PROJECT MANAGEMENT FOR ENGINEERING AND CONSTRUCTION

SECOND EDITION

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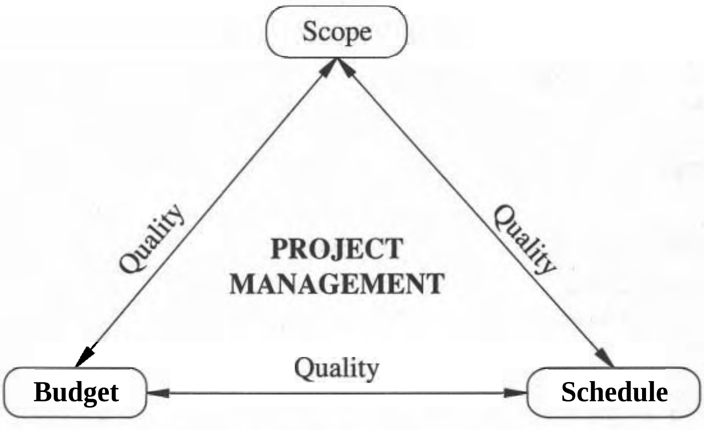

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PROJECT MANAGEMENT FOR ENGINEERING AND CONSTRUCTION
International Edition 2000

10 09 08 07 06 05 04
20 09 08 07 06 05 04 03 02
FC BJE

ISBN 0-07-039362-1

Library of Congress Cataloging-In-Publication Data

Oberlender, Garold D.
Project management for engineering and construction / Garold D. Oberlender. – 2nd ed.
p. cm.
ISBN 0-07-039360-5
1. Engineering - Management. I. Title.
TA190.024 2000
658.4'04–dc21 99-53231

When ordering this title, use ISBN **0-07-116355-7**

Printed in Singapore

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PREFACE

This book presents the principles and techniques of managing engineering and construction projects from the conceptual phase, through design and construction, to completion. It emphasizes project management during the early stages of project development because the ability to influence the quality, cost, and schedule of a project can best be achieved during the early stages of development. 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 the project to improve quality, cost, or schedule to benefit the owner.

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 second edition of the book has three new chapters: Working with Project Teams, Early Estimates, and Design Proposals. The topics in these chapters are extremely important to achieving a successful project. These topics are covered from the perspective of the engineer who is employed with either the owner's organization or the design firm.

The intended audience of this book is students of university programs in engineering and construction. It is also intended for persons in industry who aid the owner in the feasibility study, coordinate the design effort, and witness construction in the field. **A** common example is used throughout this book to illustrate project management of the design and construction process.

This book is based on the author's experience in working with hundreds of project managers in the engineering and construction industry. Much of the information in this book is based on formal and informal discussions with these project managers, who are actively involved in the practice of project management. Although the author has observed that no two project managers operate exactly the same, there are common elements that apply to all projects and all project managers. The author presents these common elements of effective project management that have been successfully applied in practice.

McGraw-Hill and the author would like to thank Martin Fischer of Stanford University and C. William Ibbs of the University of California at Berkeley for their many comments and suggestions. The author would also like to thank the many project managers in industry who have shared their successes, and problems, and who have influenced the author's thoughts in the development of this book. Finally, the author greatly appreciates the patience and tolerance of his wife, Jana, and three sons, Dan, Tim, and Ron, for their support and encouragement during the writing and editing phases in producing this finished book.

Garold D. Oberlender

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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.

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 project managers and projects. 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 to complete the project.

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 approved. 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 students enrolled in university programs in engineering and construction. It is also intended for the design firms which aid the owner in the feasibility study, coordinate the design effort, and witness construction in the field. This book is also for persons 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 management of a project generally follows these steps:

Step 1: Project Definition (to meet the needs of the end user)
Intended use by the owner upon completion of construction
Conceptual configurations and components to meet the intended use

Step 2: Project Scope (to meet the project definition)
Define the work that must be accomplished
Identify the quantity, quality, and tasks that must be performed

Step 3: Project Budgeting (to match the project definition and scope)
Define the owner's permissible budget
Determine direct and indirect costs plus contingencies

Step 4: Project Planning (the strategy to accomplish the work)
Select and assign project staffing
Identify the tasks required to accomplish the work

Step 5: Project Scheduling (the product of scope, budgeting, and planning)
Arrange and schedule activities in a logical sequence
Link the costs and resources to the scheduled activities

Step 6: Project Tracking (to ensure the project is progressing as planned)
Measure work, time, and costs that are expended
Compare "actual" to "planned" work, time, and cost

Step 7: Project Close Out (final completion to ensure owner satisfaction)
Perform final testing and inspection, archive documents, and confirm payments
Turn over the project to the owner

These steps describe project management in its simplest form. In reality there is considerable overlap between the steps, because any one step may affect one or more other steps. 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 steps 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 steps.

Chapter 1 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, Working with Project Teams, 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. As leader of the project team, the project manager acts as a coach to answer questions and to make sure the team understands what is expected of them and the desired outcome of the project.

Chapter **3,** Project Initiation, presents material that is generally performed by the owner. However, the owner may contract the services of a design organization to assist with the feasibility study of a project. The project manager should be involved at the project development or marketing phase to establish the scope. This requires input from experienced technical people that represent every aspect of the proposed project.

Chapter 4, Early Estimates, presents the techniques and processes of preparing estimates in the early phase of a 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 5, Project Budgeting, applies to all parties in a project: the owner, designer, and contractor. The budget must be linked to the quantity, quality, and schedule of the work to be accomplished. 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 6, Development of Work Plan, applies to the project manager who is responsible for management of 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 which 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 7, 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.

Chapter 8, Project Scheduling, provides the base against which all activities are measured. It relates the work to be accomplished to the people who will perform the work as well as to the budget and schedule. Project scheduling cannot be accomplished without a well-defined work plan, as described in Chapter 6, and it forms the basis for project tracking, as described in Chapter 9.

Chapter 9, Tracking Work, cannot be accomplished without a well-defined work plan, as described in Chapter 6, and a detailed schedule, as described in Chapter 8. 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 budget, and the schedule. 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 10, 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 end 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 11, 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 upon the quality of work that is performed by the construction contractors. Most of the books that have been 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, and into the construction phase until project close out.

Chapter 12, 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 13, Personal Management Skills, addresses the human aspects of project management. Although the primary emphasis of this book is on the techniques of project management, it is the project manager working with his or her people who ensures the successful completion of a project.

Chapter 14, Total Quality Management, presents the management philosophy that has gained much attention in the engineering and construction industry. Most of the attention has been attributed to the success of TQM in the manufacturing and electronics industries. However, many of the topics related to TQM are applicable to good project management of design and construction.

DEFINITION OF A PROJECT

A project is an 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, i.e., the quantity and quality of work. ***Budget*** refers to costs, measured in dollars and/or labor-hours of work. ***Schedule*** refers to the logical sequencing and timing of the work to be performed. The quality of a project must meet the owner's satisfaction and is an integral part of project management as illustrated in Figure 1-1.

Figure 1-1 is shown as an equilateral triangle to represent an important principle of project management: a balance is necessary between the scope, budget, and schedule. For any given project there is a certain amount of work that must be performed and an associated cost and schedule for producing the work. Any increase in the scope of work requires a corresponding increase in budget and schedule. Conversely, any decrease in scope of work results in a corresponding decrease in budget and schedule. This principle applies between any and all of the three components of a project. For example, any adjustment in budget and/or schedule requires a corresponding adjustment in scope. 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.

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.

Since the project scope defines the work to be accomplished, it should be the first task in the development of a project, prior to the development of either the budget or the schedule. 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.

