 CPI and SPI variation by reporting period for example problems 13-3 through 13-6.

Monitoring Project Performance

The CPI and SPI provide a quantity measurement of the progress of a project. Values of CPI or SPI that are greater than 1.0 indicate good project performance, whereas values of CPI or SPI that are less than 1.0 indicate poor project performance. Values of these indices can be plotted on a graph as shown in Figure 13-15 to evaluate project performance during routine reporting periods. The greatest value of measuring CPI and SPI regularly during a project is identifying trends early. Unexplained trends or sudden changes should alert the project manager to investigate and take corrective action if warranted.

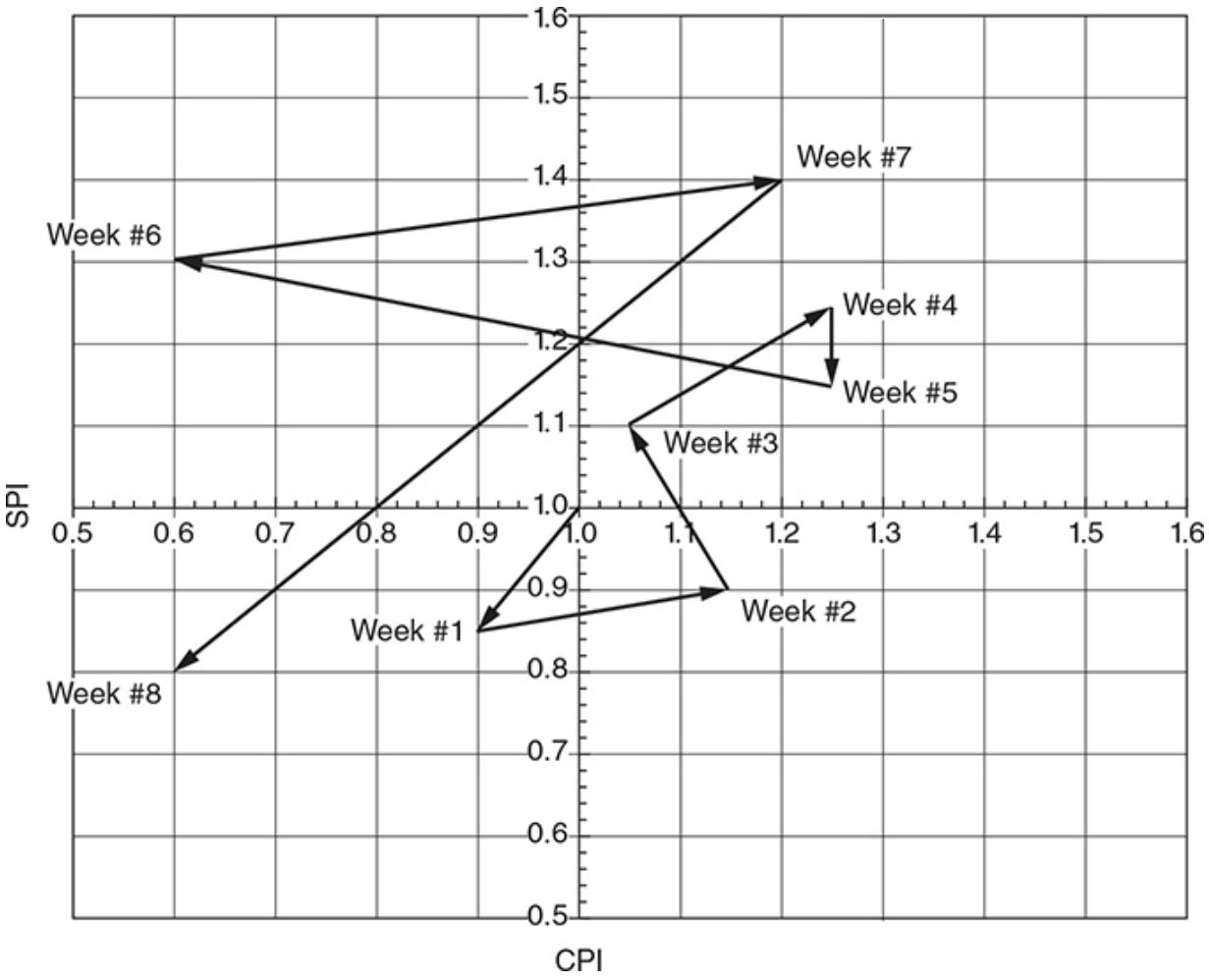


FIGURE 13-15 Monitoring project performance—the CPI and SPI.

As shown in Figure 13-15, a project begins with a CPI and SPI equal to 1.0. Projects are dynamic in nature due to events that can impact the cost and the schedule. Therefore, it is expected that these performance indices will deviate from this initial starting point of 1.0 as the project progresses from week to week. The project manager should not overreact to slight changes in the CPI and SPI. For example, the first 2 weeks of the project show small changes in the performance indices, which might be expected during the early progress of the project.

Although minor deviations are expected, major deviations from one report period to the next should alert the project manager to investigate the reason for the significant change in the project performance. For example, the report between weeks 7 and 8 shows a dramatic change toward poor project performance. This type of report merits the attention of the project manager to solicit team members to identify what has happened in the project and the reason for this dramatic change in project performance.

Concern should also be raised if the trend of the CPI and SPI is progressing toward poor performance. For example, from week 2 through week 4, the project performance trend is toward good. However, significant changes in the project begin to appear during weeks 6, 7, and 8.

Thus, the project manager must be vigilant regarding changes in the project. The CPI and SPI provide some of the information needed by the project manager to monitor the progress of work to ensure the project is moving in the right direction toward successful completion.

Interpretation of Performance Indices

The graph shown in Figure 13-15 is a valuable tool for the project manager to monitor project performance based on progress reports. It provides a measure of how well the planned cost compares to actual expenditures and work accomplished. As deviations occur between the values, several interpretations can be made.

Values of SPI greater than 1.0 indicate the project is ahead of schedule. The project may be progressing faster than expected if the original production rates were predicted too low or the actual working conditions are better than originally anticipated. There may be more staffing on the project than anticipated, which would also show the work as progressing ahead of schedule. Values of SPI less

than 1.0 indicate the project is behind schedule. The project schedule may slip due to weather delays, understaffing, or disorganized work.

Values of CPI greater than 1.0 indicate good project cost performance. Good cost performance may be reported if actual productivity is better than planned or if the measured percent of completed work is too high. Values of CPI less than 1.0 indicate poor cost performance, which may be a result of poorer than planned productivity or due to an underestimate of the measured percent of completed work.

The project manager should seek information from team members to provide a better interpretation of the meaning of project performance indices. Figures 13-16 and 13-17 provide additional interpretations of CPI and SPI data.

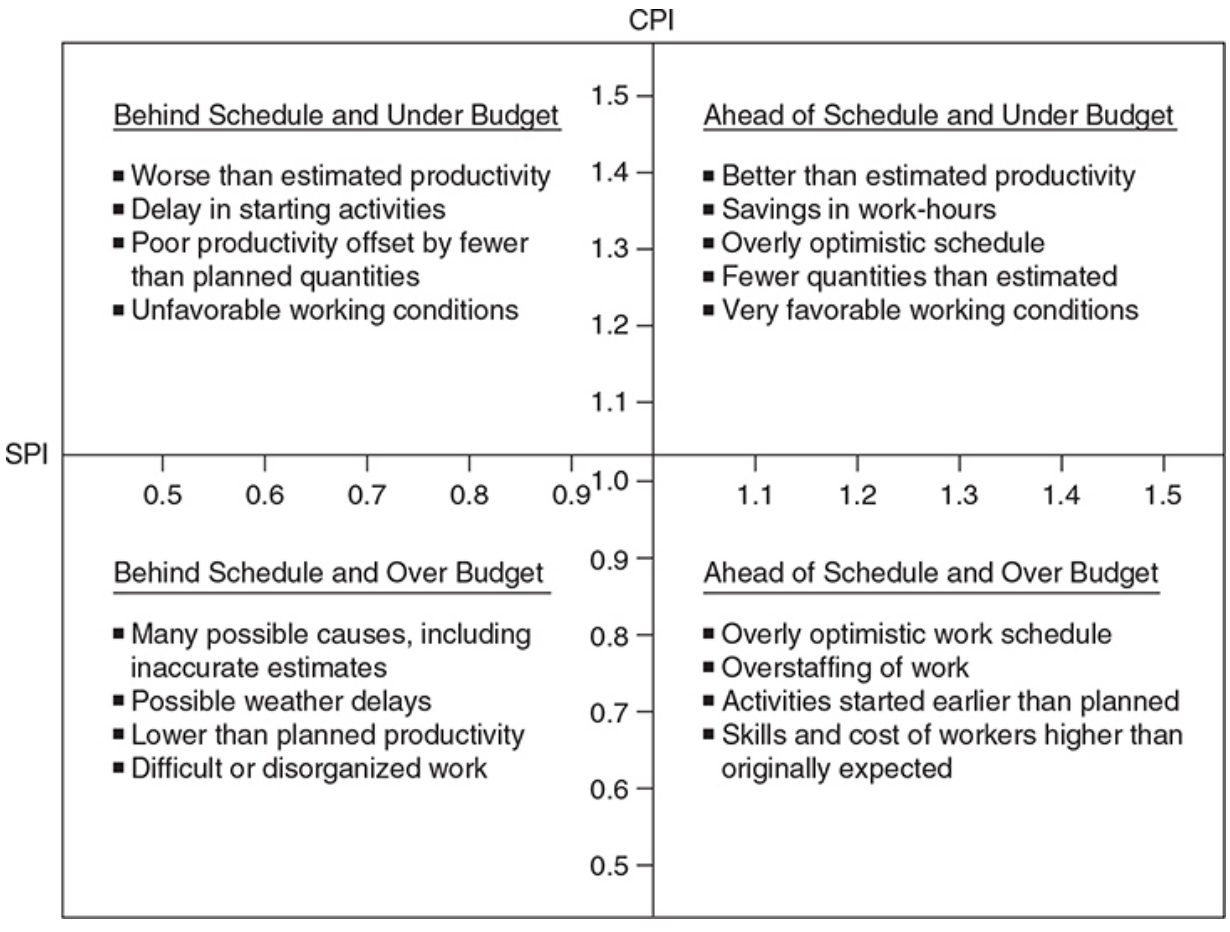


FIGURE 13-16 Interpretations of Cost Performance Index (CPI) and Schedule Performance Index (SPI).

If **CPI** is *greater* than 1.0:	
	Overestimated amount of effort required.
	Measurement of percent complete is too optimistic.
	Better than planned productivity.
If **CPI** is *less* than 1.0:	
	Underestimated amount of effort required.
	Measurement of percent complete is too pessimistic.
	Poorer than planned productivity.
If **SPI** is *greater* than 1.0:	
	Started work prior to or out of sequence to logical constraints.
	Better than planned productivity resulting in activities completing early.
	Working on critical activities.
If **SPI** is *less* than 1.0:	
	Understaffing or underequipping activities.
	Delayed in starting of activities.
	Work is more difficult than planned.
	Improper sequencing of activities.
	Work is disorganized.

FIGURE 13-17 Various interpretations of CPI and SPI.

Analysis Tree of Total Float and Schedule Performance Index

The total float is a measure of slack time in the project, and the SPI is a measure of schedule performance. In a pure CPM precedence diagram, activities with zero total float are identified as critical, and these activities form the critical path in the project schedule. However, using successor/predecessor activity constraints can cause a total float of greater than zero for activities on the critical path. Also, total float values other than zero are often the result of

updates in the schedule when actual starts and finishes are introduced.

Understanding of the schedule can be further complicated when activities are given a specific calendar start or finish date, which can lead to a total float of greater or less than zero for activities on the critical path. For example, the scheduler may specify a time certain for an activity, such as specifying the activity to start or finish on a specific date, to start or finish not earlier than a specific date, or to start or finish not later than a specific date. Refer to Chapter 10, Project Planning and Scheduling, for more on schedule logic.

For any project, the SPI may also be greater than, less than, or equal to 1.0. Values greater than 1.0 indicate good performance and values less than 1.0 indicate poor performance. Thus, the project manager's analysis of project performance is complicated due to various total float and schedule performance indices. Figure 13-18 is an analysis tree for assessment of total float with respect to SPI.

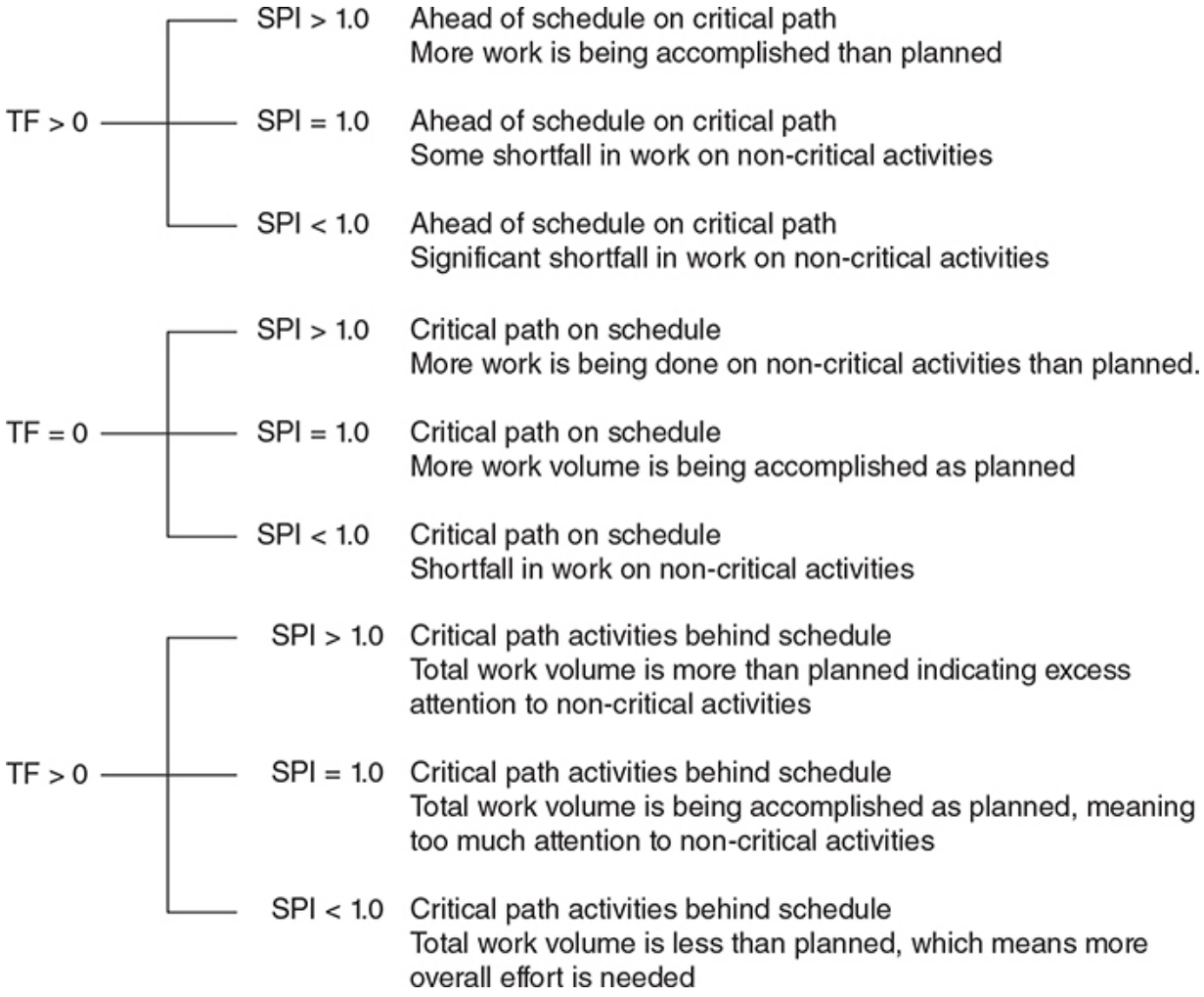


FIGURE 13-18 Analysis tree for total float and Schedule Performance Index.

Causes of Cost/Schedule Variances

The earned-value system identifies the magnitude of cost and schedule deviations from the original project plan. However, it does not identify the cause of the problem. The project manager and his or her team must assess each status report to identify the reason the project is not progressing as planned. The problems can be the result of numerous situations.

The original cost estimate is the Budget At Completion (BAC) in the earned-value analysis; this is the project budget authorized at the end of the Project Definition phase. Therefore, if the original cost estimate for the project is incorrect, then all progress measurements during execution of the project would be measured against an incorrect budget. The system of recording costs charged against the job must be consistent to provide realistic comparisons from one reporting period to another.

Also, the method of measuring work completed must also be consistently applied from one reporting period to another; otherwise, the predicted status of the job will vary widely. Each project must be assessed based on the unique circumstances and conditions that apply to the project in order to use the earned-value system to manage the project. Below is a partial list of items that can cause the cost or schedule to vary from the original project plan.

- Estimating errors
- Technical problems
- Design errors
- Test data problems
- Constructability
- Equipment problems
- Management problems
- Scope control (change orders)
- Personnel skill level
- Resource availability
- Organization structure
- Economics/inflation
- Delayed material deliveries
- Delayed equipment deliveries

- Poor production rates
- Subcontractor interference and delays
- Acts of God (weather, fire, flood, etc.)
- Accidents during construction

Trend Analysis and Forecasting

The preceding sections presented methods for measurement of planned and actual costs, schedules, and accomplishment of work. To be effective, a project control system must routinely collect and record the information from the start of the project. At each reporting period, the actual status can be compared to the planned status, so that necessary corrective actions can be taken. As the information is accumulated, a trend analysis can be performed to evaluate the productivity and the variances in costs and schedules. Figure 13-19 is a graphical display of the schedule, cost, and time variance at a particular progress reporting period.