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

FIGURE 1-1
Quality Is an Integral Part of Scope, Budget, and Schedule.

concerned about project cost overrun because it adversely affects profitability and creates adverse relationships between the parties.

Scheduling is important because it brings together project definition, people, cost, resources, timing, and methods of performing work to define the logical sequencing of activities for the project. 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 that meets 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 satisfaction of the ultimate end user of the project, the owner.

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 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 improve our work and what is the best way we can furnish a project that meets the needs and satisfaction of the owner?'

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 also need to identify their level of involvement in the project, e.g., the review process, required reports, and the levels of approval. The owner is also responsible for setting parameters on total cost, payment of costs, major milestones, and the project completion date.

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, e.g., 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 correlated to the construction schedule so the project can be completed by the construction contractor when the owner needs it.

Generally the 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 more easy 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.

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. For large projects a team consisting of a project manager for the owner, designer, and contractor forms a group of people who work together to manage the design, procurement, and construction activities. For small projects the owner may delegate overall project management responsibility to a design consultant, or a professional construction manager, and assign an owner's representative as a liaison to represent the owner's interest.

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.

The Work Managers are the 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 2 and 11.

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 four questions that must be addressed: Who? Does what? When? and How much?

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 discipline environment of management. Upon graduation from college, a person generally accepts a position in a discipline 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 discipline. Career goals are directed toward becoming a specialist in a particular technical area.

Project management requires a multi-discipline 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 disciplines. 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 upon 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 1-1 illustrates the relationship between project management and discipline management.

TABLE 1-1
DISTINGUISHING BETWEEN PROJECT AND DISCIPLINE MANAGEMENT

Project management is concerned with	Discipline management is concerned with
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

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

TABLE 1-2
KEY CONCEPTS OF PROJECT MANAGEMENT

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 and measurable 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 charge in the project
20. Keep the client informed; they pay for everything and will use the project upon completion

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 afterwards. 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 1-2.

Each of the key concepts shown in Table 1-2 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, non-repetitive 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 1-3 provides guidelines for 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 1-4 provides guidelines for 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

TABLE 1-3
PROJECT MANAGER'S ROLE IN PLANNING

1. Develop planning 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 discipline 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 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. Define clearly the authority and responsibility for all project team members

manager must understand the work to be accomplished by each discipline. The project manager should then work with his or her supervisor and appropriate discipline managers to identify the persons who are best qualified to work on the project. Table 1-5 provides guidelines for project 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 discipline (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 disciplines. He or she cannot become overly involved in detailed tasks, but should be the leader of the team to meet project objectives. Table 1-6 provides guidelines for directing the project.

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 1-7 provides guidelines for project control.

TABLE 1-5
PROJECT MANAGER'S ROLE IN STAFFING

1. Define clearly 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 upon scope, budget, and schedule

TABLE 1-6
PROJECT MANAGER'S ROLE IN DIRECTING

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 CONTROLLING

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

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* (PMB*OK*).**

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 which are comprised 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

QUESTIONS FOR CHAPTER 1—INTRODUCTION

1 As presented in this chapter, quality is an integral part of project management. Because there are different levels of quality, it is important for the owner, designer, and contractor to have a mutual understanding of the quality that is expected in a project. Describe methods that can be used to ensure that quality is adequately defined, understood, and properly included in a project.

2 Give examples of problems that may arise when an owner fails to fulfill his or her responsibility of clearly defining the operational criteria of a project.

3 Give examples of problems that may arise when a designer fails to give adequate attention to the impact of a design selection on the cost or schedule during the construction phase.

4 Give examples of problems that may arise when a contractor fails to perform his or her work in accordance with the contract documents.

5 In actuality, there are at least three project managers that are involved in a project, one each working for the owner, designer, and contractor. Since each of these individuals

works for a different organization, describe methods that you would suggest to ensure good working relationships between these three individuals.

6 Interview three project managers, one working for an owner, designer, and contractor, respectively, to identify factors that each manager believes is important for the successful completion of a project.

7 A definition of project management is given in this chapter. Review this definition and expand it to include additional items that you feel are important to the function of project management.

8 Consult publications from one or more of the references at the end of this chapter to compare and contrast the differences between "project management" and "functional management."

9 The five basic functions of management discussed in this chapter are derived from the basic principles of business management. Review two sources of publications that describe the role and functions of management, one from a journal of business management and one from a journal of engineering management. Compare the business perspective of management to the engineering perspective of management.

10 Throughout the project management process, there are four questions that must be addressed: Who? Does what? When? and How much? Expand this list to include other questions that may be appropriate for some situations in the management of a project.

REFERENCES

1 Adams, J. R. and Campbell, B., ***Roles and Responsibilities of the Project Manager,*** Project Management Institute, Newtown Square, PA, 1982.

2 Adams, J. R., Bilbro, C. R., and Stockert, T. C., ***An Organization Development Approach to Project Management,*** Project Management Institute, Newtown Square, PA, 1986.

3 "Organizing for Project Success," Publication No. 12-2, Construction Industry Institute, Austin, TX, February, 1991.

4 Stuckenbruck, L. C., ***The Implementation of Project Management: The Professional's Handbook,*** Project Management Institute, Newtown Square, PA, 1981.

2

WORKING WITH PROJECT TEAMS

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 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 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 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 challenge to the project manager.

TEAMWORK

Teamwork is not a new concept; it is just being revisited after two decades of worker isolation due to extensive emphasis on technical specialization. Reorganization and downsizing of businesses also has created a renewed emphasis on teamwork because the in-house capabilities of many businesses have been reduced, causing outsourcing of work to finish projects. Everyone agrees that teamwork is important; the real task is organizing a successful team for 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. 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 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 staffs 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. 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 principles 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.

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 2-1.

Each triangle in Figure 2-1 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.

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. Sewing on the owner's project management team are 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 2-1 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 2-1, the manager of the lower-level team serves as a member of the higher-level team. There must be one head of each team.

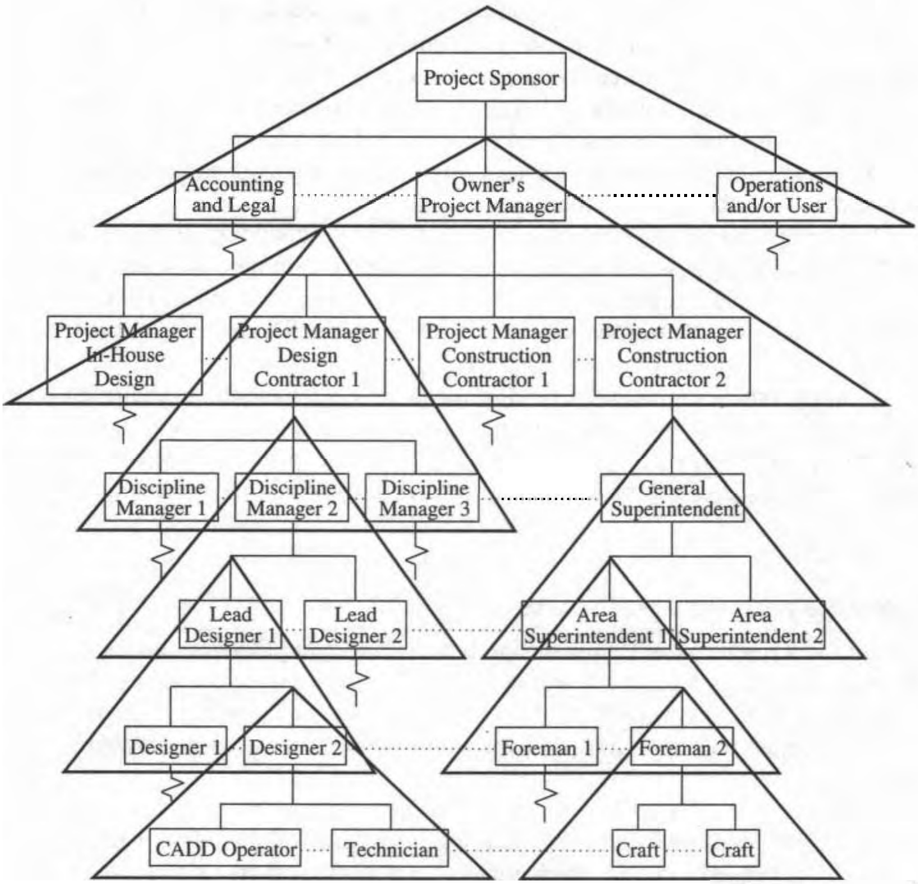


FIGURE 2-1
Overlapping Environment of Multiple Teams.

DESIGN TEAMS

Members of the design team are selected based on the specific expertise needed for a particular project. The team is composed of individuals with diverse backgrounds, including design disciplines [architectural, civil, mechanical, electrical, structural, computer aided design and drafting (CADD), etc.], project control individuals (cost control, estimating, quality control, safety, etc.), non-technical people (purchasing, legal, financial, permitting, regulatory, etc.), and the sponsor's representative.

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 sponsoring organization. He or she must have the responsibility and authority to act on behalf of the sponsoring organization.

The sponsor's representative 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. He or she reviews and approves the evolving scope, budget, and schedule. As a team member, the sponsor's representative approves any changes in scope, budget, and schedule before commitments are made. This individual should be an active participant on the design team, answering questions and providing information needed by the team to accomplish the work. Unfortunately, the sponsoring organization's representative is sometimes not involved until the project gets into trouble. Early involvement of the sponsor's representative can prevent future problems. The design project manager must make this individual feel that he or she is part of the project team.

Selecting design team members 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. Chapter *6* presents various organization structures for design firms. To illustrate selection of design team members, consider a design firm that is organized as shown in Figure 6-5. The project manager and his or her supervising manager will review the project's needs to identify required discipline expertise and required personnel. Then, a meeting is arranged with the manager of appropriate discipline managers to request team members. The people assigned to the project are selected by the department manager of engineers for each respective discipline.

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 make arrangements for additional training to ensure the work can be completed.

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 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 upon 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.

TEAM MANAGEMENT

Successful team management requires the team to be an integral unit of the organization. A team must have a well-defined mission with common goals, objectives, and strategies. The role of each team member must be clearly defined. 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 communications 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 honest communications are 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. Most workers want to do what is expected of them and will do the work, provided there are clear instructions and understandings. 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.

TEAMS AND THE PROJECT MANAGER'S RESPONSIBILITIES

When working with team members, the project manager must cross many boundaries in the organizational structure to develop the project team into a cohesive group. This must be done quickly in spite of 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 cordial environment that enables the team to work together so members will motivate themselves to peak performance.

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 communications.

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 matches the decision to be made. 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.

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.

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. 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 they do not have the respect of their leader. 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.

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 and creative, 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 communications is essential to team building. In simple terms, effective communications 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 communications. The project team cannot function when there are breakdowns in communications. Misinformation or incomplete information is a major deterrent to team building. Effective communications 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 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.

Key words for team building are pressure, responsibility, honesty, kindness, respect, and communications. 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 communications and avoid hiding mistakes and pointing blame. A successful team can achieve a successful project and have fun doing it.

Some companies have begun the team building process by holding a week-end 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.

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.

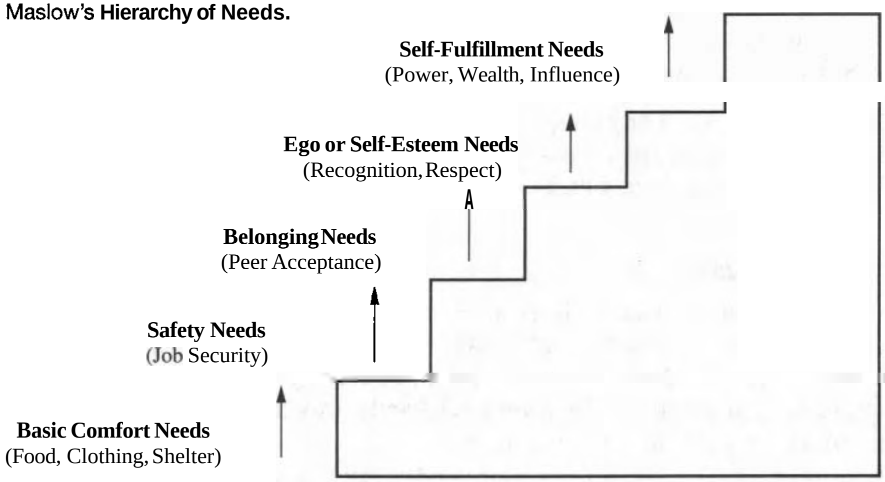
Maslow proposed that humans are a wanting animal and their wants become needs. It is the quest to satisfy their needs that drives or motivates people. The needs include basic physical and psychological needs, which are perceived in the human mind and satisfied by material things. Maslow proposed that 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 2-2 is a graphical representation of the five levels in Maslow's hierarchy of human 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 week-ends.

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

FIGURE 2-2
Maslow's Hierarchy of 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. 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.

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 that 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 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 to 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 usually 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.

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.

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 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 to 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.

QUESTIONS FOR CHAPTER 2—WORKING WITH PROJECT TEAMS

1 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, describe methods for ensuring there will be no overlap or gaps in the work of a project team.

2 You are the project manager of a team which has been newly formed. Suppose you feel one of the team members is lacking in the required skills to perform the work. Discuss methods you would use to assist the team member to ensure that his or her work will meet your expectations.

3 The composition of a design team represents individuals with diverse backgrounds, including civil, mechanical, electrical, and structural. What are methods that you would use 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?

4 Maslow's theory of hierarchy of needs lists five levels of needs that are motivators of people. As a project manager, list methods you would use to identify the needs of team members so you can be responsive to those needs in motivating your team.

5 Conflict between team members often is a result of changes. List changes during a project that could potentially lead to conflicts. For each change, how would you attempt to resolve the conflict?

6 When a team is formed that consists of people who have never worked together, team building may be necessary. Describe methods of team building for a design team that has different engineering disciplines combined with people from purchasing, quality control, and cost control.

7 There are numerous factors in team leadership. List and briefly discuss factors that are important in successful team leadership.

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3

PROJECT INITIATION

DESIGN AND CONSTRUCTION PROCESS

Early in a project, the owner must select a process for design and construction. There are many choices of processes, each with advantages and disadvantages. The process selected affects financing; selection of team members; and the project cost, quality, and schedule. Although the process 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 projects progress through three phases: project definition, design, and construction. It should be mentioned that for a total project there are business planning steps that precede design and there is an operations and maintenance phase that follows construction. This book focuses on the design and construction of projects. Project definition sets the stage for design work, and design work sets the stage for construction work. The project definition phase involves 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. Integration of the owner's requirements and constraints provides a description of the project and helps identify a plan for the time and cost of delivering the project.

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 plants, oil refining, pharmaceuticals, pulp and paper, and electrical generating. 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 contractors.

In the current practice of 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 job-site. Site construction involves labor, material, and construction equipment to physically build the project.

For non-competitive–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.