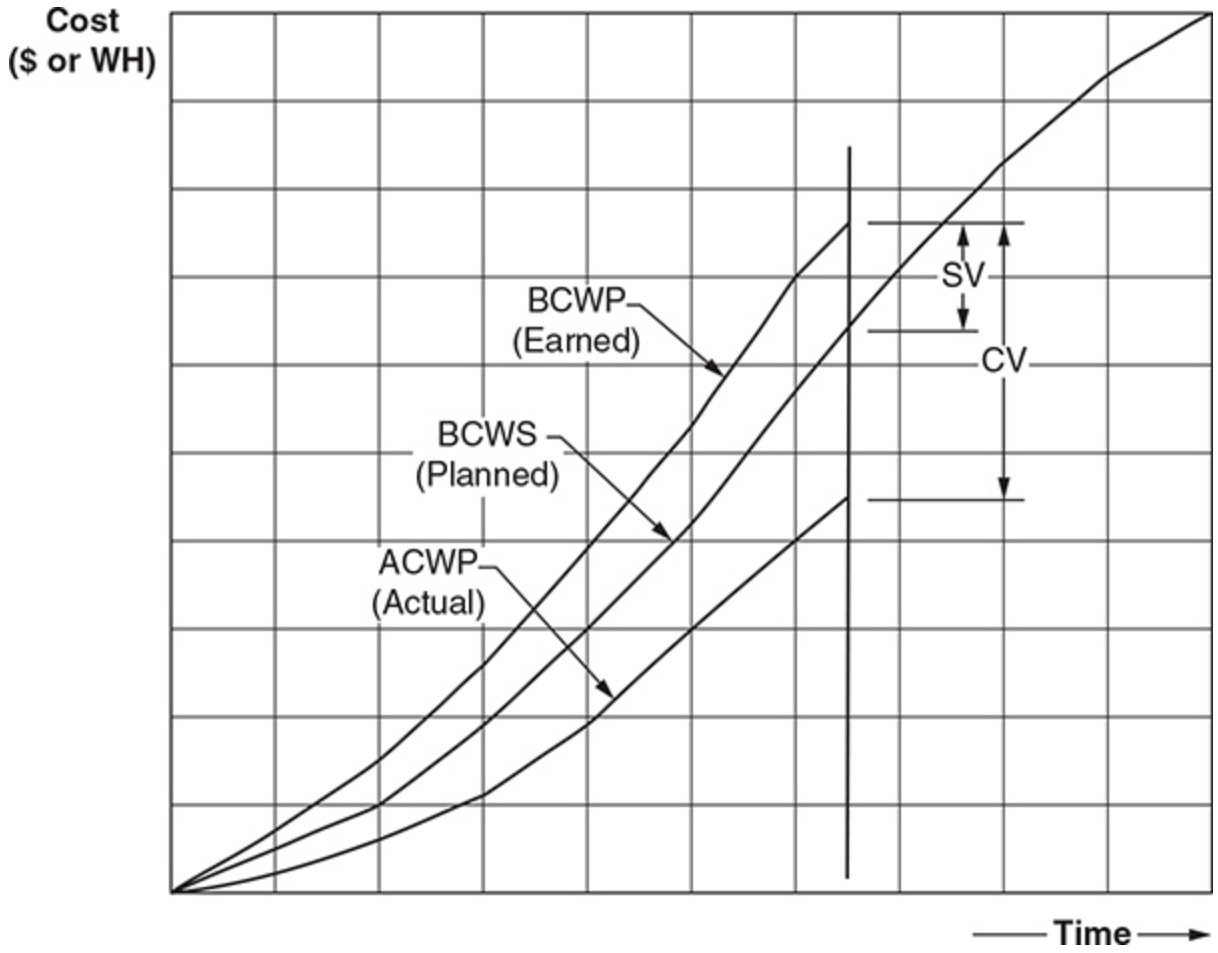


FIGURE 13-19 Cost and schedule variance graph.

A visual display of schedule status is best presented as a bar chart. A sample of an excellent format for summary level reporting to management is shown in Figure 13-20, which is an adaptation of material in CII document 6-5. This simple one-page format provides a significant amount of project information. Key scope components (Major Components) are listed at the far left. Their respective planned and earned work-hours are in the next column (Work-Hours). The % Project column calculates the percent of total project work-hours for each scope item. For example, the Steam and Condensate component of the project constitutes 33.5% of the total planned work-hours for the project (21,554 WH/64,268 WH). The bar chart area

shows the planned and earned percentages for each scope item along the timeline at the top. The lower graph is a cumulative work-hour plot for cumulative work-hours planned and cumulative work-hours earned. From the report, the project has earned 27,016 work-hours or 42% of the work-hours versus 70% planned completion. This project is significantly behind schedule.

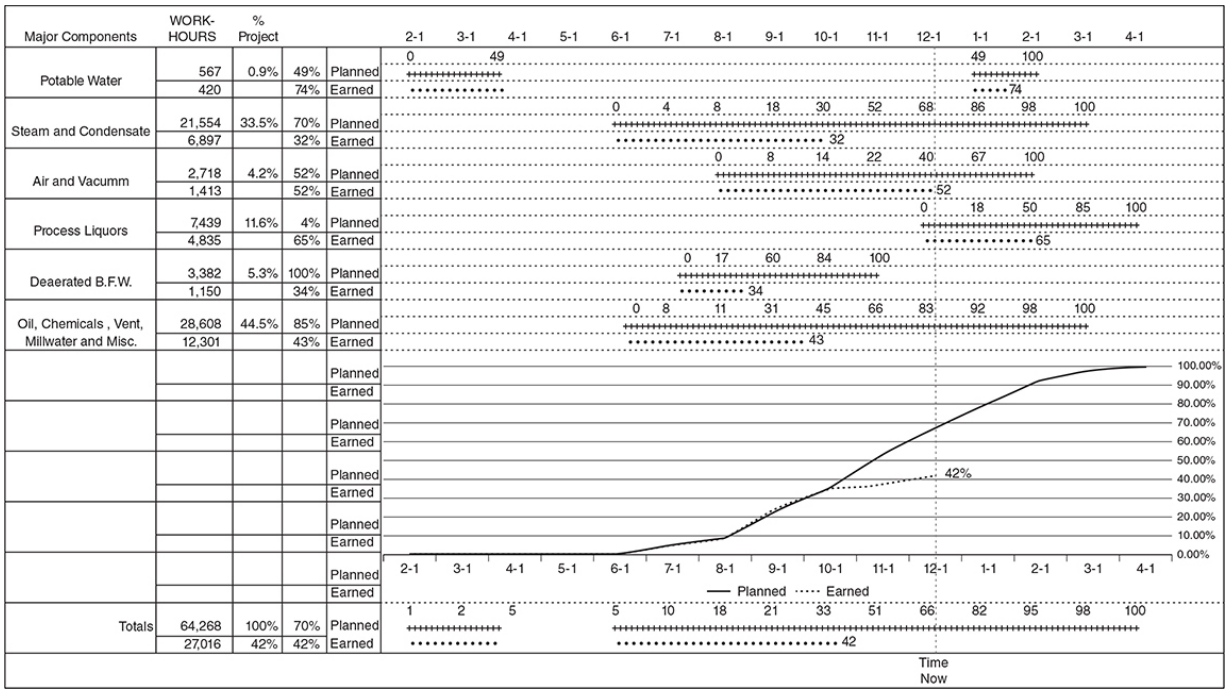


FIGURE 13-20 Illustrative summary level report for management.

While this one-page format provides much usable project performance information, a significant amount of effort is required to define and to collect the performance data used to produce the report. What this summary level report does not show are the actual work-hours expended to date. It also does not show or provide the actual start and finish dates for each major component. Finally, the report does not give any indication of project cost performance. It is one tool of many that the project manager can use to monitor project performance.

A project manager is always interested in knowing how the actual productivity compares to the productivity that was used in planning the project and estimating the budget. Although there is no industry standard for calculating productivity, the following equation is a common expression of productivity.

$$\text{Productivity index} = \frac{\text{Estimated unit rate}}{\text{Actual unit rate}}$$

This equation is valid for calculating productivity for tasks that have measurable units of work. A productivity value of 1.0 or greater is favorable, whereas a value of less than 1.0 is unfavorable. The equation can be used to calculate the productivity of tasks at each reporting period. A productivity profile can then be produced for key crafts by plotting productivity against time as illustrated in Figure 13-21. Percent complete can be used in lieu of time for the abscissa of the graph.

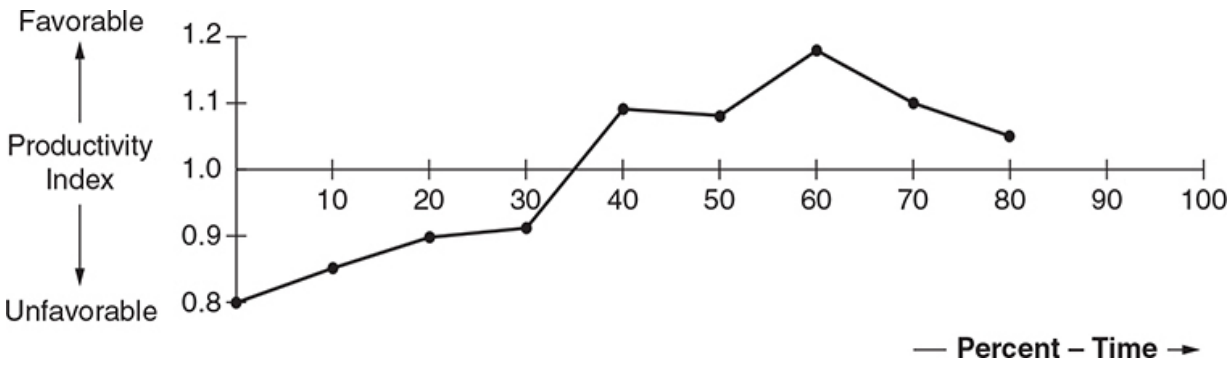


FIGURE 13-21 Craft productivity profile.

As indicated in Figure 13-21, productivity varies over the life of a project. Minor variations are normal and should be expected due to the nature of project work. Significant variations justify the attention of management to identify the source of the problem and assist in any necessary corrective action. The problem may be due to low skill or

morale of workers, insufficient staff, late delivery of material, unavailable tools or equipment, inadequate instruction, inclement weather conditions, technical difficulties, or poor field supervision. Since the productivity index includes an estimated unit rate, the source of the problem may be due to poor initial estimates. Trends in the productivity index provide an effective tool for project management. Almost everyone involved in a project is concerned with costs. As presented in previous sections, the work plan includes a distribution of costs that are anticipated throughout the duration of a project. At each reporting period, the actual costs to date can be compared to the planned costs for that period in time. The cost ratio is the ratio of estimated costs to actual costs as defined below.

$$\text{Cost ratio} = \frac{\text{Estimated cost}}{\text{Actual cost}}$$

This equation can be used to calculate the cost ratio at each reporting period and plotted against time to show cost trends for a project (see Figure 13-22). A cost ratio of 1.0 or higher is favorable, whereas a value of less than 1.0 is unfavorable. Cost ratios can be calculated for tasks, grouping of tasks, or for the entire project. A similar analysis can be performed for the schedule.

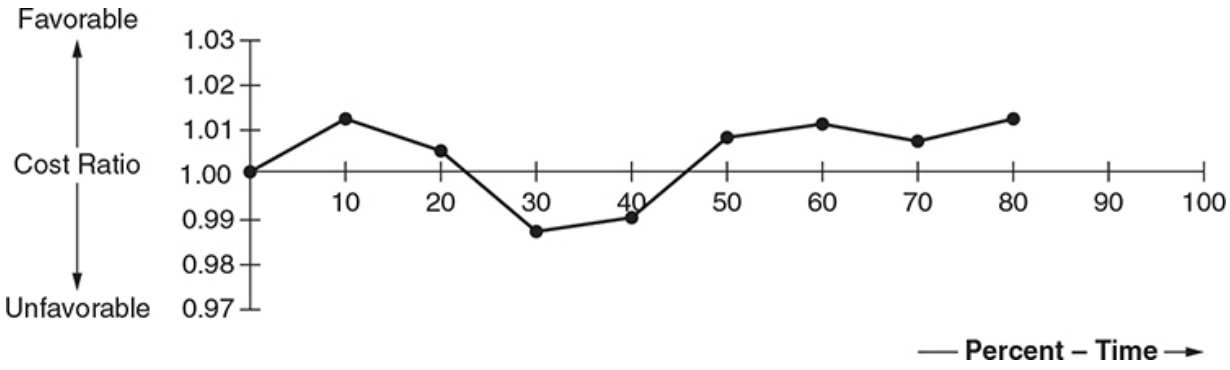


FIGURE 13-22 Cost ratio.

As a project progresses, the cost ratio trend can be used as an indicator to forecast the probable total cost at completion. Likewise, a schedule variance trend can be developed as an indicator to forecast the probable completion date of a project. The cost and schedule forecasting can be accomplished by using one of the various curve fitting techniques. Then, by extrapolating the data to produce a best fit curve, the trend may be extended to the future date.

Work Status System

The Cost and Schedule Control Systems Criteria (C/SCSC) described earlier is an effective method for managing the cost and schedule of a project. It requires a well-defined Work Breakdown Structure (WBS) and a detailed project schedule. It is only effective if the cost and schedule data are reported in a timely manner. For some engineering design, the total time to complete a project is short; therefore, the project may be substantially complete before cost data is reported. For some project managers, the C/SCSC method appears complicated and difficult to use.

An alternate method that is preferred by some project managers for tracking engineering design work is a work status system that tracks costs and work-hours. Figure 13-23 is a cost status report, and Figure 13-24 is a work-hour status report that illustrates the work status system method for project tracking. For this example, the project is divided into three general categories: direct engineering, indirect engineering, and expenses. The direct engineering category is subdivided into the disciplines that are required to accomplish the work: architectural, civil, electrical, mechanical, and structural. Likewise, major work that is required for indirect engineering and expenses are subdivided as shown in Figures 13-23 and 13-24.

EXAMPLE CLIENT
EXAMPLE WAREHOUSE FACILITIY
Example Project Location
Cost Status Report

Example Client Project Numbers
As of 31 July 2033

Description	A	B	C	D = A + B + C	E	F	G = E + F	H	I = G/D
	Original Budget	Approved by Change Order	Growth	Budget at Completion	Cumulative to Last Period	This Period	Cost to Date	Estimated at Completion	Percent Complete
	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	%
DIRECT ENGINEERING									
Architectural	$9,799		$2,900	$12,699	$0	$0	$0	$12,699	0.0%
Civil	$4,055		$3,674	$7,729	$217	$1,366	$1,583	$7,729	20.5%
Electrical	$17,203		$2,929	$20,132	$1,327	$529	$1,856	$20,132	9.2%
Mechanical	$44,330		$1,324	$45,654	$7,207	$2,999	$10,206	$45,654	22.4%
Structural	$11,278		$14,086	$25,364	$159	$0	$159	$25,364	0.6%
Subtotal	$86,665	$0	$24,913	$111,578	$8,910	$4,894	$13,804	$111,578	12.4%
INDIRECT ENGINEERING									
Project Manager	$23,412	$12,606		$36,018	$5,794	$1,921	$7,715	$36,018	21.4%
Scheduler	$0	$18,552		$18,552	$3,667	$1,245	$4,912	$18,552	26.5%
Clerical	$0	$3,530		$3,530	$529	$462	$991	$3,530	28.1%
Subtotal	$23,412	$34,688	$0	$58,100	$9,990	$3,628	$13,618	$58,100	23.4%
EXPENSES									
CADD Expense	$9,100			$9,100		$80	$80	$9,100	0.9%
Travel	$1,200			$1,200		$33	$33	$1,200	2.8%
Postage	$300			$300		$0	$0	$300	0.0%
Reproduction	$400			$400		$0	$0	$400	0.0%
Subtotal	$11,000	$0	$0	$11,000	$0	$113	$113	$11,000	1.0%
TOTAL	$121,077	$34,688	$24,913	$180,678	$18,900	$8,635	$27,535	$180,678	15.2%

FIGURE 13-23 Cost status report.

EXAMPLE CLIENT
EXAMPLE WAREHOUSE FACILITIY
Example Project Location
Work-Hour Status Report

Example Client Project Numbers
As of 31 July 2033

Description	A	B	C	D = A + B + C	E	F	G = E + F	H	I = G/D
	Original Budget	Approved by Change Order	Growth	Budget at Completion	Cumulative to Last Period	This Period	Cost to Date	Estimated at Completion	Percent Complete
	Work-Hours	Work-Hours	Work-Hours	Work-Hours	Work-Hours	Work-Hours	Work-Hours	Work-Hours	%
DIRECT ENGINEERING									
Architectural	240		104	344	0	0	0	344	0.0%
Civil	100		94	194	4	35	39	194	20.1%
Electrical	324		70	394	25	13	38	394	9.6%
Mechanical	828		42	870	135	53	188	870	21.6%
Structural	200		352	552	3	0	3	552	0.5%
Subtotal	1,692	0	662	2,354	167	101	268	2,354	11.4%
INDIRECT ENGINEERING									
Project Manager	390	210		600	120	32	152	600	25.3%
Scheduler	0	400		400	79	27	106	400	26.5%
Clerical	0	150		150	24	22	46	150	30.7%
Subtotal	390	760	0	1,150	223	81	304	1,150	26.4%
EXPENSES									
CADD Expense	961			961		0	0	961	0.0%
Subtotal	961	0	0	961	0	0	0	961	0.0%
TOTAL	3,043	760	662	4,465	390	182	572	4,465	12.8%

FIGURE 13-24 Work-hour status report.

The titles at the top of the columns identify the entries in the spreadsheet. The first column (A) of data represents the original approved project budget, the second column (B) is the approved change orders, and the third column (C) represents the growth in budget that is required to complete the work. Column (D) is the calculated total budget at the completion of the project and is calculated as the sum of the data in the first three columns.

Columns (E), (F), and (G) represent the cumulative, current, and to-date expenditure of budget as defined by the titles at the top of the columns. The percent complete for the project is calculated by dividing the “cost to date” by the “budget at completion.”

It is necessary to report the costs and work-hours separately because there are different wage rates for each classification of project personnel. In addition, there are different wage rates within each discipline. Therefore, the

status of a project cannot be accurately determined by reporting only work-hours or only costs. Both must be reported and analyzed.

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CHAPTER 14
Project Close Out

The Importance of Project Close Out

Project close out includes all of the activities in the project execution plan (PEP) to formally finish the project, including contractual obligations. In the final phase of a project lifecycle, close out includes start-up, often referred to as commissioning, final walk-through, and facility handover. Close out can be divided into three broad areas: completing the actual construction work (start-up and handover), completing all of the documentation including as-built drawings and archiving documents, and closing the administrative aspects of the project (financial reconciliation, team dissolution, post project evaluation). [blog.masterofproject.com/project-closure-phase/ provides an overview of the closing process group defined by Project Management Institute (PMI)].

The last phase in the project lifecycle often gets minimal attention. The team members including contractors have completed the majority of their work and are ready to move to the next project. The final phase in a project is important and necessary to ensure the facility meets the project objectives, to provide the operations group an opportunity to learn about the new facility, and to transmit all pertinent documents to the owner for future reference and use.

Actually, project close out begins during Project Definition. The start-up or commissioning plan is a

component of the comprehensive PEP. The close out plan is also included as a section in the PEP. Chapter 3, Work Plan Development, discusses the PEP in detail.

Depending on the size and complexity of the facilities in the project, the testing, commissioning, and start-up plans can vary significantly. For example, a small office may only require one to two weeks to test and balance the HVAC system, electronic controls, and voice and data systems. A steel manufacturing plant may require one to two years to fully commission all of the equipment, balance interfaces between equipment, and start-up all of the systems for proper and safe operation.

The purpose of close out is to conclude all of the activities and contractual obligations associated with the project. The close out process depends on the complexity of the project. The number and size of contracts, number of permits, and the number of drawings are just a few of the items to finalize during close out.

System Testing and Start-Up

For heavy industrial plant projects, inspection of construction is performed throughout the project; however, the owner's representative generally requires inspection of vessels before closure and the testing of major equipment upon installation. The term *mechanical completion* is often used to define the stage of project development in which these procedures are performed. AACE International defines mechanical completion as:

> A unit is essentially complete for start-up operation and test run. All major work is completed. Minor work that does not interfere with operation may not be completed, for example, punch list items or touch up work. Owner or client custody of the facility may begin at this point.