ADVANCES IN THE ENGINEERING AND CONSTRUCTION PROCESS

The construction industry has matured and continued to enhance the integration of activities in the design, fabrication, construction, and operation of constructed facilities. Major advancements in computer hardware and software have produced two-dimensional (2-D) and three-dimensional (3-D) computer aided design (CAD) systems. The CAD technology has progressed to versatile modeling systems that can be used throughout the design, engineering, and construction phases to greatly improve the capability to detect and prevent interference during field construction. The result is more efficient construction operations and less rework.

The biggest improvement using CAD is better 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 3-D model to extract information that meets their needs. Communication that uses 3-D 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.

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 competitive 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.

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. For public-sector projects the owner typically uses the competitive-bid method based on the lowest bid price for securing engineering and construction services. However, in recent years there has been an increase in qualification-based selection (QBS) for securing engineering and construction services. Using the QBS process, the owner selects engineering and construction services based on specific qualifications and other factors, rather than only price.

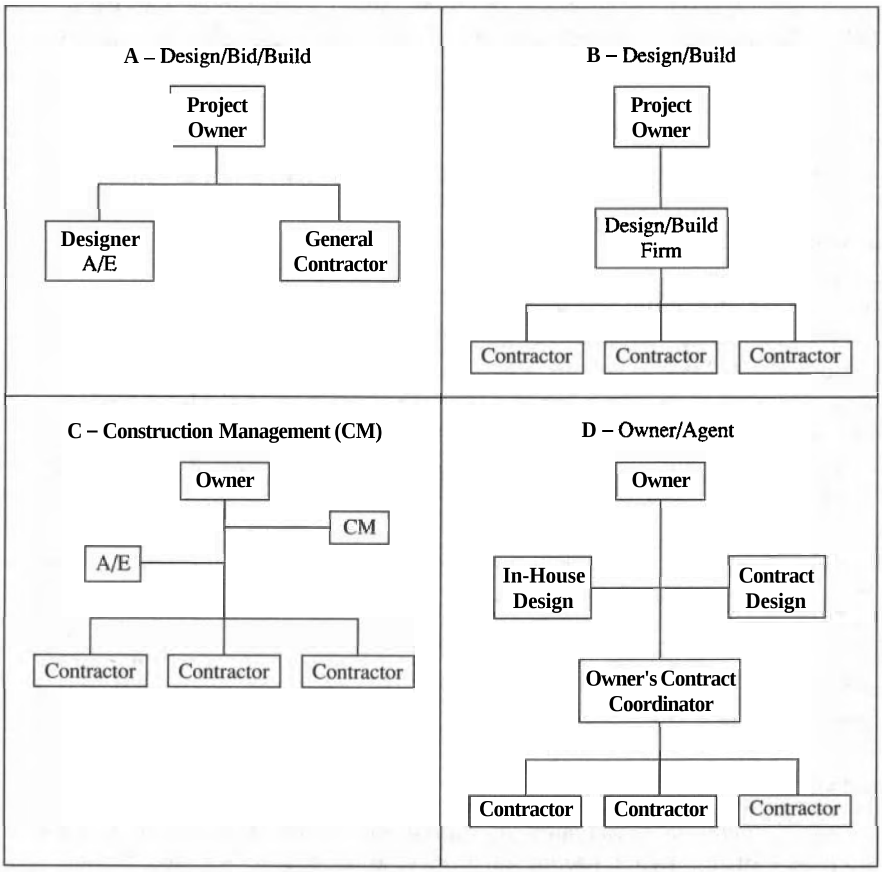
CONTRACTUAL ARRANGEMENTS

Project management requires teamwork among the three principal contracting parties. 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 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.

There are numerous combinations of contract arrangements for handling a project. Figure 3-1 illustrates the fundamental arrangements in their simplest form. Each of these arrangements is briefly described in the following paragraphs.

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

FIGURE 3-1
Contracting Arrangements.



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 upon a lump-sum, fixed-price bid before construction, rather than during construction.

A desigdbuild 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.

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 twenty years there has been considerable debate regarding the CM process and the amount of responsibility assigned to the CM firm by the owner. 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 to meet the intended use of the project by the owner. The CM method of contracting is discussed further in Chapter 11.

An ownerlagent 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.

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 construction management contract.

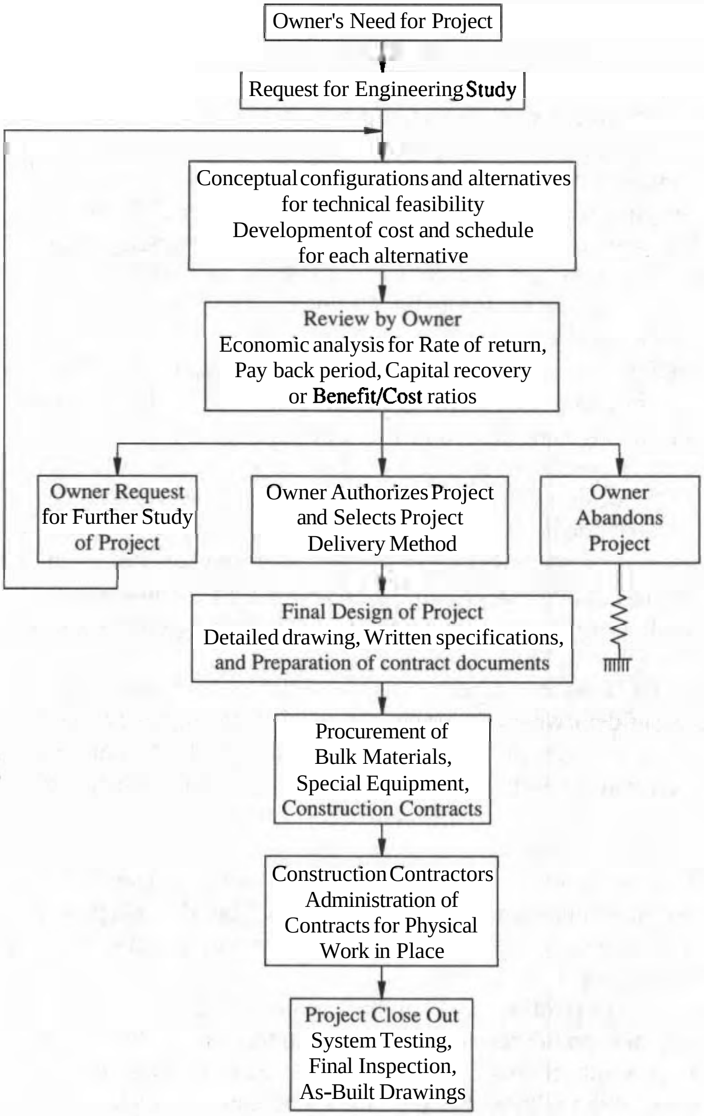
Multiple-builder owners are generally large organizations that have a continual need for projects, and generally have a staff assigned to project work. They typically will handle small-sized, short-duration projects by design/bid/build. For a project in which they desire extensive involvement, a design/build,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

PHASES OF A PROJECT

Aproject is in a continual state of change as it progresses from its start, as a need by the owner, through design development and, finally, construction. Figure **3-2** shows the various phases during the life of a project. As the project moves from one phase to another, additional parties become involved and more information is obtained to

FIGURE 3-2
Phases of a **Project.**



better identify scope, budget, and schedule. There are times when a project recycles through a phase before gaining management approval to proceed to the subsequent phase. During each phase, it is the responsibility of the project manager to keep all work within the approved scope, budget, and schedule.

In the early phases of design development, 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. This applies to the project manager in either the owner, designer, or contractor organization. The people who work around 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 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. Then 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 factor in 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 with the least amount of 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 procured. This must be coordinated with the owner's representative on the project'team.

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

OWNER'S STUDY

A project starts as a need by the owner for the design and construction of a facility to produce a product or service. The need for a facility may be recognized by an operating division of the owner, 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 needs assessment to study the merits of pursuing the project.

The first requirement of the owner is objective setting. This is 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.

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.

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 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, to 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 **3-3.**

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 doesn't know what the project requires, then no one knows what to do. Defining owner needs is the first step in a broad range of preproject activities that lead to scope definition. A project manager cannot form the project team to execute the project without a clear scope definition.

The process of identifying owner 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 needs and objectives usually involves numerous activities and discussions. It is important that "what is needed" be separated from "what is wanted." Without

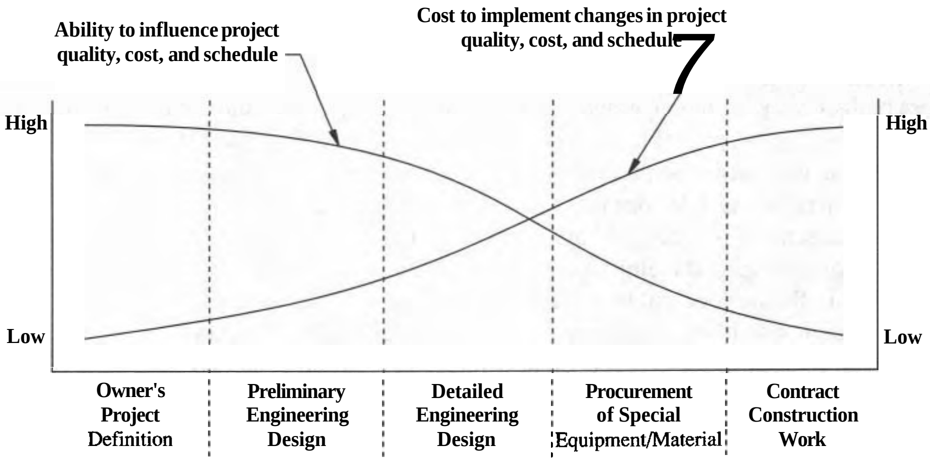


FIGURE 3-3
Importance of Clear Project Definition During the Early Phases of a Project.

constraints of cost and schedule, focus easily shifts from what is needed to what is wanted. This makes a project unaffordable and non-feasible. Because there are always constraints of cost and schedule, the owner must develop a project definition based upon 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 needs and objectives 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 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.

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 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 parameter 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 6, 8, 9 and Appendix A.

PROJECT SCOPE DEFINITION

Project scope identifies those items and activities that are required to meet the needs of the owner. 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.

The purpose of project 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. Just to state that a project consists of three buildings and an outside storage area is not enough. information to start the design phase. To assist the owner in this effort, a comprehensive check list of items should be prepared. Table 3-1 is an abbreviated check list for project 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 check list 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 check list for project scope.

Before design is started, scope must adequately define deliverables, that is, what will be furnished. 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 design because it affects the project budget and schedule. To accomplish this, the project manager from the design organization must be involved early in the project; and he or she will require input from experienced technical people to represent every aspect of the proposed project.

TABLE 3-1
ABBREVIATED CHECK LIST FOR PROJECT SCOPE DEFINITION OF A PETROCHEMICAL PROJECT

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 Preservations restrictions

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 work, to make certain all parties know the full extent of the required work.

PROJECT STRATEGY

In the early stages of project development the owner must develop the project strategy, a plan to carry out tasks in a timely manner. Project strategy forms the framework for handling the project. It includes the contracting strategy, the roles and responsibilities of the project team, and the schedule for design, procurement, and construction.

Contract strategy 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 in-house personnel 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 in-house 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 in-house 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. 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.

The project strategy includes a schedule for the timing of design, procurement, and construction tasks. 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 the project. Any change in the project schedule should be approved by all parties.

SELECTION OF DESIGN FIRMS AND CONSTRUCTION CONTRACTORS

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 completed. The method of selection depends on the owner's project 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 7. After the design organizations have submitted their proposals, the owner can review and evaluate the proposals and make a decision for award of the design contract. For public-sector projects, selection of the designer depends on the policies and restrictions of the owner's organization. Generally, designers are selected from a list of prequalified firms. Chapter 5 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 desigp 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 its 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.

Typically after all interviews are conducted, the owner lists the design firms in the order of their desirability, taking into account their location, reputation, size, experience, financial stability, available personnel, quality of references, work load, 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.

If the design is 100% complete, the owner may issue requests for bids (RFB) 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 11.

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.

A relatively new concept called ***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 non-monetary 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 work load 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 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.

QUESTIONS FOR CHAPTER 3—PROJECT INITIATION

1 There are many contractual arrangements for handling a project. This chapter describes the arrangements in four basic forms: design/bid/build, design/build, construction management, and owner/agent. Describe the advantages and disadvantages of each of these arrangements, considering factors such as the cost, time, and level of involvement desired by the owner of the project.

2 Review one of the references at the end of this chapter, or choose another reference, and briefly describe the many forms of construction management that are currently being used in the engineering and construction industry.

3 The various phases for development of a project are shown in Figure 3-2. Review each phase and identify the party that most likely would be involved in performing the work of the phase, and the party whose work will be most influenced by the results of the phase. Identify parties as one of the following: owner, consultant to the owner, designer, construction manager, or construction contractor.

4 A part of the owner's study is defining the requirements of the project. Identify and describe methods that can be used to assist an owner with this important study assuming that the owner does not have the expertise to perform the study.

5 Review the list of references at the end of this chapter and summarize the process of setting project objectives to assure the successful completion of a project.

6 Describe the differences between project objectives and project scope definition. Define the interactive role of the owner and designer in this process to ensure a well-defined understanding between the two parties.

7 Review published articles that describe the concept and process of partnering, and list major differences between partnering and traditional methods of contracting strategies.

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4

EARLY ESTIMATES

IMPORTANCE OF EARLY ESTIMATES

For engineering and construction projects, accurate early cost estimates are extremely important to the sponsoring organization and the engineering 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.

An early estimate is also important to the project team because it becomes one of the key project parameters. It helps formulate execution strategies and provides a basis to plan engineering and construction. The early estimate often serves as a baseline for identifying changes as the project progresses from design 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 estimate.

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 4-1. Initial cost estimates form the basis to which all future estimates are compared. Future estimates are often expected to agree with

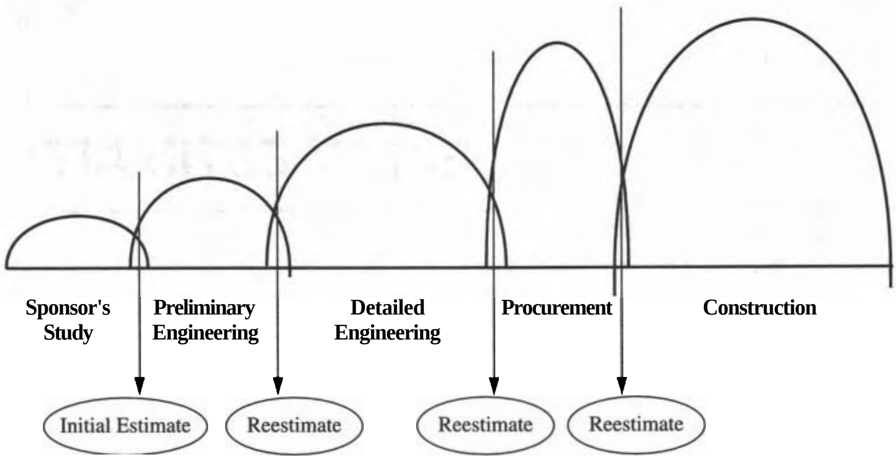


FIGURE 4-1
Estimates and Reestimates Through Phases of Project Development.