Because it is often difficult to define mechanical completion, the project manager must develop a plant completion standard with the owner's representative to clarify what constitutes mechanical completion. This is an essential part of the PEP's start-up plan. This plant completion standard should be in the construction contract so that all involved in the project know who is to do what for each aspect of the project.

For system testing, the project manager for the owner needs to coordinate the interface between the owner's representatives, principal designers, construction contractors, and equipment manufacturers. The roles and responsibilities of each must be clearly defined and documented in the start-up plan in the PEP. There must be agreements on the systems to be tested, the types of tests required, and who will witness the tests. It is important to develop a plan and schedule for construction to support system testing in a timely manner. Planning of activities for start-up should start with the "need date" by the owner's operating personnel. Work packages should be developed to prepare for and conduct system testing. The required tests should be identified by 30% into construction duration, and the start-up plan should be completed by 70% into construction duration.

A formal plan should be prepared for defining when a vessel can be closed, the lead time notice required for inspection, what is to be monitored, and a sign-off sheet for the owner's representative. This is required to eliminate unnecessary opening and closing of vessels, which can require a substantial amount of project time.

The project manager must obtain in writing from the owner's representative the procedure for turning equipment over to the owner. Care and custody are important because substantial costs are involved. It is important for each party involved to know who is responsible and when they are

responsible. The project manager should notify the plant when a certain piece of equipment is complete, tested, and ready for turnover to the owner. Upon acceptance, any additional changes require a work authorization from the owner. This procedure should be handled in a formal manner with signatures required from the responsible representatives.

The project manager needs to coordinate with the contractor and designer to define the procedure for start-up. The process must be formal, but also flexible. The project manager should obtain in writing from the owner's representative what they require from the various members of the project team for support during start-up. The project manager must have the owner's input and should not make assumptions as to their needs.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on commissioning plan outline.

Final Inspection

Inspection of construction work is performed throughout the duration of a project. Before completion of the entire project, various equipment, electrical systems, and mechanical systems may be completed and ready for testing and acceptance in accordance with the contract documents. The project manager must work closely with the owner's representative and the design professionals who are responsible for inspection, testing, and final acceptance.

A definition of mechanical completion should be developed, and a formal notification provided to the construction contractor that allows adequate lead time for the process. This is necessary so substantial time is not lost, which may adversely affect the project completion date.

There must be a clear understanding regarding what the owner wants to verify during tests, what tests they want to witness, and the types of testing required. The responsibilities of the three principal contracting parties (the owner, designer, and contractor) must be clearly defined. It is the duty of the project manager to effectively coordinate this effort.

The start of project close out begins near the end of a project, when the contractor requests a final inspection of the work. Prior to the request, a punch list is prepared listing all items still requiring completion or correction. To develop this punch list, the field inspection personnel must carefully review their daily inspector's log to note all work items which have been entered that require corrective actions. It is sometimes necessary to recycle through the punch list process several times before the work is satisfactory for acceptance. The final walkthrough inspection should include representatives of the owner, contractor, and the key design professionals (the architect, as well as civil, electrical, and mechanical engineers, etc.) who have worked on the project. The project manager should schedule and conduct the final walkthrough inspection.

Acceptance of the work and final payment to the contractor must be done in accordance with the specifications in the contract documents. Substantial completion of a project is the date when construction is sufficiently complete in accordance with the contract documents so the project can be used for the purposes it was intended. This means that only minor items remain to be finished and that the project is complete enough to be put in use. At this time, the contractor may issue or originate a Certificate of Substantial Completion. The engineer will review and approve the certificate with an attached list of all work remaining to be done to complete the project. The engineer's approval and issuance of the

Certificate of Substantial Completion, with the attached deficiency list (or punch list), certifies acceptance of the work that is completed. Thus, it is important to ensure the list is complete because the contractor has no further obligations under the contract after the owner signs the certificate. Depending on the contract specifications, the Certificate of Occupancy for a building may or may not be required before final payment is made to the contractor. Generally, final payment, including the release of all retainage, is withheld for 30 to 45 days after completion of all deficiencies. Before final payment, the contractor is to submit final paperwork: warranties, lien releases, and other documents required under the contract.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on the ultimate guide to project close out and project close out checklist.

Guarantee and Warranties

Generally, the contract requires the contractor to guarantee all material, equipment, and work to be of good quality and free of defects in accordance with the contract documents for a period of 1 year after completion of construction. The guarantee of the overall project can be extended beyond the normal 1-year period; however, this is not common.

Individual pieces of equipment often have warranties that extend from 1 to 5 years after installation. Operating instructions, manuals, spare parts, and warranty certificates must be supplied to the owner. The project manager must ensure that all warranties are compiled and supplied to the owner before final payment to the contractor.

Lien Releases

Material suppliers, subcontractors, or workers who have furnished materials, equipment, or performed work on a project for which payment has not been made may file a lien against the property. The unpaid party has a right to file a lien even though the owner has paid the general contractor the full contract amount. Consequently, the owner may be forced to pay for some of the contract twice if the general contractor fails to pay its subcontractors, material suppliers, or employees.

During construction, the owner can withhold payments (called retainage) from the general contractor to cover open accounts and/or liens. The general conditions of most contracts have a clause that requires the general contractor and all tiers of subcontractors to supply a lien release for all labor and material for which a lien could be filed, or a bond satisfactory to the owner that indemnifies the owner against any lien. The project manager must ensure receipt of all lien releases, or the bond, prior to approval of final payment to the contractor.

Record and As-Built Drawings

Revisions and changes to the original drawings are almost certain for any project. At least one set of the original contract documents that were issued for bidding purposes must be kept in a reproducible form. This is necessary for the resolution of claims and disputes, because inevitably the question will arise, “What did the contractor bid on?” In addition, there must be a thorough documentation of all change-orders during construction.

A common contract requirement is that the contractor must develop an as-built copy of all specifications, drawings, addenda, change-orders, and shop drawings. The as-built drawings show dimensions and details of work that were not performed exactly as they were shown on the Issued For

Construction (IFC) drawings. Examples are changes in the location of doors, the routing of electrical wires or air conditioning ducts, or the location of underground piping, utilities, and other hidden work. These documents show all the changes to the original contract bid documents and are provided to the owner upon completion of the project.

Checklist of Duties

Table 14-1 provides a partial checklist of duties for project close out for the construction management (CM) method of contracting. If the project is not handled by the CM method, the duties of the construction manager are performed by either the owner or the designer.

Project Close Out		Owner	CM	Designer*	Contractor
1.	Certificate of Substantial Completion	Approve	Review, approve, file	Review, approve	Originate
2.	Cleanup	Observe & comment	Coordinate, enforce	Observe	Responsible
3.	Punch list	Approve as required	Expedite & coordinate work	Prepare, evaluate work	Respond
4.	Call backs (after construction)	Request	Arrange & coordinate	Review & approve work	Respond

Source: NSPE/PEC Reporter, Vol. VII, No. 2.

*The referenced NSPE/PEC publication cited "architect"; however, the term "designer" is used here to imply the architect may be the principal design professional for building projects, whereas the engineer may be the principal design professional for heavy/industrial projects.

TABLE 14-1 Checklist of Duties for Project Close Out

Disposition of Project Files

During a project, the project manager usually maintains two files: a record file and a working file. The record file contains

original copies of important information related to agreements, contracts, and other legal matters. The working file is the project manager's file that is used for the day-to-day management of the project and usually contains copies of documents from the record file plus correspondence, minutes of meetings, telephone logs, reports, etc. Upon completion of a project, a large amount of information pertinent to the project, including the records and files, is accumulated. Typical documents that should be provided to the owner include the following:

- Operation and Maintenance manuals
- Certified manufacturer's drawings of all equipment purchased or supplied by the contractor
- Instrumentation data sheets including calibration requirements
- As-built drawings for structures, underground utilities
- As-built drawings for electrical schematics and wiring diagrams
- Calculations: structural, mechanical systems
- Warranties and written guarantees
- Keys and keying schedules
- Test reports

Most organizations have a defined procedure for disposition of files. Information from the record file should be organized and indexed for easy access and retrieval for future reference. The working file often has duplicate information of the record file, some of which may have handwritten notes that should not be destroyed. Although much of the contents from the file can be discarded, sufficient information should be retained so the project manager can retrace his or her work on the project. Chapter 4, Document Control, provides more information.

In addition to project documents, other electronic data must be addressed during project closure. Survey data, GIS data, CADD 3-D models and other types of electronic data must be properly formatted and provided to the owner for use. The design and construction contracts should stipulate the required data formats and how the data files will be transmitted to the owner.

Post Project Analysis

A post project critique should be held at the conclusion of every project because there are lessons to be learned from every project that can be used to improve the success of future projects. The results of the project should be evaluated quantitatively and qualitatively.

Quantitative analysis consists of comparing planned values to the final values in several areas of the project. Table 14-2 presents a simple example to illustrate a general quantitative analysis. Criteria for a specific quantitative analysis are derived from the key performance indicators identified in the project objectives.

Area of Project	Possible Quantitative Measure
Scope	Number of scope changes Value of scope changes in dollars Percent of total project cost
Schedule	Planned in-service date vs. actual in-service date Deviation from critical path: number of instances Deviation from critical path: number of activities Deviation from critical path: percent of total activities
Design	Design performance (capacity, throughput, gallons per day, etc.) vs. actual performance Drawing revisions after issued for construction (IFC)
Materials	Percent defective or faulty materials Surplus materials value
Compliance	Environmental permit deviations
Construction	Number and value of claims or extra work requests
Safety	Incident rate Near misses Number of lost time accidents

TABLE 14-2 Basic Post Project Quantitative Analysis Comparisons

Qualitative analysis of project performance is typically accomplished at a joint meeting of project participants. Attendees should include the owner and key contributors in the project, including lead designers and construction representatives. The feedback that is gained through a non-accusatory discussion of the problems and solutions encountered during a project is beneficial to all team members in the planning and execution of future projects.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtE

ng&Constr4E for more information on the project completion report template.

For the meeting to achieve the desired results, it is important that the entire discussion be presented in an objective, positive, and professional manner. The good, as well as the bad, aspects of the project need to be discussed. The emphasis should be on how to avoid or lessen the problems on future jobs based on problems encountered on this job, not who was at fault or caused the problem on this project. Minutes of the meeting should be distributed to others who did not attend the post project critique, so they also can benefit from the lessons learned.

It is vital that the feedback be routed back through the organizations to precipitate process changes or training that can improve future project performance. Figure 14-1 shows 10 years of project qualitative feedback for medium to large projects (costs ranging from $20 million to $90 million in 2022 dollars). As part of project close out, each project conducted a post project assessment meeting. The results were collected and analyzed to identify the most important areas for improvement. Project planning, project communication, and project processes constitute two-thirds of the improvement opportunities. Project planning encompasses planning, scope definition including operational requirements, and creating comprehensive schedules. Project communication includes internal team communication and effective communication with clients and project stakeholders. Project processes/documentation/procedure includes using standard client agreements, standard procedures, and documentation for start-up. It also includes formalizing operational requirements (for example spare parts and redundant equipment), not changing project managers and other key team members during the project, and following common processes and procedures.

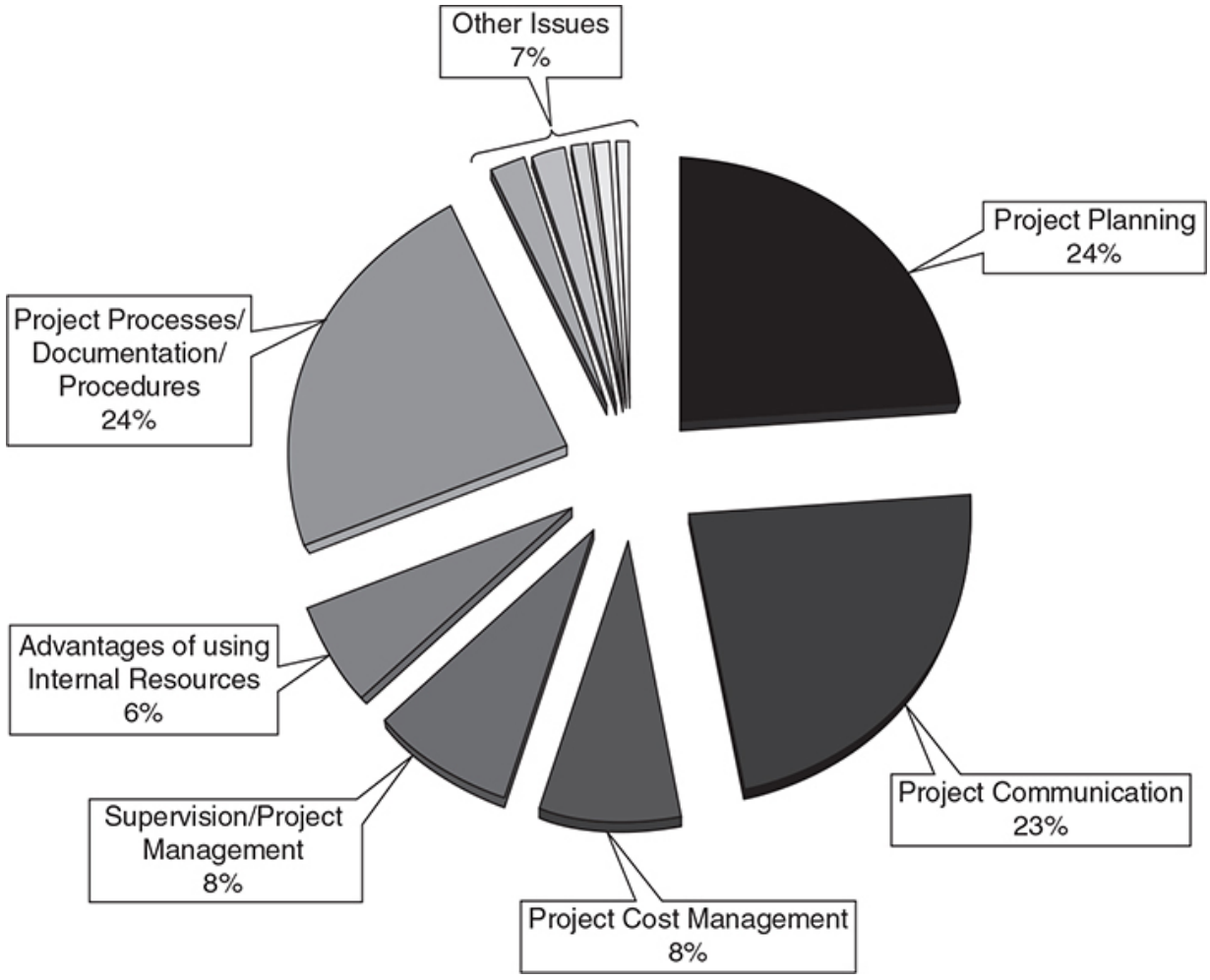


FIGURE 14-1 Project assessment results for 10 years of project performance.

It may be desirable to perform a project peer review, which is an independent evaluation of a particular project's design concepts or management procedures. Project peer reviews can address the needs of the owner, designer, or another interested party. The American Consulting Engineer's Council (ACEC) and the American Society of Civil Engineers (ASCE) have produced a document entitled *Project Peer Review: Guidelines*, which describes the process of project peer review.

Owner Feedback

After a project is completed and in use by the owner, a formal meeting should be held with representatives from the owner's organization to obtain feedback regarding performance of the project. This is an important activity for evaluation of the quality of a completed project and satisfaction of the owner because the true measure of the success of a project can only be determined by how well the project is utilized by the owner's organization.

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CHAPTER 15

Personal Management Skills

Challenges and Opportunities

There is a great amount of pride and satisfaction in seeing a project completed and in operation. There are many challenges in managing engineering and construction due to the dynamic nature of projects and the variety of people and personalities involved. Guiding the team to solve problems as they arise instills a sense of satisfaction in the project manager and members of the project team. Most project managers agree that lifelong friends are created by working with people on projects. Years after a project is completed, conversations between people who have worked together on past projects often turn to amusing memories of the problems that occurred and the methods used to resolve the problems. Generally, the problems seem much less serious after the project is completed than they were during execution of the project.

Successful people convert challenges to opportunities. Regardless of how difficult a problem may appear, there is always a way to resolve it. After completing a project, most project managers are enthusiastically ready to start a new project. They look forward to the next project and the opportunity to apply the lessons learned from previous

projects. Most project managers agree that they have fun doing their work.

Stakeholder Management

Stakeholders are defined as decision makers, people, or organizations that can affect or be affected by a project decision. Depending on the project's size, the stakeholder group can be a large and varied collection of people and organizations. Stakeholders include senior management, project partners, local government, and community entities. Each of these stakeholders possesses a unique view of the project that may or may not align with the project's objectives. The project manager should include a stakeholder management plan in the Project Execution Plan (PEP).

The stakeholder management plan is based on stakeholder analysis. First, the project manager should work to identify all of the interested parties that can influence important project decisions. After this list of stakeholders is developed, the project manager needs to prioritize them. A simple matrix is one method that allows the project manager to identify stakeholders by their level of influence and the amount of time and effort required to keep them informed and engaged in the project. This ranges from those stakeholders who have direct influence and require significant effort from the project manager (for example the Board of Directors) to those who have minimal influence on the project and require little effort from the project manager (minor subcontractor or supplier). In prioritizing stakeholders, it is helpful to answer questions such as "What is their stake in the project outcome?" "How will they be involved?" "What information do they want or need?" "What financial or emotional interest do they have?"

An important responsibility for the project manager is gaining alignment among the stakeholders regarding the project objectives. As discussed above, the stakeholders can be numerous and diverse in their expectations regarding the project. Some stakeholders may even oppose the project. The project manager must sharpen their skills to understand and align with key stakeholders, spanning from upper management leaders to project partners, and external stakeholders. The project manager must have or acquire the same philosophical mindset regarding the project as the leadership of the company.

For projects involving a partnership between owners, the project manager must consider the effect the project partners will have on the development, planning, and authorization of the project and eventually its execution. What role will the partner organization play? The partnership agreement should clearly describe the partner's role in and contributions to the project. The project manager must determine if any personnel from the partner will be assigned to the project. The project manager should also establish the processes, procedures, and software systems that will be utilized for the project. The project can benefit from active partner involvement, such as garnering increased buy-in and support of the project. If the partner desires strictly an oversight role, this can distract project performance by spending excessive time answering inquiries, rather than working on project activities.

The project manager will inevitably have to deal with power and politics within the project. This may happen at any level within the project from external stakeholders, internal management, and project partners, to project functional areas. Power (the ability to get others to do something) and politics (activities to acquire power) must be acknowledged and deftly managed. This cannot be overemphasized. The project manager should engage and

coach the project sponsor to help manage the political environment of the project. The project manager has the responsibility to manage and influence the power and political maneuvering within the project. The project manager can do this by staying connected with and informing the project sponsor regularly. The project manager should also build a cohesive and high functioning team using interpersonal skills, making decisions by consensus when possible, and motivating team members. The most important aspect of stakeholder management is communication.