(i.e., be equal to or less than) the initial estimates. However, too often the final project costs exceed the initial estimates.

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 Advancement of Cost Engineering (AACE) International shown in Figure 4-2 and by the Construction Industry Institute (CII) shown in Figure 4-3.

In general, an early estimate is defined as an estimate that has been prepared before completion of detailed engineering. 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.

FIGURE 4-2
AACE International Cost Estimation Classifications (18R-97).

Estimate class	Level of project definition	End usage (Typical purpose of estimate)	Expected accuracy range
Class 5	0% to 2%	Concept Screening	–50% to 100%
Class 4	1% to 5%	Study or Feasibility	–30% to +50%
Class 3	10% to 40%	Budget, Authorization, or Control	–20% to +30%
Class 2	30% to 70%	Control or Bid/Tender	–15% to +20%
Class 1	50% to 100%	Check Estimate or Bid/Tender	–10% to +15%

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%	Based on detailed drawings

FIGURE 4-3
Construction Industry Institute Cost Estimate Definitions (CII SD-6).

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 4-1.

These concepts are illustrated in the estimating work process of Figure 4-4. 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.

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

TABLE 4-1
PRIMARY FACTORS IN PREPARING ESTIMATES.

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. Feed-back from project implementation

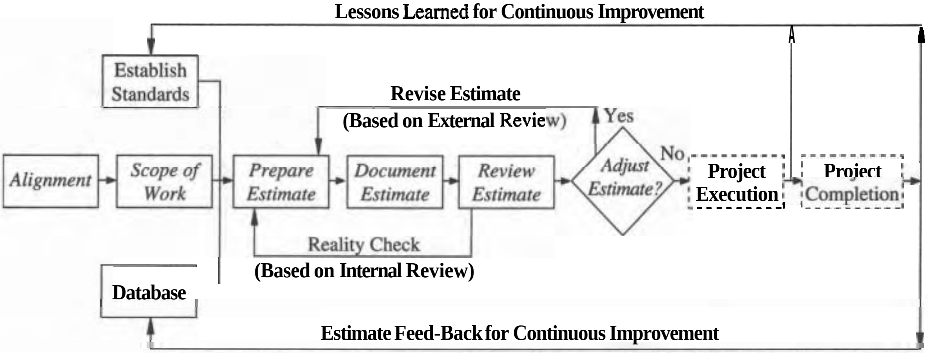


FIGURE 4-4
Estimating Work Process.

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 estimating team should develop a standard cost estimate presentation format that is easily understood by internal business and engineering management.

Contingency is the amount of money that must be added to the base estimate to account for risk and uncertainty. 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 feed-back loops shown in Figure 4-4. To improve early estimates, the estimating process must be a continuous cycle. Actual cost information from completed projects must be captured in a feed-back 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 4-2 is a list of 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.

TABLE 4-2
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 4-3
CRITICAL QUESTIONS FOR PREPARING EARLY ESTIMATES.

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?

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. The customer must also define the required deliverable 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 4-3.

The estimate kick-off meeting is an effective method of achieving alignment by addressing the issues shown in Table 4-4. 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.

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 4-5.

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 thirty years, numerous papers have been published, emphasizing the importance of scope definition. The lack of scope definition has been identified

TABLE 4-4
CHECK LIST OF ISSUES FOR THE ESTIMATE KICK-OFF MEETING.

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?

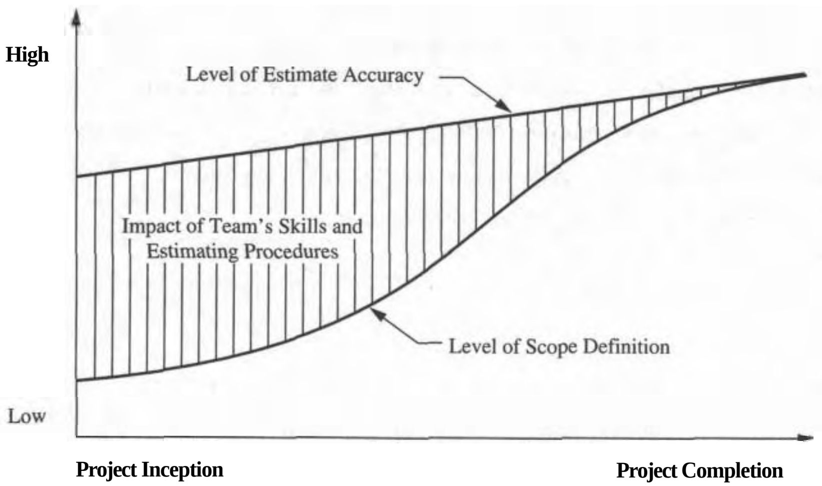
as the root cause of cost overruns, late completion dates, excessive rework, unnecessary disputes, poor team alignment, and other problems associated with engineering and construction projects.

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 4-5 illustrates the importance of having the team involved early in a

TABLE 4-5
COMMON PITFALLS IN TEAM ALIGNMENT FOR PREPARING EARLY ESTIMATES.

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



RGURE 4-5
Relative Impact of Team's Skills and Estimating Procedures on Estimate Accuracy.

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.

PREPARING EARLY ESTIMATES

Issues that should be discussed, defined, and documented when preparing estimates are shown in Table 4-6. 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

- Simple "intuitive" checks for reasonableness
- Comparisons with similar projects
- Comparisons with industry data ($/square foot, costlmegawatt, 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 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.

TABLE 4-6
ISSUES FOR PREPARING EARLY ESTIMATES.

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

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

- Disseminating knowledge and sharing expertise among the estimating staff
- Assigning and sharing the work load 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 feed-back. 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 improve efficiency.

ESTABLISHING AN ESTIMATE WORK PLAN

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 4-6 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.

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

Estimate Work Plan

Project Name: ____________________
Project Number: ____________________
Customer's Name: ____________________

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

Estimating Services to Be Provided
- Deliverables of Estimate by In-House Resources
- Deliverables of Estimate by Outside Resources

Budget for Preparing Estimate
- Anticipated work-hours for estimating staff
- Dollars budget for non-salary estimating work

Required Staffing for Preparing Estimate
- Principle Estimate (leader of estimating team)
- In-House and Outside Resources
- Availability of Personnel for Staffing

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

Estimating Methodology
- Tools
- Technique
- Method
- Procedures

Estimate Control
- Level of Scope Definition
- Check Lists
- Review Process

Presentation
- Format for Presenting Estimate
- Audience of Presentation

FIGURE 4-6
Typical Information to be Addressed in the Estimate Work Plan.