Interface Management

Project interface management is the management of communication, coordination, and responsibility across a common project boundary. Interfaces occur anytime separate systems interact. This could be an organizational boundary (owner organization to design firm organization or functional group to functional group), a project phase boundary (Conceptualization into Detailed Scope), or where physical components of the project are interdependent.

Interface management is the project manager's responsibility. Project management by its very nature is interface management. The project manager must plan, coordinate, and control the work at project interfaces throughout the project lifecycle. By doing this, he or she improves the likelihood of project success. Communication serves as the vehicle for coordination and control. As the project manager's skills advance, she or he should be able to anticipate and discern interface difficulties and adjust communication as needed.

Interfaces vary with the size and complexity of the project. An interface is created or exists any time a separate group is added to the project or working on the project.

Each interface can become a point of conflict, error, risk, or misunderstanding.

The project manager needs to approach project definition, especially project execution planning, with attention to the interfaces created by the project strategy and execution plan. Table 15-1 provides a partial list of interface management principles.

1.	Project size, complexity, and speed drive the amount of project management effort required
2.	Project organization structures need to change as the project develops
3.	Organizational factors should be prevented from inhibiting required project integration
4.	For effective project control, the project manager must establish early, firm control of design
5.	Static project interfaces (those that do not change as the project progresses) should be kept clearly defined
6.	Fluid or dynamic interfaces (those that mark key transitions in project progress) should be tightly controlled in order to achieve project objectives

TABLE 15-1 Interface Management Principles

With increasing project complexity including a Project Interface Management Plan as part of the PEP will prove valuable. A single project trait such as a joint venture approach may not necessitate the creation of a Project Interface Management Plan. However, a project with several project characteristics creating interfaces may require such a plan. Table 15-2 provides project traits to evaluate relative to their effect on interfaces.

Size	Business structure	Is the project being done under a new partnership?
	Estimated cost	How much capital is at stake?
	Number and type of facilities	Are new facilities tying into existing facilities? How will the components operate together after the project is complete?
Complexity	Project team	How many project teams? How many people will work on the project? Where are the core team members located? Design firm staff? Material suppliers? Constructors?
	New technology	Is the project introducing new technology?
	Facility components	How many components and how do they interact?
Speed	Schedule driven	Will the project be Design/Build? Fast-tracked?

TABLE 15-2 Project Traits Influencing Interface Management

The Interface Management Plan should clearly define the interface points and associated roles and responsibilities. The plan should be written for the team with their participation. It should be written based on a clear, real understanding of the project objectives and the project execution plan including processes and procedures to be followed. Communicating information is the central issue for managing interfaces. As listed above, organizational factors should not inhibit the flow of information. In other words, the organization of the project team should aid information sharing versus hindering it. The project manager and project sponsor should consider changing the project organization as the project progresses through the lifecycle phases. For instance, the project organization may begin as a traditional hierarchical structure. As the project moves into Detailed Scope phase when design firms and consultants are incorporated into the team, a different organization structure may better serve the project and the team. For example, a flat organizational model, also called organic

(refer to Figure 15-1), minimizes the need for information to flow through a central person. Information can easily move between lower levels of the project where it is most needed. The flat model increases the number of interface points; therefore, specific individuals are needed to manage the interfaces for each area.

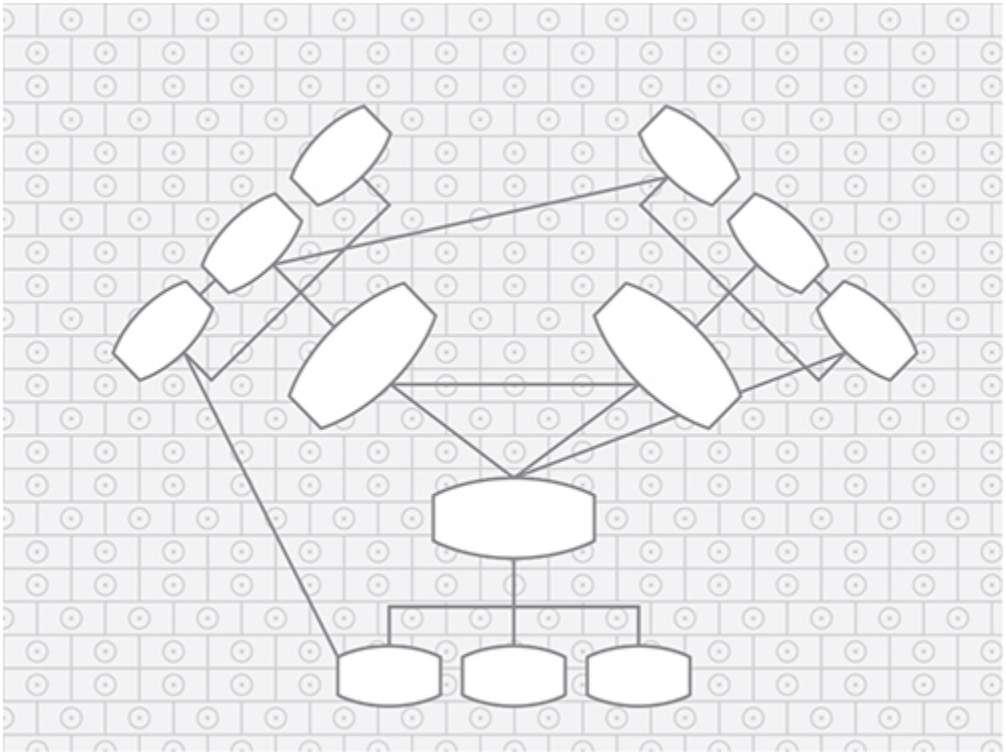


FIGURE 15-1 Organic (flat) organizational structure.

If the Interface Management Plan is neglected, the project is in jeopardy of failing to meet project objectives. An excellent resource for interface management can be found at www.interfacemanagement.org. An example Interface Management Plan can be found at https://hsr.ca.gov/wp-content/uploads/docs/programs/eir_memos/TM%201600.02%20Interface%20Management%20Plan,%20R0%20130521%20no%20sigs.pdf.

The list below provides characteristics of effective interface management.

- Establish and maintain contact with all principal groups
- Emphasize equalizing power differences
- Work to increase trust across interfaces
- Emphasize influencing and spurring decision making

Organizational Management

Organizing the Team

As discussed above and in Chapter 4, Team Selection and Development, the people assigned to the project are key to its success. Team members need to have the right skill sets, the right attitudes, and the right motivation to make a project successful. These factors are directly affected by the clarity of the project objectives, the leadership provided by the project manager, and the suitability of the project organization structure. In order to organize the human resources for the project, the project manager and team members must develop a comprehensive execution plan through detailed planning. Using the detailed plan, the project manager and the project team can create an organization with the following characteristics:

- Defines and communicates who does what and when
- Reduces impediments to workflow
- Closely locates team members based on who must communicate most often
- Keeps team members that must cooperate closely within the same reporting line
- Avoids incentives that counter the project objectives
- Build an organization that reflects the project

No organizational structure can ensure a successful project. The project manager should be alert to the hidden

incentives inherent with the project's organization structure. The new organization structure creates opportunity for team members to gain or build turf, boosts the egos of some groups while allowing other groups to take control or withdraw to the fringes of the project. The project manager should remember that the project organization structure is a tool, but it will not solve any problems in and of itself.

Assigning Work

Project management involves coordinating the work rather than doing the work; therefore, the project manager delegates the work to members of the project team. The Organizational Plan contained in the PEP should contain a Responsible, Accountable, Consult, Inform (RACI) chart that provides clear ownership of specific project tasks. The RACI chart should be developed through team member participation, which creates understanding and agreement to the assigned work. By assigning work to another person, the project manager delegates authority and responsibility to that person to accomplish the work and to make decisions that may be necessary. However, delegating authority, responsibility, and decision making does not necessarily cause the project manager to relinquish control. A project manager may define different levels of delegation, such as complete the work and provide the results, propose the work to be performed and inform before proceeding, or perform part of the work and submit for review and approval.

Assigning work requires assigning it to the right person with a clear explanation of what is expected and when it must be completed. Because miscommunication is a common problem in project management, the project manager and the team member must be certain that they mutually understand what has been assigned and the expectations associated with it. The RACI chart aids and

supports good communication. A project manager must give each person on the team an opportunity to do the job the way he or she wants to do it. Simply stated, “Their way is often as good as my way of doing a task.”

A project manager should be reasonable in his or her expectations. If an assignment is not reasonably achievable, the person who is assigned to do the task usually will recognize this fact and resist pressure and responsibility to do the work. The best way to evaluate the reality of achieving an assigned task is to work with the person to obtain his or her assistance in defining the work that is required to achieve the final end result.

During the course of accomplishing work, many obstacles arise. A project manager must be accessible to explain things that may not be clearly understood and to make any adjustments that may be necessary. In short, the project manager must also be available when he or she is needed and be willing to make decisions that remove roadblocks to work. Periodic team meetings are needed to keep the work flowing in a well-identified manner so that everyone concerned can work as a unit.

An effective project manager must lead the project team and reinforce the confidence of individuals. Trust must be shown in their capability, intelligence, and judgement. The leader of any group must occasionally check with members to see what is going on and how they are doing. This builds confidence and respect among the team members, who in turn will strive to accomplish quality work.

A project manager must recognize and reward successful and outstanding performance. People relish recognition and are entitled to it. Likewise, a manager should hold an employee responsible for unacceptable work, show why the work is unacceptable, where mistakes were made, determine how to improve the work, and identify ways of preventing future problems.

Many project managers are assertive with a tendency to rush in and take over. Although each person must develop their own style of management, he or she must be cautious of overreacting to situations. With the right attitude and working relationship, problems can be changed to solutions in due time.

Motivation

Experienced managers readily agree that there are all types of people: those who make things happen, those who watch things happen, those who don't know what's happening, and in some instances, those who don't want to know what's happening. The project manager must devise methods to motivate each one of these types of people.

Each member of a project team provides an expertise that is needed to accomplish a project. Usually, individual team members are assigned to the project from various functional departments by their respective supervisors. Although everyone works for the project, each person may report to a different supervisor. Therefore, the project manager as the leader of a project team is placed in a situation of motivating individuals who actually report to a supervisor other than the project manager. Thus, the project manager must develop effective methods of motivating team members other than the traditional methods of promotion in title or salary.

Many managers believe that money is the best motivator of individuals. Obviously, few people would work if they were not being paid. Although money may be a motivator to a certain degree, other factors influence the motivation of some people. Unless the pay is exceptionally different, other aspects to motivation must be considered. If money were the only motivator, the project manager would have a problem with motivation because he or she usually is not the person who directly establishes the pay of individual

team members. Because most project managers do not control pay rates, they must motivate by providing individual recognition and, most importantly, by challenging each team member with responsibilities and a chance to grow.

Many books have been written and numerous theories have been proposed related to motivating people. Most people are motivated by needs. As presented in Chapter 4, Maslow's theory of needs identifies five levels of needs that people strive to achieve: basic survival, safety, social, ego, and self-fulfillment. The theory proposes that an individual strives to satisfy the basic survival needs of food, clothing, and shelter. Upon satisfaction of these needs, a person strives for the next level of need: safety, which may include continued employment, financial security, etc. As each level of need is satisfied, the next higher level of need is sought. A project manager must strive to identify the needs of the people who are involved in the project in order to effectively motivate them. This is difficult to do during day-to-day activities, so it is sometimes desirable to associate with individuals outside the work environment. Many times, an awareness of a person's interests and recognition of their needs is a positive step in understanding why they react to situations and can lead to productive motivation. Utilizing personality assessments for team development is another tool that can help the project manager better understand how individuals process information, what motivates them, and how they behave under stress. Good management recognizes the motivational needs of each member of the team and develops methods to improve the performance of people.

Professional people seek job interest, skill enhancement, recognition, and achievement. Everyone wants to feel important and to accomplish meaningful work. People who feel good about themselves produce good results; therefore,

a project manager should help team members reach their full potential and recognize that everyone is a potential winner. This type of attitude among team members can create motivation for everyone.

Using Technology

Discussions of technology, electronic technology, and its uses on a project have been presented throughout this book. Technology can be an effective tool for managing a project; however, it cannot replace the human effort in managing a project. With planning and discipline, using technology improves work performance and information flow. Technology and how it will be used to manage the project needs to be included in project definition. For example, depending on the size of the project organization and complexity of the project, a separate Information Technology (IT) environment may be required. As discussed in Chapter 5 on document control, data storage and management are essential. Provisions for the disparate data sources must be addressed early to prevent risks of data loss, data security, and data integration. Too often, the project team assumes that “IT can take care of it.” Technology cannot replace the human effort required to carefully plan and execute the project. In reality, proper planning, budgeting, and scheduling for IT system additions or creation must be included in the project plan. This also includes those scope components requiring integration with existing control systems.

The disadvantages of technology are real. Relying on technology to create project processes is a reverse order. First, project processes need to be clearly defined and followed with discipline. Then technology can serve to facilitate the process and assure data integrity and data flow. Conference calls and video meetings provide for team collaboration, especially for scattered team members. Too

often, team members are trying to multitask during meetings. This causes inefficiency in the meeting because participants are distracted. Often, colocated participants will not join the meeting in the scheduled conference room, preferring to work from their office in order to do other work during the meeting. This may be because too many meetings are being scheduled, the meetings are poorly managed, or any other reason. The participants need to be committed to the meeting for the scheduled time and focus on the discussions. The project manager needs to be firm regarding this behavior. One example involves a project manager that held an offsite planning meeting scheduled for two full days of discussion. On the first day of the session, the project manager established the meeting rule that all cell phones and computers had to be left in a designated spot at the front of the conference room. Regular breaks were scheduled in the meeting agenda and were honored during the course of the 2-day session. Restricting cell phone and laptop use to breaks had the effect of focusing participant attention to the discussion topics. The team completed the first day 2 hours early! On the second day, the project manager utilized the same restrictions. Discussion including action planning completed 3 hours early. Feedback from all of the participants praised restricting the use of cell phones and laptops during the meeting.

Technology provides an opportunity to enhance project management work, but to achieve that opportunity requires tenacity and perseverance. Resistance to adopting technology, such as undermining it, prevents the many advantages of using technology. Technology can help improve project management by

- improving collaboration between team participants.

- using current project data to improve the speed and quality of project decisions.
- automating information capture for integration into project systems.
- improving team compliance with compliance requirements.
- improving team access to current data to address issues.

Essential Leadership Skills

The importance of the project manager as a leader of the project team increases as projects grow in size and complexity. The numerous functions, stakeholders, risks, and other aspects of projects require the project manager to be a generalist rather than a technical specialist. Effective team management focuses on three areas: organizational structure, people skills, and management style. Considering that the project manager must work closely with a variety of leaders, their focus should be upward and outward. They should trust functional leaders to focus on technical matters (inward and downward). Project leadership skills include being politically astute about their company and have the ability to communicate upward.

The project manager's leadership skills need to mature to a level that, for their project, they clearly understand the project objectives, the economic stake being made, and why they are the right person (knowledge, skills, and abilities) to own and manage the development and execution of the project. The project manager as leader should possess the ability to identify key project drivers and their impact to the project. The project manager needs to be able to identify required capabilities of the team. The project manager as leader should be able to articulate the project's vision and

strategy. They must hold themselves to the highest ethical standards. They will face difficult decisions and issues during the life of the project. Acting with utmost integrity influences similar behavior throughout the project. The project manager as leader must possess critical thinking skills. They must keep the big picture, but see and understand the influence of lower-level details on the project outcomes. Since the project manager acts as the center for the project, their ability to make decisions and manage their time are essential skills.

Human Aspects

The preceding chapters defined the information that must be gathered and managed to successfully bring a project to completion. Although a system must be developed for management and control of a project, it is people who make things happen.

A project management system serves as a guide for overall coordination of the entire project; however, some refinement and modification of the system is sometimes necessary for a particular project. People are the only resource that have the capability to detect problems and make the adjustments that are necessary to successfully manage a project. Thus, a project manager should not depend solely on the system of project management and neglect the importance of the people who are associated with the project.

To summarize, *successful project management* can best be described as *effective communications* between the people who perform the work that is necessary to complete the project. Management of any project requires coordination of the work of individuals who each provide an area of specialization. A successful project manager must be a good planner, delegator, and communicator.

There is a tendency of some project managers to complain that the work is not being accomplished because of factors beyond their control. For example, a project manager may feel that team members are too inexperienced, or that it takes more time to explain what needs to be done than the time it takes to do it themselves, or fear that a mistake by a team member would be too costly. Other typical examples are the feeling that others are too busy and don't have time for additional assignments or that others avoid accepting responsibility. Although these factors are of concern, they and similar factors are a routine part of working with people and can be overcome with good management skills.

Usually, project managers have many years of experience of doing the work before their assignment of managing the work. Because they are familiar with what is required, they may prefer doing the work themselves rather than delegating it to others. The result is they become overworked from attempting to both do and manage the work, spend nights and weekends devoted to their job, and then complain that the work is not accomplished because others are too inexperienced. A project manager must realize that others can only gain experience by doing the work; also that many times others can do the work just as well, if not better, than managers. The problem is acceptance of the fact that others may not do the work exactly the same way the manager would do it. The criterion should not be who can do the job best, but who can do the job satisfactorily. The project manager must balance accuracy and quality of the work for the entire project. The feeling that a person is too inexperienced can be overcome by close communications and training.

The feeling by project managers that it takes more time to explain the job than to do it themselves often results in the project manager doing the work, at nights or on

weekends. Many times, a person can do the work quicker than explaining what is needed by others. However, if the work must be repeated on a particular project, or on future projects, it usually is more efficient to explain it to others one time, so they are experienced in doing it in the future. Project managers must realize that before telling someone what to do, they must know what needs to be done themselves. A well-defined work plan, as discussed in previous chapters, provides the plan of action to effectively communicate job assignments to team members.

The accomplishment of a project usually involves high costs over an extended period of time with many risks. The fear that a mistake by a person would be too costly is a concern by every project manager. Because of this fear, a project manager may be reluctant to assign the work to others and end up doing the work himself or herself. The problem is the lack of confidence in others and the fear that they don’t have sufficient judgement to handle the situation if a problem arises. The excuse that is often given is “If you want it done right, you must do it yourself.” However, a good control system will help ensure that work is done right. Fear of taking a chance can prevent finding hidden ability.

Because everyone appears busy, a manager may be reluctant to assign work because of the feeling that others don’t have time for additional assignments. This situation often arises when the work to be done requires the expertise that can only be performed by a small number of individuals. A system must be developed to ensure that people who are involved in the project are using their time efficiently. This is best accomplished by developing a well-defined project schedule at the beginning of the project, with participation and input from each person who will be involved. There is always enough time to do what is required.

Another complaint of some project managers is that people avoid accepting responsibility. People will avoid accepting responsibility if they fear unjust criticism if they make a mistake or feel they will receive inadequate recognition of their work. A manager must develop a project control system that protects a project from major mistakes that are catastrophic, yet tolerates minor mistakes that are inevitable. Some people simply find it easier to ask the manager than to decide themselves because some managers want to make all the decisions. A project manager must clearly define the work required because people tend to achieve what is expected of them.