Typically, the technical definition and the completion date for an estimate is 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, 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
- 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
- Computer-generated estimates

Cost-Capacity Curves

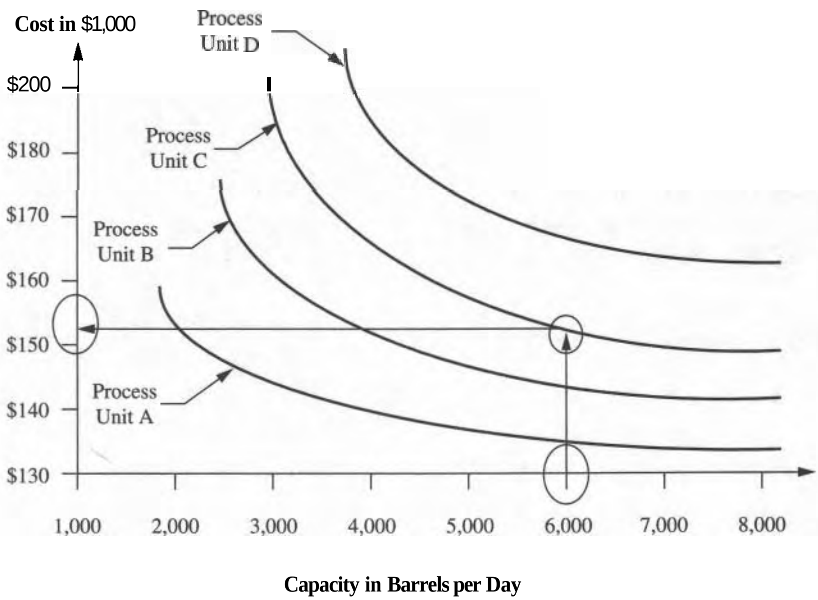
A cost-capacity curve is simply a graph that plots cost on the vertical axis and capacity on the horizontal axis. These curves are developed for a variety of individual process units, systems, and services. The minimum information needed to prepare an estimate by cost-capacity curves is the type of unit 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 4-1

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 C 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 C cost curve. Then, draw a horizontal line to the left to read the estimated cost as $153,000.

Capacity Ratios Raised to an Exponent

Capacity ratios raised to an exponent is another estimating technique for conceptual estimating. This approach takes into account 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:

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

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 non-linear 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 4-2

The cost of a 320 cubic feet per hour (ft^3/h) process unit is \$675,000. From historical cost records, the capacity ratio exponent of a process unit is 0.72. Estimate the cost of a similar process unit with a capacity of 450 ft^3/h.

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

$$= (\$670{,}000) \times \left(\frac{450\ ft^3/h}{320\ ft^3/h}\right)^{0.72}$$

$$= (\$675{,}000) \times (1.2782183)$$

$$= \$862{,}797$$

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 to 6.0, depending on the nature of the process unit. Conditions that affect the equipment to TIC factors are

- 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 is 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

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 can operate on a personal computer and 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 detail 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-rack, structures, buildings, automation and control philosophy, etc.
- Adequate scope definition
- Site and soil conditions
- Local labor conditions relating to cost, productivity, and indirect costs
- Subcontract 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 non-commercial 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 CHECK LISTS

Check lists are valuable tools to reduce the potential of overlooking a cost item. Check lists 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.

Check lists are useful during initial client/customer meetings where they serve as agenda items for discussion. Check lists 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 4-7 is an illustrative example of an early estimate check list for a project in the process industry.

ESTIMATE DOCUMENTATION

Effective communication is necessary during the estimating process. A support document should be developed and available for presentation, review, and future use of

TABLE 4-7
CHECK LIST FOR AN EARLY ESTIMATE 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

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 non-aligned assumptions. Documenting the estimate will minimize these inaccuracies by

- Improving communications among all project participants
- Establishing a mechanism for review of the estimate
- Forming a solid basis for project controls

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

- 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

TABLE 4-8
RECOMMENDED DOCUMENTATION OF EARLY ESTIMATES.

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. Check lists used—a list of completed check lists
13. Description of cost categories--codes used in preparing the estimate
14. Excluded costs—list of items excluded from the cost estimate

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 4-8.

ESTIMATE REVIEWS

Well-executed estimate reviews will increase the credibility and accuracy of the estimate. They also help the team and project management 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 have 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 following information for comparisons:

- Historical data used in preparing the estimate
- Actual total installed costs (TIC) of similar projects
- Percent of TIC on key cost accounts

Comparisons of the estimate with the above 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 4-9 is an illustrative example of presentation items for review of an early estimate for a project in the process industry.

RISK ASSESSMENT

Assessing risk and assigning contingency to the base estimate is one of the most important tasks in preparing early estimates. Risk assessment is not the sole responsibility of the estimators. Key members of the project management team must provide

TABLE 4-9
PRESENTATION ITEMS FOR REVIEW OF AN EARLY ESTIMATE 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. Check lists used to prepare estimate

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.

The business unit is responsible for overall project funding and for 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 is responsible for converting the information from the business unit and engineering into an appropriate procedure for assessing risk and assigning contingency. The estimator must communicate the risk, contingency, and level of accuracy that can be expected of the final estimate.

RISK ANALYSIS

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. 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 for a project must assess the uniqueness of each project and select the technique of risk analysis that is deemed most appropriate. For very early estimates, 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. Engineering and construction are risk endeavors with many uncertainties, particularly in the early stages of project development. Contingency is assigned based on uncertainty and may be assigned for many uncertainties, such as pricing, escalation, schedule, omissions, and errors. 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.

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. However, sometimes an allowance is assigned for known unknowns and a contingency is assigned for 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 18R-97 defines contingency as "An amount of money or time (or other resources) added to the base estimate to ***(a)*** achieve a specific confidence level or ***(b)*** allow for changes that experience shows will likely be required."

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 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 end result is an estimate that represents the judgment of the project management team, not just the estimator's perspective.

Figure 4-7 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.

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.

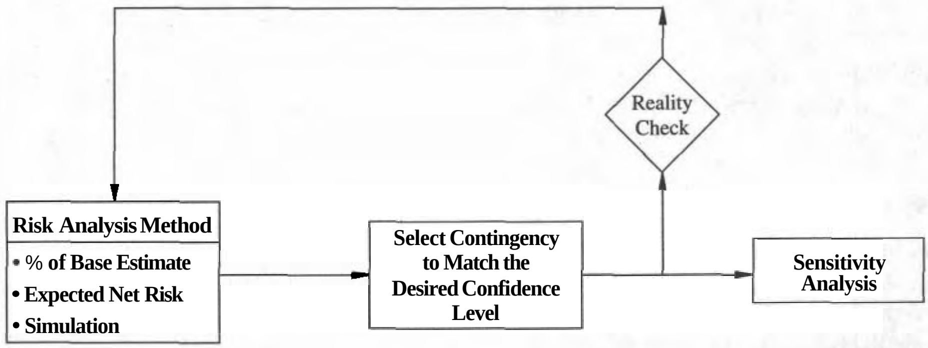


FIGURE 4-7
Risk Assessment Process.

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 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. Figure 4-8 illustrates an expected net risk analysis.

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 are 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 twenty critical elements. The range of each critical element is defined and probability analysis is used to form the basis of simulation. Using this method, non-critical 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.

FIGURE 4-8
Expected Net Risk Analysis.

Element	Base estimate	Max. cost	Max. risk	% probability	Expected net risk
#1	$400	$500	$100	30%	$ 30
#2	$ 80	$120	$ 40	80%	$ 32
#3	$100	$200	$100	50%	$50
Total	$580	$820	$240		$112

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 non-critical 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 also 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 4-9 and 4-10 show a sample sensitivity analysis for a $3,000M base estimate.

FIGURE 4-9
Base Estimate Summary ($M). (WH = work-hours.)

Equipment cost	$1,200	
Material cost	$ 600	
Labor cost	$1,000	← (= $50/WH × 20,000 WH)
Subcontractor cost	$ 200	
Total base estimate	$3,000	

Risk element	% Change from estimate	New base estimate ($M)
Labor rate ($50/WH)	0	$3,000
Labor rate	+10	3,100
Labor rate	−5	2,950
Total work-hours (20,000 WH)	0	$3,000
Total work-hours	+15	3,150
Total work-hours	−7	2,930
Equipment ($1,200M)	0	$3,000
Equipment	+5	3,060
Equipment	−5	2,940

FIGURE 4-10
Sensitivity Analysis. (WH = work-hours.)