Establishing Project Vision and Strategy

Although projects have a fixed duration, often the duration can span years, for example, a large industrial plant or a large infrastructure project. Chapter 4 discussed the importance of establishing clear project objectives for the project team and developing a project execution strategy. Creating a project vision that describes the ideal state of project success can give the team a rallying point and a goal worthy of their effort. A project vision can inspire stakeholders and keep them engaged with the project.

A project vision offers a forward-looking perspective of the project. The vision describes the economic wager being made by the business in straightforward statements looking to the future. It will serve as a guidepost for all project participants when making project-related decisions. A project vision provides a guiding purpose to the project participants.

Ethics

The project manager’s conduct must be unblemished. When a project manager is assigned to a project, he/she is given the care and custody of financial, physical, and human

resources. The standards to which project managers hold themselves must not tolerate any compromise. Since this book focuses on project management for engineering and construction, a review of the Code of Ethics for Engineers is provided. [https://www.nspe.org/resources/ethics/code-ethics]

The Engineers Code of Ethics serves to guide engineers to the highest standards of honesty and integrity. First and fundamental to everything an engineer does is to hold paramount the safety, health, and welfare of the public. This means ensuring that competent engineers produce designs adhering to codes and standards. This means raising issues regarding aspects of the project that may pose a threat to the public, operators, or others. Engineers should only perform work in the areas of their competence. This means that a structural engineer cannot sign off on an electrical design because a Professional Engineer (PE) stamp is needed or any similar shortcut that might be requested of the engineer. Engineers shall be objective and truthful when making public statements. This encompasses reports, statements, or testimony. This includes stating opinions that are not founded on the facts of the issue or outside of the engineer's competence. Engineers shall perform their duties faithfully for clients or employers. Engineers should report potential conflicts of interest and refuse compensation from more than one party for services on the same project. Engineers shall avoid deceptive acts. They will not falsify their qualifications nor misrepresent their qualifications or experience.

Following the Engineers Code of Ethics obligates an engineer to follow the highest standards of honesty and integrity. They should strive at all times to serve the public interest, such as career guidance or volunteering to advance the health, safety, and well-being of their community. Engineers should avoid conduct or practice that

deceives the public, nor should they share confidential information without permission regarding the business or technical aspects of former clients, employers, or public bodies they serve. As to conflicts of interest, engineers should not be influenced by them including refusing financial or other considerations. Engineers should not mislead or lie about other engineers in order to advance their careers or obtain employment. The consequence to this is that engineers shall not try to harm the professional reputation of other engineers. Engineers should accept personal responsibility for their professional activities including not hiding behind the cover of corporation or partnership for unethical acts. Finally, engineers should give credit for engineering work to those who deserve the credit and recognize the proprietary interest of others.

The American Institute of Constructors (AIC), founded in 1971, is dedicated to promoting professional development and recognition for those involved in the management of the construction process. The organization has established a Code of Ethics for Constructors which is provided below. [www.aic-builds.org/ethics/code-of-ethics]

AIC Code of Ethics for Constructors

The construction profession relies upon a system of ethical competence, management excellence, and fair dealing in undertaking complex works to serve the public with safety, efficiency, and economy. The members of the American Institute of Constructors are committed to the following Standards of Professional Conduct:

- A Constructor shall have full regard to the public interest in fulfilling his or her responsibilities to the employer or client.
- A Constructor shall not engage in any deceptive practice, or in any practice which creates an unfair

advantage for the Constructor or another.

- A Constructor shall not maliciously or recklessly injure or attempt to injure, whether directly or indirectly, the professional reputation of others.
- A Constructor shall ensure that when providing a service, which includes advice, such advice shall be fair and unbiased.
- A Constructor shall not divulge to any person, firm, or company, information of a confidential nature acquired during the course of professional activities.
- A Constructor shall carry out responsibilities in accordance with current professional practice, so far as it lies within his or her power.
- A Constructor shall keep informed of new thought and development in the construction process appropriate to the type and level of his or her responsibilities and shall support research and the educational processes associated with the construction profession.

Critical Thinking

Because the project manager is central to the project, they will be able to see all aspects of the project from every functional perspective. The project manager needs to think about the big picture including the business objectives and the aggregate of the project parts. From this, the project manager should identify any risks or unintended cause-and-effect relationships that any functional area or decision might insert to the project. The project manager's critical thinking ability needs to progress to a level that they can clearly relate the project objectives and associated economics with the components making up the project.

A project manager that exhibits good critical thinking skills will have the ability to:

- Raise vital questions and problems, formulating them clearly and precisely
- Collect and analyze relevant information to reach a well-reasoned solution and conclusion
- Test the solution and conclusion against project objectives
- Think open-mindedly and is aware of assumptions, implications, and practical consequences
- Communicate effectively to develop appropriate decisions for the project

Critical thinking is the ability to think logically and clearly to understand the connection between ideas, concepts, or components. It involves rigorously questioning ideas, arguments, and assumptions representing the complete picture. The project manager needs to objectively question actions or assumptions by team members regarding the work. Through this probing, they should determine the impacts or influence, intended or unintended, throughout the project and the overall effect on achieving the project objectives. To be able to think critically, the project manager needs to be able to think about the issue in an objective and critical way, then identify the related aspects. Considering all of the related issues, the project manager can identify risks or opportunities to the project. Finally, the project manager should decide or act based on their analysis. [Additional information at www.criticalthinking.org]

Decision Making

Numerous decisions requiring a significant amount of time and effort from the project manager must be made during management of a project. While many decisions are routine and can be made rapidly, others are significant and may

have a major impact on the quality, cost, or schedule of a project.

Good decisions cannot be made unless the primary objectives and goals that are to be accomplished are known and understood. Decision making involves choosing a course of action from various alternatives. It is the duty of the project manager to know, understand, and clearly communicate the project objectives to all participants so their efforts can be focused on alternatives that apply to the desired end results. This is important because a significant amount of time and cost can be expended toward evaluation of alternatives that may solve a problem, but not pertain to the central objective to be achieved. The project manager must coordinate the effort of the project team to ensure a focused effort.

Decisions must be made in a timely manner to prevent delays in work that may impact the cost and/or schedule of a project. Most of the project decisions are made internally (within the project manager’s organization), which can be managed relatively easy. However, some decisions are made externally (outside the project manager’s organization) by owners or regulatory agencies, particularly in the review and approval process. Early in the project, the project manager must identify those activities that require external decisions so the appropriate information will be provided, and the person can be identified who will be making the decisions. This must be included in the project schedule to alert the responsible parties, so work is not disrupted, and the project is not delayed due to lack of a decision at the proper time.

Many organizations have established policies regarding the authority for decision making that a project manager can refer to during management of a project. However, there are many times when others can be consulted who have had similar situations, and who can provide valuable

opinions and assistance. Regardless of the situation, there is almost always another person who has had a similar problem.

The project manager should avoid crisis decisions, although many decisions are made under pressure. As discussed above, one must gather all pertinent information, forecast potential outcomes, think, and then use their best judgement to make the decision. It is not possible to anticipate all eventual outcomes, but with careful thought and review, one can eliminate the unlikely events. There is a certain amount of risk in everything one does, and sometimes wrong decisions are made by good managers. However, new information may become available or changed circumstances may arise that will require a change in the previous decision.

Decisiveness is required of a project manager to gain the respect of team members. A project manager must avoid procrastination and vacillation and should encourage decision making in team members. Indecision creates tension in most people, which causes stress and further indecisiveness. Failure to be decisive can cause many things to go wrong; no one knows what to do, work is not done because of lack of direction, all of which causes a waste in talent, resources, and time. Relying on the project objectives and the PEP coupled with critical thinking skills, decisions can be made with confidence.

It is the responsibility of the project manager to ensure that appropriate decisions are made by the right people, at the right time, based on correct information. Once a decision is made, it should be communicated to all participants involved in the project so all concerned will know what is to be done. This can be easily accomplished by distributing the minutes of the meeting (or record of the conversation) where the decision was made, with a highlight or flag to denote the decision.

Time Management

Time is irreplaceable and vital to the personal and business life of everyone. A project manager spends a large amount of time communicating and interacting with others who are involved in the project. Therefore, it is important that time is spent in a productive and effective manner. A project manager must be cautious, because there are always more interesting and worthwhile things to do than time allowed to do them.

An analysis of how time is spent is necessary in order to determine how effective time is used. Occasionally, a time log of how major portions of one's time is spent should be maintained. A daily log should be compiled over 2 or 3 weeks that shows how much time is spent doing each activity, who was involved, and what was accomplished. Activities can be grouped by categories, such as telephone calls, meetings, unscheduled visitors, and special requests. An analysis of the distribution of time by categories will enable the project manager to determine where his or her time is spent most, so improvements can be made. It is usually easier to reduce a category with high time expenditure by a small amount than it is to reduce a category with low time expenditure.

Common time wasters of project managers are unproductive telephone calls and meetings. Although the telephone is necessary for a manager to perform his or her work, it can be quite disruptive. There are times when calls should not be received so other tasks can be done. An aide, administrative assistant, or voice mail can intercept calls to assist in the management of telephone usage. Meetings are mandatory for project management. Meetings will be discussed in greater detail later in this chapter. Table 15-3 provides a partial listing of common time wasters.

1.	Unproductive telephone calls
2.	Unproductive meetings
3.	Unscheduled visitors
4.	Special requests
5.	Attempting too much at once
6.	Lack of goals and objectives
7.	Procrastination on decisions
8.	Involvement in routine items that others can handle
9.	Inability to set and keep priorities
10.	Inability to say no

TABLE 15-3 Common Time Wasters

The project manager must set priorities and develop a system to manage his or her time. Tasks that are the least interesting can be scheduled at the peak of one's energy. There should be a thorough review to evaluate job activities that can be assigned to others and an analysis of work to determine how and what can be combined or eliminated. Emphasis should be placed on long-term items, rather than short-term items that can often be delegated to others. Most people are more motivated by work that is planned than work that "just happens" at the moment. Priorities should be set and kept to effectively manage time.

Communication

One of the most frequent sources of errors and misunderstandings in the management of a project and working with people is miscommunications. Too often, the receiver does not hear or interpret the information the way it was intended. Communications may be oral (both speaking and listening) or written (both writing and reading). In each instance, it is important that clear,

coherent, and efficient communication skills exist to ensure successful work by all participants in a project. The project manager must realize that all people do not interpret the same thing in the same way and that a communication is of no value unless it is both received and understood.

The project manager is responsible for the continuous and comprehensive flow of information to and from team members, with special attention to communicating information and decisions that may influence the project team's work. The objectives of project communications include the following:

- Exchanging information
- Assisting in the achievement of project objectives
- Directing the work of team members
- Motivating the team
- Increasing the efficiency of the work
- Educating and training team members
- Improving the support of project stakeholders

These communications include conversations, meetings, minutes, correspondence, reports, and presentations. A good online resource for business communications can be found at www.commercemates.com/category/business-communication/.

Conversations

Much of the day-to-day work on a project is accomplished by informal exchanges of information among team members. Examples are telephone calls and informal meetings between two or more individuals. Although most of these exchanges are routine, some may impact the work of others or may impact project decisions related to scope, budget, or schedule. Informal exchanges of information that

affect the scope, budget, or schedule must be documented into the written record at the next regularly scheduled team meeting.

The project manager should maintain a record of telephone conversations, including the names of parties in the conversation, date, time, place, items discussed, and any pertinent information resulting from the exchange. Phone log templates are available or easily created (see Figure 15-2). The important point is to be disciplined in recording telephone conversations pertinent to the project. Telephone records should be considered project documents. They should be maintained and filed with each project. A project manager assigned to several projects may find it helpful to maintain a master phone log that records each call for all projects assigned to the project manager. The project manager can modify a template or create a master log that records the project name in addition to the date, time, number, individual, and pertinent information discussed (see Figure 15-3). This master log can be filtered and sorted to isolate specific telephone conversations. A master log is helpful in keeping track of the overall work of the project manager. Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on telephone log.

Telephone Conversation Log for *Project Name*

Date	Start time	End time	Name	Phone Number	Subject	Notes	Action Items	Follow-up Needed? Y/N

FIGURE 15-2 Project telephone log using a template.

Telephone Log for *PM D Mitchell*

Date	Start time	End time	Project Name	Individual	Phone #	Subject	Notes	Action Items	Follow-up Needed? Y/N

FIGURE 15-3 Project manager's master telephone log.

The project manager must develop and practice good speaking skills. Conversations must be clear, coherent, and to the point without rambling. Thoughts and ideas should be organized in a systematic manner before communicating. This can be accomplished by knowing the objectives of the communication, for example, to give information, to get information, to make decisions, or to persuade someone. Consideration must also be given to timing and location to ensure the other person has your attention, because listening is an important part of communicating. It is often necessary to follow up a conversation to be certain the communication is received and understood. This can be done by obtaining feedback.

Presentations

As the prime contact person for the project, the project manager is the spokesperson who often makes presentations to the owner, agencies, boards, and other interested parties. For an effective presentation, it is important to know the audience and to convey information that is of value and interest to the audience. A presentation is given for the audience, not the individual giving the presentation. It should be prepared from the audience's point of view and organized in a logical pattern so each part of the presentation will relate to other parts. Examples are

problem to solution, unknown to known, cause to effect, or a chronological order. The golden rule for presentations is “tell them what you’re going to say, say it, tell them what you said.” This means that the speaker should introduce the content of the presentation succinctly, then proceed into the core of the presentation. The speaker should conclude by summarizing the presentation preferably with three but no more than five key points.

A flaw of many presentations is an attempt to tell the audience too much, giving a step-by-step description of everything about the subject. A presentation normally has a limited time, and the audience frequently is a busy group. Therefore, the presentation should be more of a summary of important factors of direct interest, leaving detailed information in a report that can be read later. Only a limited number of graphs, tables, or computer printouts should be presented; therefore, the project manager should be judicious in selecting them.

Another challenge for presentations is managing questions. The project manager should anticipate the information needs of the audience thereby anticipating the questions they may have. The project manager should strive to answer those questions with the material presented and should expect additional questions. Every presentation should allow for questions, how they will be addressed should be based on the audience and the presentation objective. Questions can be deferred to the end of the presentation, or they can be addressed during the course of the presentation. It is important to state how questions will be addressed at the beginning of the presentation. Answering questions as they arise during the presentation poses the problem of sidetracking the presentation or consuming time to address a concern that could be handled with a follow-up discussion. Asking the audience to hold their questions until the appropriate point in the

presentation allows for all of the information to be presented, possibly answering questions in the process. Delaying questions is an incentive for the audience to pay attention and listen to the presentation.

The structure for a presentation should begin with a title, which is a simple statement of the subject, followed by a brief overview of the material to be presented. It is important to provide a concise objective for the presentation: informing, status, decision, or request. This is the “tell them what you’re going to say” aspect of the presentation.

The bulk of the presentation is focused on “telling them.” During a presentation, the speaker must realize that the audience cannot remember every word that is said. To increase clarity and to emphasize key points, the speaker should limit the number of key points. Limiting the number of key points allows them to be repeated by selecting alternate words and phrases to bring out the same major ideas. This is necessary for effective speaking, but is not, and should not, be done in writing because a reader can reread material to clarify or understand what is written.

The speaker should define words and acronyms that he or she thinks the audience may not know or understand. This should be done at the time the words are used, not at the beginning or end of the presentation. Defining or clarifying words ensures that the listener hears and understands what is being said. It also ensures that the listener is thinking about the presentation and focusing on the speaker’s key points.

Visual aids greatly enhance any presentation, particularly tables of numbers, equations, and technical data. The value of visual aids is that the audience both hears and sees the presentation, which greatly increases their understanding and the amount of information they retain from the

presentation. Visual aids also help the speaker keep the presentation flowing in a continuous manner.

Few people are impressed with complicated sentences or an attempt by the speaker to impress the audience. The project manager should thoroughly understand their audience and the presentation objective, then determine the level of detail to include. The level of detail that should be presented depends on how much the audience knows about the subject or needs to learn. Therefore, it is essential for the speaker to know the audience. Simple and direct language should be used that presents the material, so it is easily understood. To gain the attention of the audience, the speaker should not make the audience insecure. Apologies and negative comments should be avoided. A positive attitude should prevail, even when controversial subjects are being discussed.

The presentation should be summarized at the end, just as the audience was told the purpose of the presentation at the beginning, “tell them what you said.” A summary slide of key points or takeaways should always be included. Because this is the conclusion for the presentation, keeping the points succinct and easy to understand is important.

Written Communication

Written communications document most of the activities of a project and often have major impacts related to decisions, costs, schedules, and legal matters. Because of this, all written material should be dated and written in a clear, concise, coherent, and legible manner.

To be effective, the project manager must consider who is going to read the material and the purpose of the document, such as to obtain information, to give information, to clarify an item, or to submit a proposal for approval. As the leader of the project team, the project manager must prepare status reports that describe the

progress of a project. Many of these reports contain a significant number of graphs and tables with short written narratives. Other typical correspondence is in the form of letters or interoffice memorandums and minutes of meetings.

The project manager must rely on their own writing skills to produce a coherent written document. Cutting, pasting, merging, and spell checkers do not necessarily ensure a coherent document. For example, a spelling check of a document does not verify the correctness of the use of the words of to, too, or two. Likewise deleting or adding lines or paragraphs in one portion of a document can have a major impact on other portions of the document. Even small errors can lead to big problems and misunderstandings. Thus, a project manager must take/use special precautions to ensure a coherent document.

The arrangement and format of reports vary, depending on the material to be produced. The project manager and team members should understand the type of report being written and utilize templates wherever possible. Table 15-4 is a suggested outline for a report. The subsections will need to be changed based on the type of report being written. Useful report writing tips can be found at www.visme.co/blog/report-writing-format/#the-best-report-wriging-format-tips.

Report Outline	
Section	**Guidelines**
Title	Be concise and clear
Table of Contents	Prepare last to ensure proper page numbers
	Include List of Figures, List of Tables
Executive Summary	Write the summary after the body of the report
Introduction	Prepare after the body
	State scope of report
	State what is included and excluded
	May be 1 paragraph to 1 page in length
Body of report	Prepare using an outline to be consistent
	Subsections: Test equipment used Procedures used Data obtained Analysis of data
	Use bullet points and visuals
Conclusion	Clear and brief summary of body of report
	Reference Recommendation & Appendix sections
Recommendations	Action steps
	Decisions to be made
Appendices	List of abbreviations
	References
	Additional detail supporting visuals used in body

TABLE 15-4 Report Outline

Letters should be written with at least three paragraphs: an introductory paragraph, the main body of the letter (one or more paragraphs), and the final closing paragraph, (see Table 15-5).

Letter Outline	
Introductory paragraph	State the purpose of letter
	State the cause or need for the letter
Main body	One or more paragraphs covering the subject matter
	Bulk data should be in an attachment or enclosure
Closing	Summary and conclusions
	Leave an open invitation for follow up from the recipient
	Close with final good will sentence for example, "Thank you for your attention to this matter."

TABLE 15-5 Letter Outline

Meetings

Numerous meetings are held throughout the duration of a project to exchange information and make decisions. The project manager should be familiar with and skillful in conducting seven types of project meetings. Table 15-6 lists these types with key aspects of each meeting type.

Types of Project Meetings	
Project Kickoff Meeting	Orient & properly initiate the project with the project team
	Hold this meeting as soon as the PM is assigned to the project
	Make time for team introductions
	Provide & emphasize the project's objective statement
	Share key project details
	Provide an outline of the next steps
Project Status Meeting	Keeps project moving toward successful completion.
	Fixed date, time, and agenda. Hold to tight time frames for status updates.
	Review work accomplished for the last period (week, two weeks, month) Include review of scope, schedule, budget, risks Include team member updates
	Review work planned for the next period (week, two weeks, month) Include review of activities, responsible person, issues
	Identify action items, person responsible and due dates
Design Coordination Meeting	Integrating designs prepared by different members of the project team into single comprehensive package
	Include Design Coordination Meetings (DCMs) in the project schedule at appropriate points during design such as Piping & Instrumentation Drawings (P&IDs) or Process Flow Charts (PFCs)
	Identify the appropriate team members
	Provide an agenda with clearly stated meeting objective
	Summarize decisions and agreements and distribute
Stakeholder Meeting	Gain and sustain support from stakeholders
	Focus on most influential stakeholders
	Identify the appropriate stakeholders
	Present a tailored presentation: update, issues, decisions required
	Solicit feedback
	Summarize action item or follow up
Construction Kick Off Meeting	Determine selected contractor's readiness to start construction activities
	Identify attendees
	Review contractor's compliance with pre-construction contract requirements Construction schedule submittal List of sub-contractors under contract Safety requirements Review progress payment procedure
	Solicit feedback
	Summarize action items or follow up

Types of Project Meetings	
Change Control Meeting	Disciplined discussion & presentation of requested changes
	Provide an agenda clearly stating the purpose of the meeting
	Provide summary analysis of each change being requested
	Provide recommendation: approve, deny
	Summarize follow up required based on the decision
Closure Meeting	Held at the end of a phase or the end of the project to review work
	Provide summary project performance information in advance of the meeting
	Set ground rules for the meeting
	Enlist the aid of a facilitator if necessary
	Identify value-adding practices
	Identify areas requiring change; do not focus on single occurrence events
	Document, distribute findings

TABLE 15-6 Types of Project Meetings

Design is a creative process that involves diverse areas of expertise and numerous decisions that have major impacts on a project. The work of each designer influences the work of one or more other designers. A difficult task in design coordination is interfacing related work to ensure compatibility of the whole project. Generally, the problem is not finding design people who know how to do the work, it is interfacing the work of all designers. This can only be accomplished through effective communications at regularly scheduled team meetings.

Team meetings should be held weekly throughout the duration of a project. These meetings are necessary to keep the team acting as a unit and to ensure a continuous exchange of information. These team meetings should be scheduled on the same day and at the same time each week.

A typical project involves numerous conflicts. The best way to resolve these conflicts in a timely manner is by input from all those who are affected. This can only be achieved through open discussions and compromise. The project manager is the leader of all team meetings; however, he or

she should not dominate discussions. Often a team member may be assigned the role of leading discussions to resolve a problem that is related to his or her particular area of expertise. Project managers need to use their own judgement and develop the skillful art of knowing when to lead and when to let others lead.

An agenda should be prepared and distributed in advance of the meeting to ensure that important items are addressed and to conclude the meeting in the shortest time. The agenda should include a list, in chronological order, of the items to be discussed, including work completed, work in progress, work scheduled, and special problems. Each attendee should participate in team meetings. The project manager should prepare and distribute minutes of the meeting to all participants. Minutes of the meeting that include issues, risk items, and action items should be promptly distributed to the team including document control for archiving.

The project manager must ensure that meetings are productive. Meetings are inevitable and important. When thoughtfully planned and conducted, they can be highly productive; when they are mishandled, they can be a source of irritation and wasted time. Table 15-7 provides guidelines for conducting team meetings.

1.	Develop and publish an agenda in advance to promote better participation by attendees.
2.	List unfinished items from previous meetings on the agenda, including the names of individuals who are responsible for reporting on status.
3.	Restrict attendance only to individuals who need to attend.
4.	Don't waste time by discussing events that do not pertain to the purpose of the meeting.
5.	Pick a meeting leader who is a leader and facilitator, not a dictator, to ensure the meeting is conducted in an informative environment.
6.	Assign someone to take notes for distribution after the meeting.
7.	Maintain strict agenda control; follow the items in order with set time limits for discussions.
8.	Avoid interruptions, such as phone calls, as much as possible.

TABLE 15-7 Guidelines for Productive Meetings

Occasionally, special meetings may be needed to discuss special problems or unforeseen situations. Minutes of these meetings should also be kept in the project files. Other meetings are held with the owner to report progress or obtain approvals. Special meetings may be held with other interested parties, such as regulatory agencies or the general public. The project manager may not chair these meetings and often is accompanied by lead project team members to assist in discussing the issues related to the project.

Meetings should be conducted in an efficient manner because those in attendance are usually busy people who have other work that must be accomplished. An agenda provides an effective means of organizing a meeting to define and sequence the items that are to be discussed, to prevent discussions from wandering. The time required to conduct a meeting is also significantly reduced when an agenda is used to guide the discussions. An agenda can also prevent an individual from dominating the discussions and give each person an opportunity to participate. Calculators are available to estimate the cost of project meetings (https://meetingking.com/meeting-cost-calculator/). Recognizing the cost of meetings in addition to their potential to demotivate the project team, the project manager needs to practice good meeting management skills and seek to improve them with each meeting.

Meetings should be started and finished on time. Starting late penalizes those who arrive on time and rewards those who arrive late. It is preferable to define the start and end time on the agenda. Meetings with constrained times will often cover as much material, if not more, than meetings that have an open-ended time.

Minutes should be prepared for every formal meeting. As previously noted, minutes of the meeting should record items discussed, decisions made, and actions to be taken (including the responsible person and the due date). Copies of the minutes should be distributed to all attendees and a record copy placed in the project file. Minutes provide each attendee with the opportunity to verify the items discussed and decisions made. Minutes also assist the project manager in preparing the agenda for the next meeting.

Please see the online ancillaries at https://www.mhprofessional.com/9781264268443ProjMgmtEng&Constr4E for more information on agenda template, action item template.

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APPENDIX A
Example Project

Statement of Work

This example project is an actual project that has been reduced in size and simplified for illustrative purposes. The management of this type of project is discussed in the previous chapters of this book. Chapter 2 presented a discussion of the owner's study, including the needs assessment and project objectives. A discussion of project budgeting based on square foot estimating is presented in Chapter 6. The work breakdown structure (WBS) and development of the project work plan (Chapter 3), a discussion of project scheduling (Chapter 10), and project progress measurement (Chapter 13) presented pertinent information for this project.

The project is a service facility that consists of an industrial building (Building A) for servicing equipment and vehicles and an employee's administrative office building (Building B) for management of the operation of the service facility. A warehouse building (Building C) is proposed as a future addition to the project, but is not initially included in the project scope due to constraints in the owner's budget. Site work consists of grading, drainage, and all on-site utilities that are required for operation of the service facility. The project is located on 100 acres of land. Figure A-1 is a site plan that shows the layout of buildings, driveways, and parking areas.

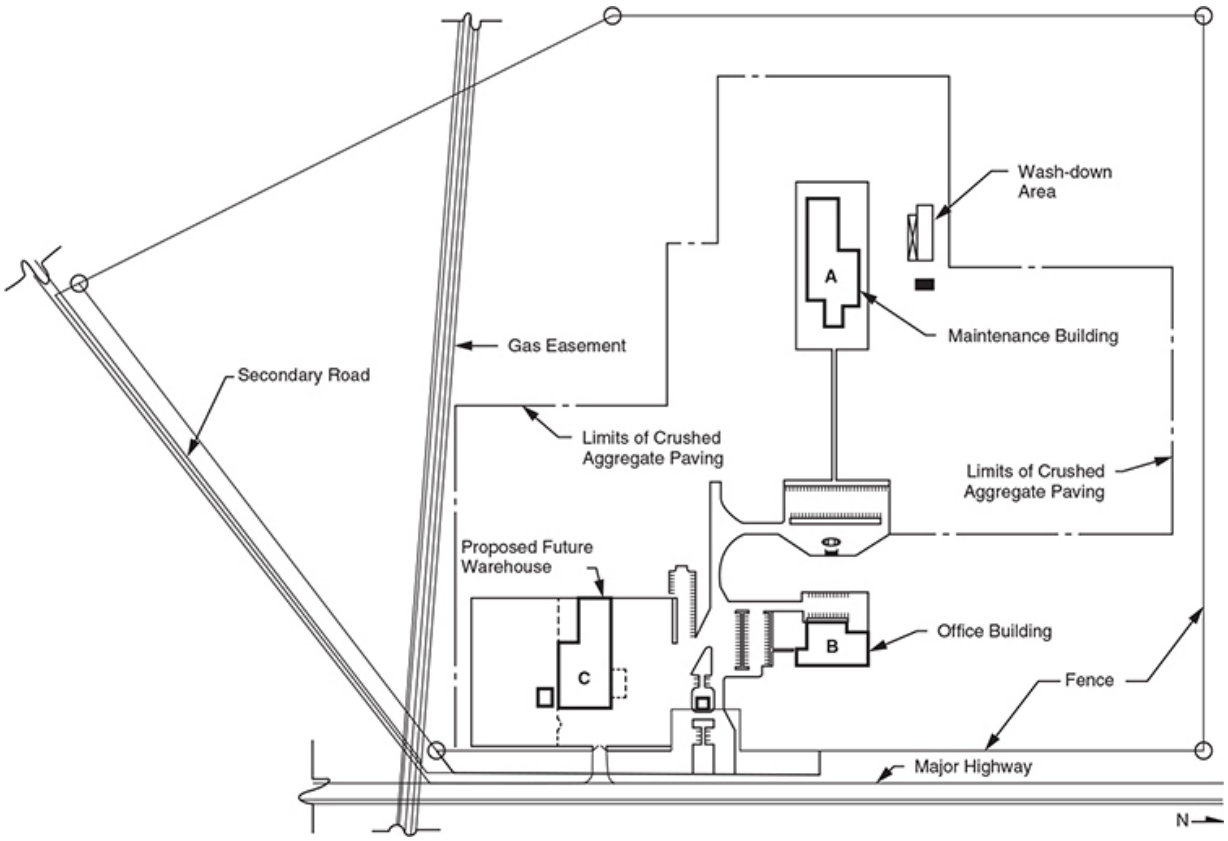


FIGURE A-1 Site plan for EPC project.

The scope of work includes engineering, procurement, and construction for the site work and two buildings. A soil investigation, legal boundary survey, and contour map is provided by the owner. Figure A-2 shows the contour map. Special procurement includes the overhead crane for Building A and the elevator conveying system for Building B. The maintenance building has a 40-foot clear ceiling height, with a 20-ton overhead crane. The owner anticipates 45 employees will be using the building during a day shift and plans expansion of work to include a night shift at a future date. A small office area and a shop with machining equipment is to be located in the maintenance building. A wash-down area is to be provided for washing and servicing of truck vehicles.

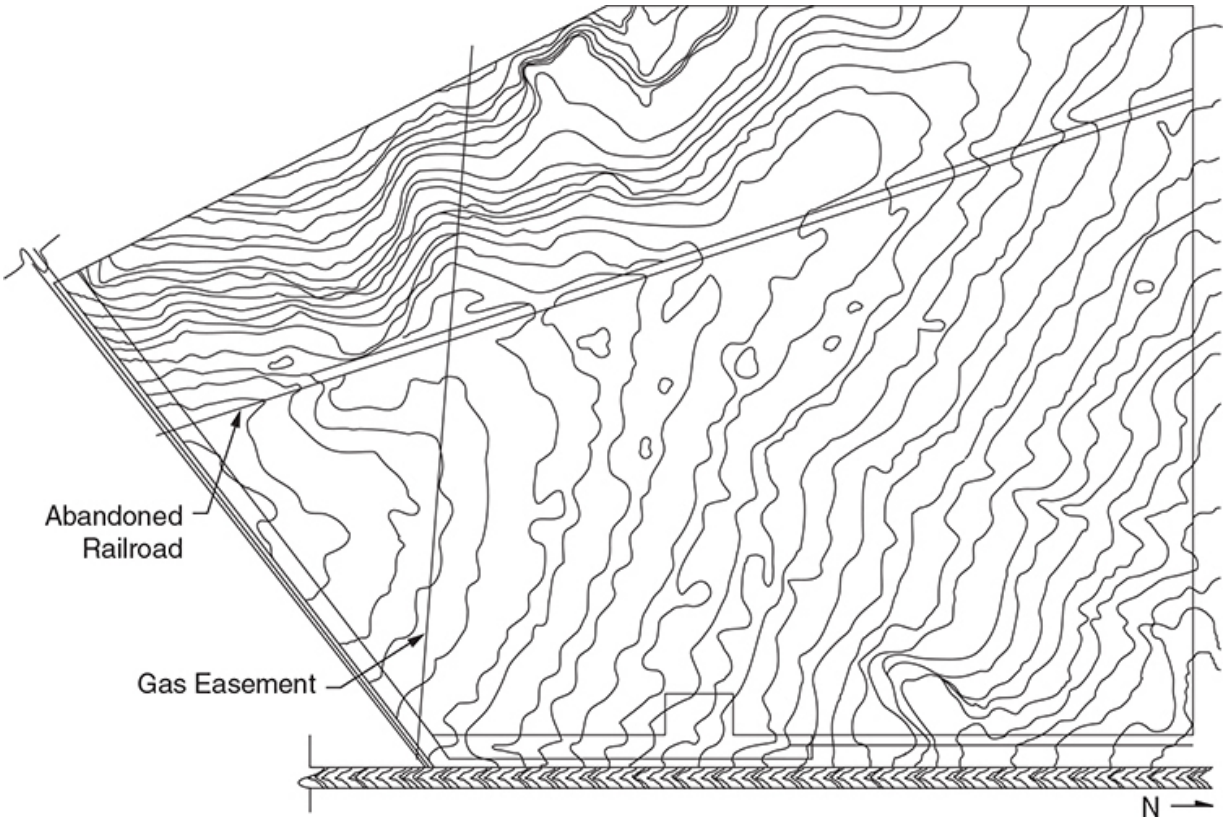


FIGURE A-2 Contour map for project.

The employee's office building is a two-story structure that will be used by 70 employees who will be involved in clerical work. A conference room, training facilities, computer workstations, and small cafeteria are to be included in the building.

All sealed surface paving and parking areas are to be constructed with portland cement concrete. The layout for the crushed aggregate paving area, for storage of major equipment and materials, is shown on the site plan.

The owner's feasibility study involved a needs assessment to produce the project budget that is shown in Figure A-3. Acquisition of land and permits are completed by the owner. Anticipated design fees are included in the total project budget. The owner's required time of completion of the project is 17 months, including engineering, procurement, and construction.

Facility	Budget
Site Work	$7,836,000
Grading	
Paving	
Landscape	
On-Site Utilities	$2,605,500
Stormwater	
Sanitary Sewer	
Domestic Water	
Underground Electrical	
Natural Gas	
Building A – Maintenance	$16,254,000
Architectural	
Structural	
Electrical	
Plumbing	
Heat & Air	
Building B – Administrative/Offices	$16,456,500
Architectural	
Structural	
Electrical	
Plumbing	
Heat & Air	
Project Management	$290,250
Administrative	
Procurement	$2,355,000
Crane	
Elevators	
Construction Bids	

	Total Direct Cost	**$45,797,250**
Contingency		$6,870,000
	Total Approved Budget	**$52,667,250**

FIGURE A-3 Approved EPC project budget.

Development of Project Work Plan

The responsibility of the project manager is to develop a comprehensive work plan to guide all aspects of the project. The first step in the process is a detailed review of the two sets of project data: the owner's study that developed the statement of work, budget, and schedule for the project; and the proposal that was approved to issue the contract to the project manager's organization. Ideally, the project manager and key members of his or her project team would have been involved in the development of both of these sets of project data; however, many project managers are assigned the responsibility of managing a project in which they have had no prior involvement.

Chapter 3 presents a discussion of the items to be reviewed by the project manager at the start of a project. A thorough review must be performed so the project manager has a clear understanding of the work that must be accomplished. In particular, the project budget must be evaluated to ensure it is realistic, and the project schedule must be evaluated to ensure it is reasonably attainable.

After the project manager's initial review, he or she develops a WBS in sufficient detail to identify major areas of work to be performed. The purpose of this initial development of the WBS is to define the required disciplines for selection of project team members. The project manager must work with the managers of the different disciplines and

functions to staff the project based on available resources from the organizational breakdown structure (OBS). For this example project, the design work for Building B is to be assigned to an outside design organization because the building requires architectural expertise that is not available in the project manager's organization and the time constraints that would be placed on in-house personnel to accomplish the work.

Figure A-4 shows the WBS for the project, which indicates the tasks to be performed, the grouping of the tasks, and the person responsible for each part of the project. Each project team member is responsible for development of a work package for the work that he or she is to perform. The format for the contents of a work package is shown in Figure A-5. The total cost of the project is derived from the sum of the costs of the work packages from all team members.

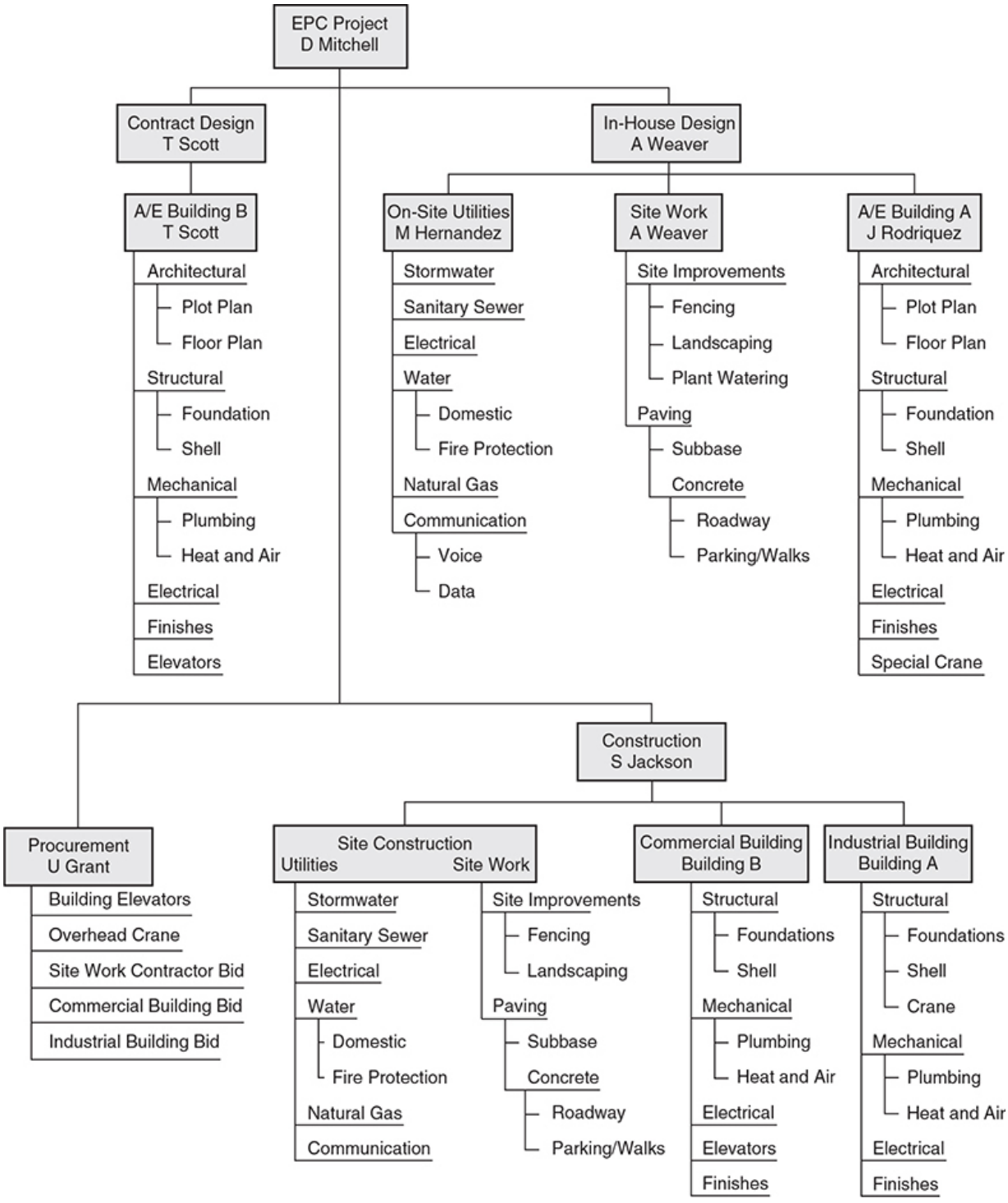
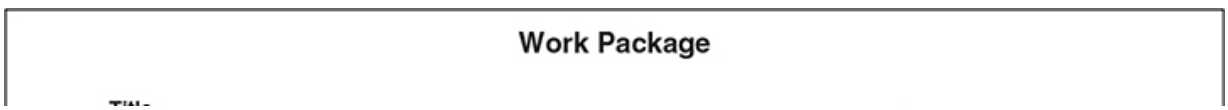


FIGURE A-4 Work breakdown structure for service facility project.



Title _____

WBS Code _____

1. Scope

Required scope of work

Services to be provided

Services excluded from this work package but included in another work package

Services excluded from this work package but performed by

2. Budget

Personnel Assigned to Job	Job Title	Work Hrs	$-Cost	CBS Code

Total Work Hrs 0

Total Personnel Cost $0

Other personnel costs

Travel Expenses $0

Training Expenses $0

Overhead loading $0

Total budget = Personnel + Other $0

3. Schedule

OBS Code	Work Task	Responsible Person	Start Date	End Date

Work Package: Start & End Dates _____ _____

Additional Comments

Prepared by: _____ Date: _____

Approved by: _____ Date: _____

FIGURE A-5 Team member's work package.

As discussed in Chapter 10, a project schedule [critical path method (CPM)] is developed by the project manager in cooperation with the team members based on an integration of the schedule of the work packages (reference Figure A-7). The project manager works with the team members to develop a coding system for the project to sort and report project reports. The coding system for the example project is shown in Figure A-6.

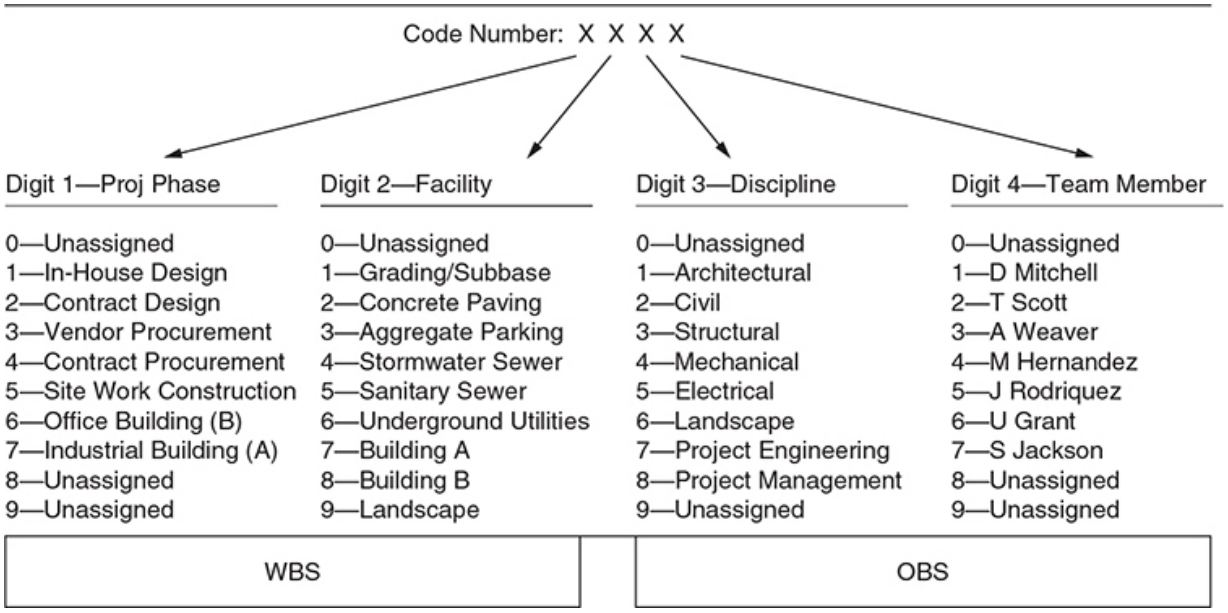


FIGURE A-6 Coding system for EPC service facility project.

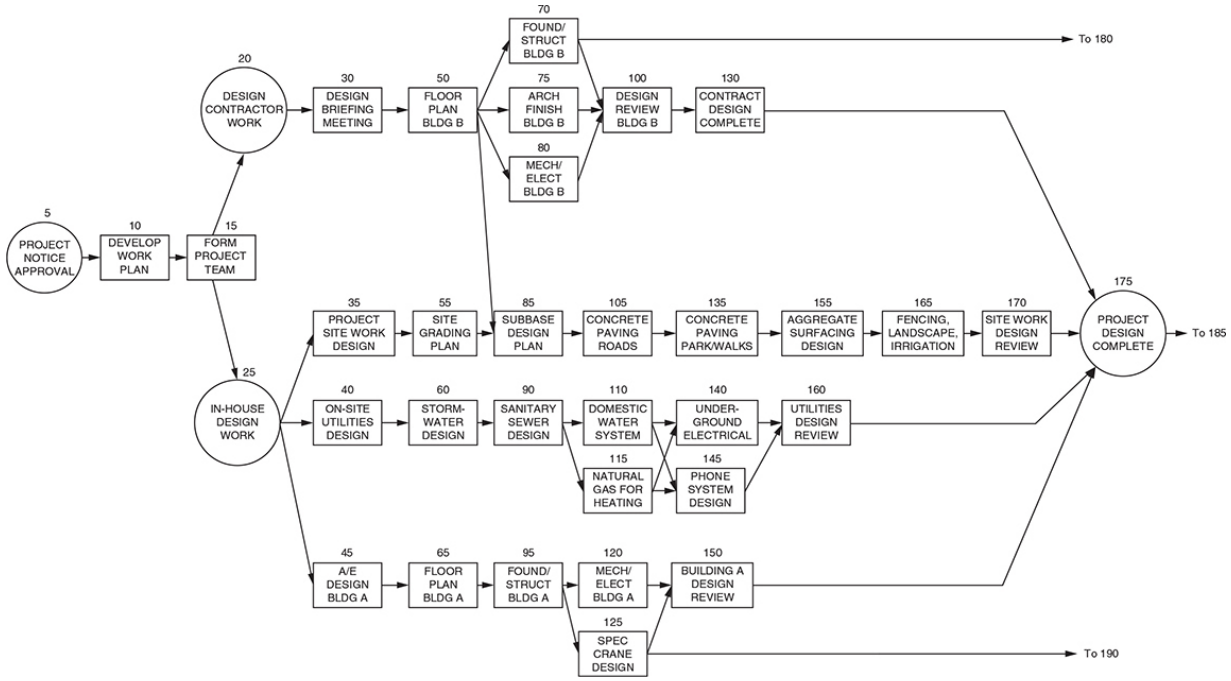


FIGURE A-7a CPM diagram for EPC service facility project

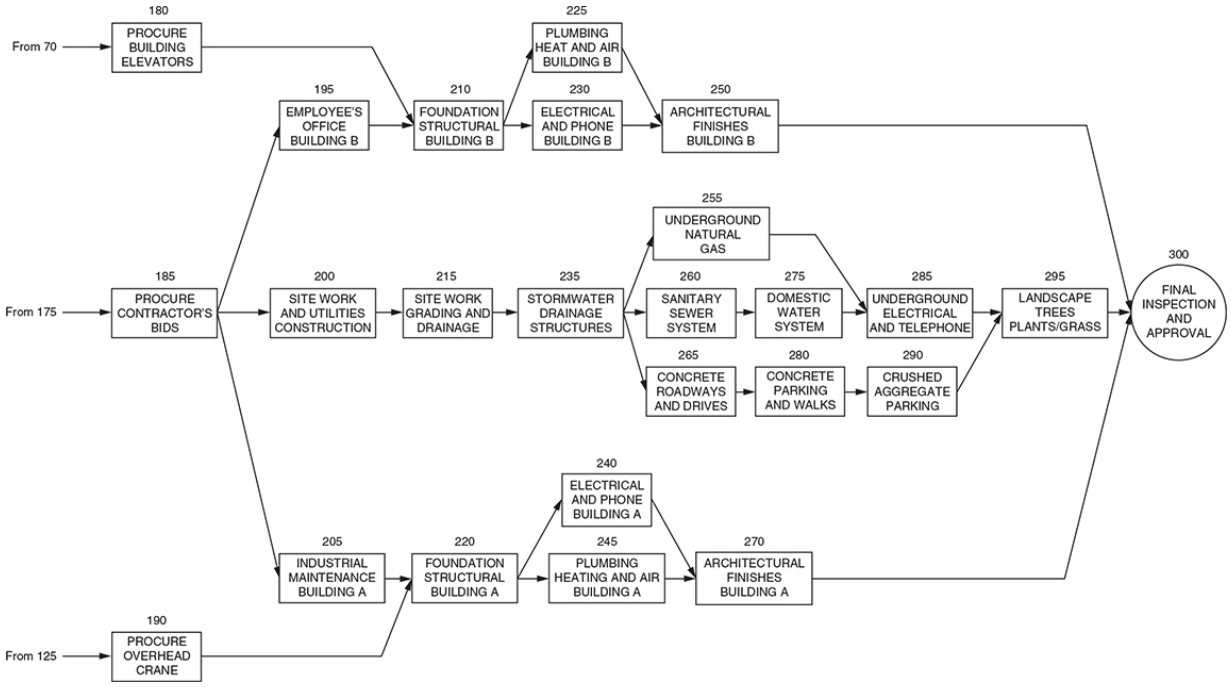


FIGURE A-7b CPM diagram for EPC service facility project

A complete listing of all input data for the project is shown in Figure A-8. The information that is contained in Figure A-8

is the only project data that are used to generate all the reports, (A-9 through A-14), that are shown in the remainder of this appendix. These reports are illustrative examples of typical project reports. The title at the top of each report identifies the contents of the report.

Project Title: Service Maintenance Facility
Project Data

Activities ID	Code				Description	Duration	Cost	$/Day
5	0	0	7	1	Project Notice Approval	3	$7,500	2,500
10	0	0	7	1	Develop Work Plan	7	$180,000	25,714
15	0	0	7	1	Form Project Team	5	$12,750	2,550
20	2	8	7	2	Design Contractor's Work	2	$45,000	22,500
25	1	0	7	3	In-House Design	3	$22,500	7,500
30	2	8	7	2	Design Briefing Meeting	1	$18,000	18,000
35	1	0	7	3	Project Site Work Design	1	$21,000	21,000
40	1	6	2	4	On-site Utilities Design	1	$18,000	18,000
45	1	7	1	5	A/E Design Building A	1	$22,500	22,500
50	2	8	1	2	Floor Plan Building B	10	$148,500	14,850
55	1	1	2	3	Site Grading Plan	12	$210,000	17,500
60	1	4	2	4	Stormwater Design	10	$30,000	3,000
65	1	7	1	5	Floor Plan Building A	15	$390,000	26,000
70	2	8	3	2	Found/Struct Building B	45	$468,000	10,400
75	2	8	1	2	Arch Finishes Building B	30	$742,500	24,750
80	2	8	4	2	Mech/Elect/Voice/Data Building B	45	$559,500	12,433
85	1	1	2	3	Subbase Design Plan	5	$60,000	12,000
90	1	5	2	4	Sanitary Sewer Design	10	$180,000	18,000
95	1	7	3	5	Found/Struct Building A	30	$1,390,500	46,350
100	2	8	7	1	Design Review Building B	10	$120,000	12,000
105	1	2	2	3	Concrete Paving Roads	20	$180,000	9,000
110	1	6	2	4	Domestic Water System	7	$135,000	19,286
115	1	6	2	4	Natural Gas System	8	$90,000	11,250
120	1	7	4	5	Mech/Elect/Voice/Data Building A	30	$333,000	11,100
125	1	7	3	5	Special Overhead Crane	11	$162,000	14,727
130	2	8	7	2	Contract Design Complete	1	$15,000	15,000
135	1	2	2	3	Concrete Paving Parking/Walks	10	$105,000	10,500
140	1	6	5	4	Underground Electrical	14	$180,000	12,857
145	1	6	5	4	Underground Voice and Data	4	$45,000	11,250
150	1	7	7	1	Building A Design Review	3	$75,000	25,000
155	1	3	2	3	Aggregate Surfacing Design	8	$90,000	11,250
160	1	6	7	7	Utilities Design Review	1	$16,500	16,500
165	1	9	6	3	Fencing/Landscape/Irrigation	14	$420,000	30,000
170	1	0	7	1	Site Work Design Review	5	$105,000	21,000
175	0	0	7	1	Project Design Complete	1	$15,000	15,000
180	3	8	7	6	Procure Building Elevators	25	$1,425,000	57,000
185	4	0	7	6	Tender for Contractor's Bids	20	$105,000	5,250
190	3	7	7	6	Procure Overhead Crane	40	$825,000	20,625
195	6	8	8	7	Employees' Office Building B	3	$15,000	5,000
200	5	0	8	7	Site Work/Utilities Construction	4	$22,500	5,625
205	7	7	8	7	Industrial/Maintenance Bldg A	2	$21,000	10,500
210	6	8	8	2	Found/Struct Building B	45	$2,925,000	65,000
215	5	0	8	3	Site Work/Grading/Drainage	18	$1,275,000	70,834
220	7	7	8	5	Found/Struct Building A	110	$5,850,000	53,182
225	6	8	8	2	Plumbing, HVAC Building B	75	$4,275,000	57,000
230	6	8	8	2	Electrical/Voice/Data Building B	60	$3,225,000	53,750
235	5	4	8	4	Stormwater/Drainage Structures	15	$330,000	22,000
240	7	7	8	5	Electrical/Voice/Data Building A	65	$2,505,000	38,539
245	7	7	8	5	Plumbing, HVAC Building A	85	$2,880,000	33,882
250	6	8	8	2	Arch Finishes Building B	50	$3,900,000	78,000

255	5	6	8	4	Underground Natural Gas	5	$157,500	31,500
260	5	5	8	4	Sanitary Sewer System	21	$498,000	23,715
265	5	2	8	3	Concrete Paving Roads & Drives	60	$2,775,000	46,250
270	7	7	8	5	Arch Finishes Building A	30	$2,625,000	87,500
275	5	6	8	4	Domestic Water System	7	$198,000	28,286
280	5	6	8	3	Concrete Parking & Walkways	15	$525,000	35,000
285	5	6	8	4	Underground Electrical/Voice/Data	14	$705,000	50,357
290	5	3	8	3	Crushed Aggregate Parking	40	$1,140,000	28,500
295	5	9	8	3	Landscape Trees/Plants/Grass	20	$930,000	46,500
300	9	9	7	7	Final Inspection & Approval	3	$52,500	17,500
							$45,797,250	

FIGURE A-8a Project data used for creation of project reports that are shown on the following pages of this Appendix.

Sequence of Activities		Sequence of Activities	
Predecessor	Successor	Predecessor	Successor
5	10		
10	15	140	160
15	20	145	160
15	25	150	175
20	30	155	165
25	35	160	175
25	40	165	170
25	45	170	175
30	50	175	185
35	55	180	210
40	60	185	195
45	65	185	200
50	70	185	205
50	75	190	220
50	80	195	210
50	85	200	215
55	85	205	220
60	90	210	225
65	95	210	230
70	100	215	235
70	180	220	240
75	100	220	245

80	100	225	250
85	105	230	250
90	110	235	255
90	115	235	260
95	120	235	265
95	125	240	270
100	130	245	270
105	135	250	300
110	140	255	285
110	145	260	275
115	140	265	280
115	145	270	300
120	150	275	285
125	150	280	290
125	190	285	295
130	175	290	295
135	155	295	300

FIGURE A-8b

Maintenance Facility Project—Activity Schedule

Activity ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float	Free Float
5	***Project Notice Approval***	3	26-May-2033	30-May-2033	26-May-2033	30-May-2033	0	0
10	***Develop Work Plan***	7	31-May-2033	8-Jun-2033	31-May-2033	8-Jun-2033	0	0
15	***Form Project Team***	5	9-Jun-2033	15-Jun-2033	9-Jun-2033	15-Jun-2033	0	0
25	***In-House Design Work***	3	16-Jun-2033	20-Jun-2033	16-Jun-2033	20-Jun-2033	0	0
20	Design Contractor's Work	2	16-Jun-2033	17-Jun-2033	27-Jun-2033	28-Jun-2033	7	0
30	Design Briefing Meeting	1	20-Jun-2033	20-Jun-2033	29-Jun-2033	29-Jun-2033	7	0
45	***A/E Design Building A***	1	21-Jun-2033	21-Jun-2033	21-Jun-2033	21-Jun-2033	0	0
35	Project Site Work Design	1	21-Jun-2033	21-Jun-2033	27-Jun-2033	27-Jun-2033	4	0
50	Floor Plan Building B	10	21-Jun-2033	4-Jul-2033	30-Jun-2033	13-Jul-2033	7	0
40	On-Site Utilities Design	1	21-Jun-2033	21-Jun-2033	9-Aug-2033	9-Aug-2033	35	0
65	***Floor Plan Building A***	15	22-Jun-2033	12-Jul-2033	22-Jun-2033	12-Jul-2033	0	0
55	Site Grading Plan	12	22-Jun-2033	7-Jul-2033	28-Jun-2033	13-Jul-2033	4	0
60	Stormwater Design	10	22-Jun-2033	5-Jul-2033	10-Aug-2033	23-Aug-2033	35	0
70	Found/Struct Building B	45	5-Jul-2033	5-Sep-2033	22-Jul-2033	22-Sep-2033	13	0
80	Mech/elect/voice/data building B	45	5-Jul-2033	5-Sep-2033	22-Jul-2033	22-Sep-2033	13	0
75	Arch Finishes Building B	30	5-Jul-2033	15-Aug-2033	12-Aug-2033	22-Sep-2033	28	15
90	Sanitary Sewer Design	10	6-Jul-2033	19-Jul-2033	24-Aug-2033	6-Sep-2033	35	0
85	Subbase Design Plan	5	8-Jul-2033	14-Jul-2033	14-Jul-2033	20-Jul-2033	4	0
95	***Found/Struct Building A***	30	13-Jul-2033	23-Aug-2033	13-Jul-2033	23-Aug-2033	0	0
105	Concrete Paving Roads	20	15-Jul-2033	11-Aug-2033	21-Jul-2033	17-Aug-2033	4	0
115	Natural Gas System	8	20-Jul-2033	29-Jul-2033	7-Sep-2033	16-Sep-2033	35	0
110	Domestic Water System	7	20-Jul-2033	28-Jul-2033	8-Sep-2033	16-Sep-2033	36	1
140	Underground Electrical	14	1-Aug-2033	18-Aug-2033	19-Sep-2033	6-Oct-2033	35	0
145	Underground voice and data	4	1-Aug-2033	4-Aug-2033	3-Oct-2033	6-Oct-2033	45	10
135	Contract Paving Parking/Walks	10	12-Aug-2033	25-Aug-2033	18-Aug-2033	31-Aug-2033	4	0
160	Utilities Design Review	1	19-Aug-2033	19-Aug-2033	7-Oct-2033	7-Oct-2033	35	35
120	***Mech/elect/voice/data building A***	30	24-Aug-2033	4-Oct-2033	24-Aug-2033	4-Oct-2033	0	0
125	Special Overhead Crane	11	24-Aug-2033	7-Sep-2033	31-Aug-2033	14-Sep-2033	5	19

Activity ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	Total Float	Free Float
155	Aggregate Surfacing Design	8	26-Aug-2033	6-Sep-2033	1-Sep-2033	12-Sep-2033	4	0
100	Design Review Building B	10	6-Sep-2033	19-Sep-2033	23-Sep-2033	6-Oct-2033	13	0
180	Procure Building Elevators	25	6-Sep-2033	10-Oct-2033	22-Dec-2033	25-Jan-2034	77	23
165	Fencing/Landscape/Irrigation	14	7-Sep-2033	26-Sep-2033	13-Sep-2033	30-Sep-2033	4	0
190	Procure Overhead Crane	40	8-Sep-2033	2-Nov-2033	15-Sep-2033	9-Nov-2033	5	5
130	Contract Design Complete	1	20-Sep-2033	20-Sep-2033	7-Oct-2033	7-Oct-2033	13	13
170	Site Work Design Review	5	27-Sep-2033	3-Oct-2033	3-Oct-2033	7-Oct-2033	4	4
150	***Building A Design Review***	3	5-Oct-2033	7-Oct-2033	5-Oct-2033	7-Oct-2033	0	0
175	***Project Design Complete***	1	10-Oct-2033	10-Oct-2033	10-Oct-2033	10-Oct-2033	0	0
185	***Procure Contractor's Bids***	20	11-Oct-2033	7-Nov-2033	11-Oct-2033	7-Nov-2033	0	0
205	***Industrial/Maintenance Bldg A***	2	8-Nov-2033	9-Nov-2033	8-Nov-2033	9-Nov-2033	0	0
195	Employees' Office Building B	3	8-Nov-2033	10-Nov-2033	23-Jan-2034	25-Jan-2034	54	0
200	Site Work/Utilities Construction	4	8-Nov-2033	11-Nov-2033	24-Jan-2034	27-Jan-2034	55	0
220	***Found/Struct Building A***	110	10-Nov-2033	12-Apr-2034	10-Nov-2033	12-Apr-2034	0	0
210	Found/Struct Building B	45	11-Nov-2033	12-Jan-2034	26-Jan-2034	29-Mar-2034	54	0
215	Site Work/Grading/Drainage	18	14-Nov-2033	7-Dec-2033	30-Jan-2034	22-Feb-2034	55	0
235	Stormwater/Drainage Structures	15	8-Dec-2033	28-Dec-2033	23-Feb-2034	15-Mar-2034	55	0
265	Concrete Paving Roads & Drives	60	29-Dec-2033	22-Mar-2034	16-Mar-2034	7-Jun-2034	55	0
260	Sanitary Sewer System	21	29-Dec-2033	26-Jan-2034	27-Jun-2034	25-Jul-2034	128	0
255	Underground Natural Gas	5	29-Dec-2033	4-Jan-2034	28-Jul-2034	3-Aug-2034	151	23
225	Plumbing, Heat, & Air Bldg B	75	13-Jan-2034	27-Apr-2034	30-Mar-2034	12-Jul-2034	54	0
230	Electrical/Voice/Data Building B	60	13-Jan-2034	6-Apr-2034	20-Apr-2034	12-Jul-2034	69	15
275	Domestic Water System	7	27-Jan-2034	6-Feb-2034	26-Jul-2034	3-Aug-2034	128	0
285	Underground Elect, voice, data	14	7-Feb-2034	24-Feb-2034	4-Aug-2034	23-Aug-2034	128	73
280	Concrete Parking & Walkways	15	23-Mar-2034	12-Apr-2034	8-Jun-2034	28-Jun-2034	55	0
245	***Plumbing, Heat & Air Bldg A***	85	13-Apr-2034	9-Aug-2034	13-Apr-2034	9-Aug-2034	0	0
240	Electrical/Voice/Data Building A	65	13-Apr-2034	12-Jul-2034	11-May-2034	9-Aug-2034	20	20
290	Crushed Aggregate Parking	40	13-Apr-2034	7-Jun-2034	29-Jun-2034	23-Aug-2034	55	0
250	Arch Finishes Building B	50	28-Apr-2034	6-Jul-2034	13-Jul-2034	20-Sep-2034	54	54
295	Landscape Trees/Plants/Grass	20	8-Jun-2034	5-Jul-2034	24-Aug-2034	20-Sep-2034	55	55
270	***Arch Finishes Building A***	30	10-Aug-2034	20-Sep-2034	10-Aug-2034	20-Sep-2034	0	0
300	***Final Inspection & Approval***	3	21-Sep-2034	25-Sep-2034	21-Sep-2034	25-Sep-2034	0	0

Bold Italicized *Activities are critical*

FIGURE A-9 Schedule of all activities for EPC project

Monthly Cost Schedule

Project: Service Maintenance Facility **Project ID:** 22-739-04

Project Manager: D. Mitchell

Start Date: 26-May-2033 **Finish Date:** 25-Sep-2034

		Early Start		Late Start		Target Schedule			
No.	Month, Year	$/Month	Cum. $	$/Month	Cum. $	$/Month	Cum. $	% Time	% Cost
1	May 2033	$58,935	$58,935	$58,935	$58,935	$58,935	$58,935	1.2%	0.1%
2	Jun 2033	$732,615	$791,550	$519,675	$578,610	$626,145	$685,080	7.5%	1.5%
3	Jul 2033	$2,658,915	$3,450,465	$1,518,060	$2,096,670	$2,088,488	$2,773,568	13.5%	6.1%
4	Aug 2033	$1,958,745	$5,409,210	$1,962,570	$4,059,240	$1,960,658	$4,734,225	20.1%	10.3%
5	Sep 2033	$2,503,965	$7,913,175	$2,407,875	$6,467,115	$2,455,920	$7,190,145	26.4%	15.7%
6	Oct 2033	$1,038,825	$8,952,000	$956,760	$7,423,875	$997,793	$8,187,938	32.4%	17.9%
7	Nov 2033	$2,702,805	$11,654,805	$937,605	$8,361,480	$1,820,205	$10,008,143	38.7%	21.9%
8	Dec 2033	$3,706,740	$15,361,545	$1,679,175	$10,040,655	$2,692,958	$12,701,100	45.0%	27.7%
9	Jan 2034	$4,861,005	$20,222,550	$2,713,995	$12,754,650	$3,787,500	$16,488,600	51.3%	36.0%
10	Feb 2034	$4,993,500	$25,216,050	$3,536,130	$16,290,780	$4,264,815	$20,753,415	57.1%	45.3%
11	Mar 2034	$4,744,185	$29,960,235	$3,515,430	$19,806,210	$4,129,808	$24,883,223	63.7%	54.3%
12	Apr 2034	$3,630,330	$33,590,565	$3,689,505	$23,495,715	$3,659,918	$28,543,140	69.5%	62.3%
13	May 2034	$3,757,335	$37,347,900	$4,625,145	$28,120,860	$4,191,240	$32,734,380	76.1%	71.5%
14	Jun 2034	$4,260,255	$41,608,155	$4,943,835	$33,064,695	$4,602,045	$37,336,425	82.4%	81.5%
15	Jul 2034	$1,342,185	$42,950,340	$4,840,650	$37,905,345	$3,091,418	$40,427,843	88.4%	88.3%
16	Aug 2034	$1,656,915	$44,607,255	$5,083,395	$42,988,740	$3,370,155	$43,797,998	95.0%	95.6%
17	Sep 2034	$1,189,995	$45,797,250	$2,808,510	$45,797,250	$1,999,253	$45,797,250	100.0%	100.0%

FIGURE A-10 Monthly distribution of costs for all activities of EPC service facility project.

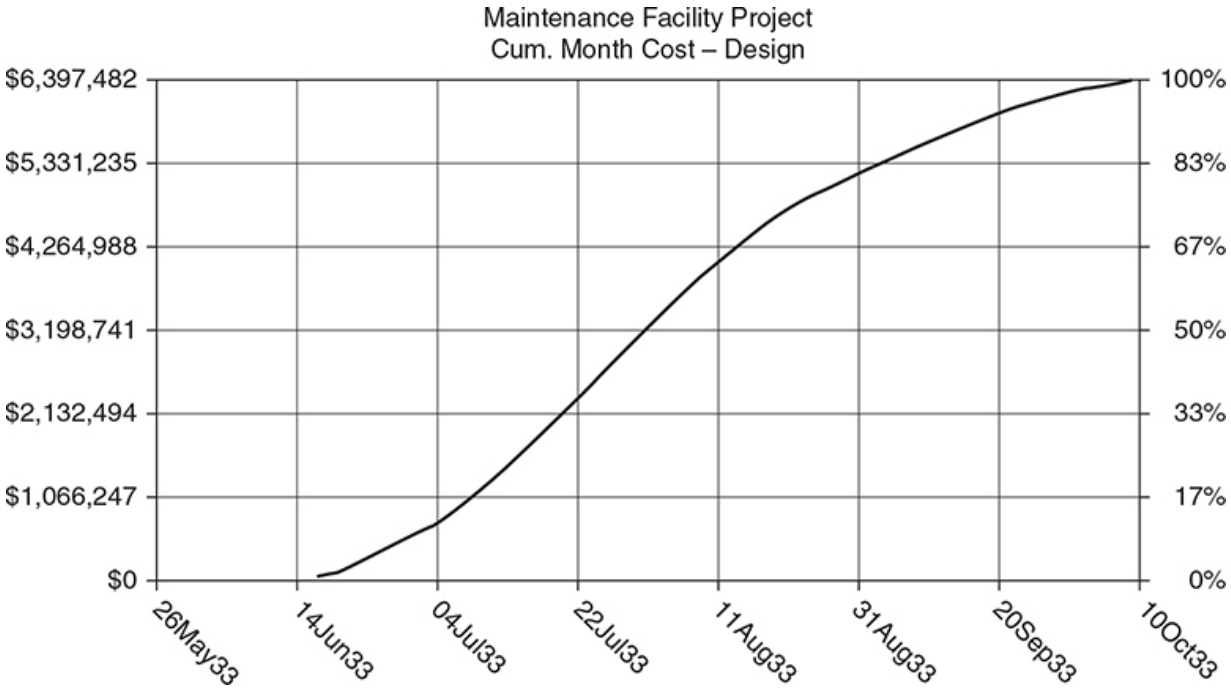


FIGURE A-11 S-curve for design activities only (code digit 1 equal to 1 and 2).

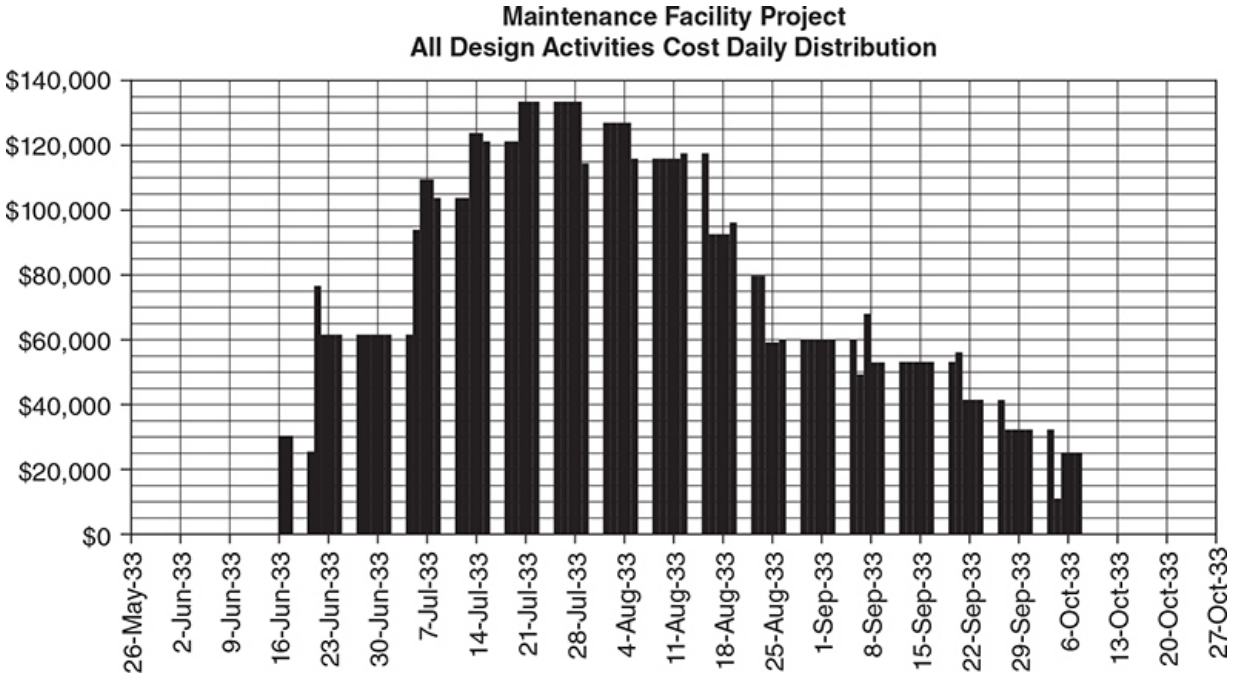


FIGURE A-12 Daily distribution of costs for design work only (code digit 1 equal to 1 and 2).

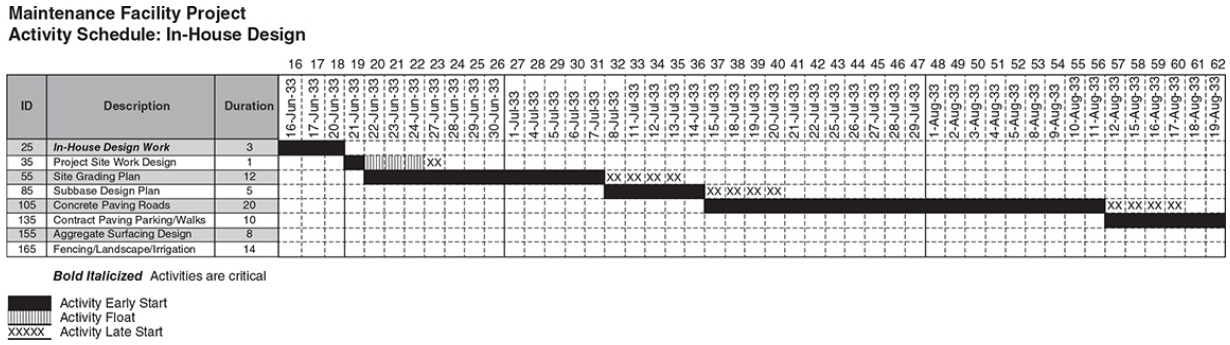


FIGURE A-13 Bar chart for design work of team member A. Weaver (code digit 1 equal to 1 and code digit 4 equal to 3).

Maintenance Facility Project
Activity Schedule

ID	Description	Duration	Early Start	Early Finish	Late Start	Late Finish	ES Day	EF Day	LS Day	LF Day	Total Float	Free Float
45	***A/E Design Building A***	1	21-Jun-2033	21-Jun-2033	21-Jun-2033	21-Jun-2033	19	19	19	19	0	0
65	***Floor Plan Building A***	15	22-Jun-2033	12-Jul-2033	22-Jun-2033	12-Jul-2033	20	34	20	34	0	0
95	***Found/Struct Building A***	30	13-Jul-2033	23-Aug-2033	13-Jul-2033	23-Aug-2033	35	64	35	64	0	0
120	***Mech/Elect Building A***	30	24-Aug-2033	4-Oct-2033	24-Aug-2033	4-Oct-2033	65	94	65	94	0	0
125	Special Overhead Crane	11	24-Aug-2033	7-Sep-2033	31-Aug-2033	14-Sep-2033	65	75	70	80	5	19
190	Procure Overhead Crane	40	8-Sep-2033	2-Nov-2033	15-Sep-2033	9-Nov-2033	76	115	81	'20	5	5
150	***Building A Design Review***	3	5-Oct-2033	7-Oct-2033	5-Oct-2033	7-Oct-2033	95	97	95	97	0	0
205	***Industrial/Maintenance Bldg A***	2	8-Nov-2033	9-Nov-2033	8-Nov-2033	9-Nov-2033	119	120	119	120	0	0
220	***Found/Struct Building A***	110	10-Nov-2033	10-Apr-2034	10-Nov-2033	10-Apr-2034	121	230	121	230	0	0
240	Electrical/Phone Building A	65	11-Apr-2034	6-Jul-2034	9-May-2034	3-Aug-2034	231	295	261	315	20	20
245	***Plumbing, Heat & Air Bldg A***	85	11-Apr-2034	3-Aug-2034	11-Apr-2034	3-Aug-2034	231	315	231	315	0	0
270	***Arch Finishes Building A***	30	4-Aug-2034	14-Sep-2034	4-Aug-2034	14-Sep-2034	316	345	316	345	0	0

Bold Italicized *Activities are critical*

FIGURE A-14 Schedule for all activities related to Building A (sort by code digit 2 equal to 7).

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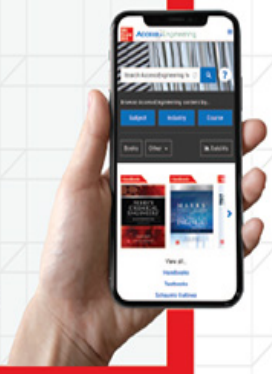
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