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.

ASSIGNING CONTINGENCY BASED ON THE QUALITY AND COMPLETENESS OF THE ESTIMATE

The accuracy of an estimate is measured by how well the estimated cost compares to the actual total installed cost. The accuracy of an early estimate depends on four determinants: *who* is involved in preparing the estimate, *how* the estimate is prepared, *what* is known about the project, and *otherfactors* that can influence the cost of a project.

To measure the impact of these four determinants with respect to estimate accuracy, a research team of the Construction Industry Institute developed an estimate scoring system that evaluates 45 elements, organized in 4 divisions. The research team collected data to correlate estimated cost with actual total installed cost, based on the score of an estimate. Data was collected from 72 projects, representing $5.6 billion in total installed costs from projects in the process industry. A breakdown of the 4 divisions of the estimate scoring system is shown in Figure 4-11.

The Estimate Score Program (ESP) is a computer software package developed by the research team to automate the scoring procedure and to assess accuracy and predict contingency based on historical cost data. After completing the estimate, the user can enter the base estimate into ESP and then rate each of the 45 elements. ESP automatically calculates the estimate score as the user rates each element. After the score is calculated, the user can then query the historical database of ESP to view the estimate scores of previously completed projects.

The *Query* portion of the ESP software allows the user to filter the database to compare the estimate with similar type projects. After querying the database,

Estimate Score Sheet

DIVISION 1 – WHO WAS INVOLVED IN PREPARING THE ESTIMATE ?	1 (Best)	2	3	4	5 (Worst)
1.1 Owner's experience level					
1.2 Engineer/Designer's experience level					
1.3 Relevant experience of the estimating team					
1.4 Level of involvement of the project manager					
1.5 Involvement of other resources in preparing estimate					
1.6 Review and acceptance of estimate by appropriate parties					
1.7 Impact of team integration and alignment					
1.8 Purpose and intended use of estimate					
1.9 Attitude/culture toward changes					

DIVISION 2 – HOW WAS THE ESTIMATE PREPARED ?	1 (Best)	2	3	4	5 (Worst)
2.1 Completeness of cost information					
2.2 Applicability of cost information					
2.3 Accuracy and reliability of cost information					
2.4 Standard procedure for updating cost information					
2.5 Time allowed for preparing the estimate					
2.6 Alignment of estimate methodology with available project information					
2.7 Is the estimating work process formally defined and followed?					
2.8 Formal structure to categorize and prepare the cost estimate					
2.9 Utilization of check lists to ensure completeness and technical basis					
2.10 Documentation of information used in preparing the estimate					
2.11 Method used to determine contingency					

DIVISION 3 – WHAT WAS KNOWN ABOUT THE PROJECT?	1 (Best)	2	3	4	5 (Worst)
3.1 Capacities					
3.2 Technology					
3.3 Processes					
3.4 Site location					
3.5 Plot plan					
3.6 Utility sources and supply conditions					
3.7 Environmental assessment					
3.8 Process flow sheets					
3.9 Mechanical equipment list					
3.10 Heat and material balances					
3.11 P&ID's					
3.12 Project strategy					
3.13 Project design criteria					
3.14 Project schedule					

DIVISION 4 – FACTORS CONSIDERED WHILE PREPARING THE ESTIMATE	1 (Best)	2	3	4	5 (Worst)
4.1 Owner's costs					
4.2 Impact of project type					
4.3 Impact of contract type					
4.4 Impact of project schedule					
4.5 Impact of governmental requirements					
4.6 Work force					
4.7 Labor productivity					
4.8 Bidding climate					
4.9 Taxes and insurance					
4.10 Money factors					
4.11 Logistics for engineering and construction					

FIGURE 4-11
Estimate Score Sheet.

the user can display various statistical information in the ***Statistics*** portion of the software. The ***Statistics*** portion of ***ESP*** enables the user to view up to 15 different combinations of statistical information about the current set of completed projects as selected from the ***Query.***

After querying the database, the user can also view graphs of the results in the ***Graphs*** portion of ESP. The ***Graphs*** portion enables the user to graphically view the scatter plot and S-curve for the current data set of completed projects as selected from the ***Query.*** Figure 4-12 is a screen copy of a scatter plot graph from the ESP software program. Figure 4-13 is the S-curve, which is a graphical display of the cumulative probability curve based on the current data set and score of the estimate.

The ESP software provides a means of assigning contingency to the base estimate. The S-curve in Figure 4-13 is a cumulative probability curve based on projects selected in the query and the value of the estimate score. The user can determine the confidence level, in percent, for a predicted level of cost overrun or underrun. The confidence level for a desired cost range, upper or lower limit, can also be obtained. The user can also determine the cost range, upper and lower limits, of a desired confidence level.

This method of assigning contingency is based on two years of study by the research team that correlated estimate scores with total installed costs for projects in the process industry. The research results showed a significant positive correlation between estimated costs and total installed costs, based on the score of an estimate. ESP can be used as a tool to "check" the amount of contingency determined by other methods, as well as a method of assigning contingency on its own.

Thus, ESP allows the user many choices of analysis to determine the amount of contingency to be applied to the base estimate. It can benefit the business unit and the team by providing information to enable the business unit to make a better decision on the economic feasibility of a project. It also improves team alignment by providing a better understanding of the estimate and the factors that can affect the accuracy of an early estimate.

ESTIMATE FEED-BACK 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 feed-back loops shown in Figure 4-4. Feed-back from project execution provides lessons learned to the estimator that allows the estimating team to modify estimating standards and

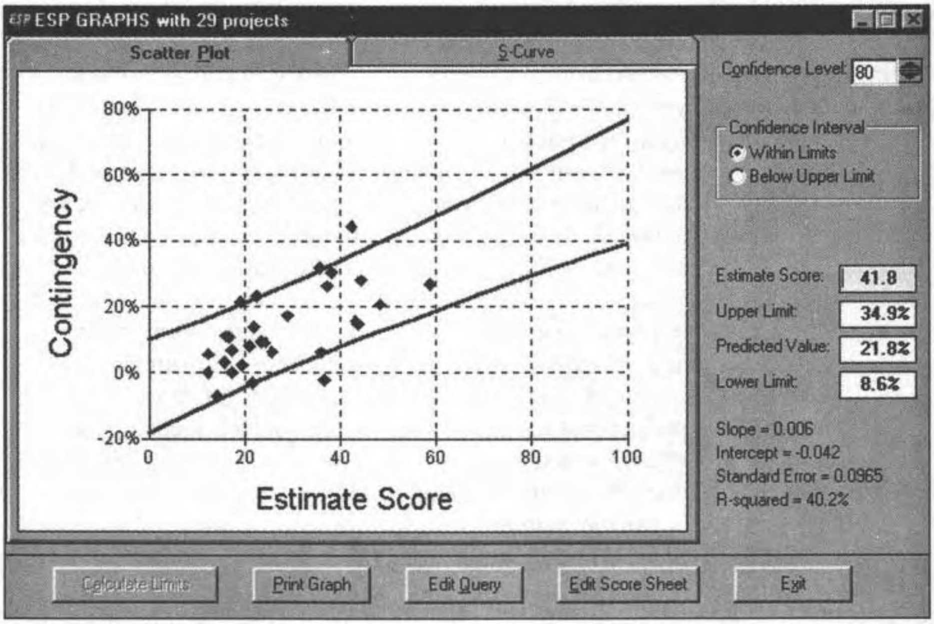
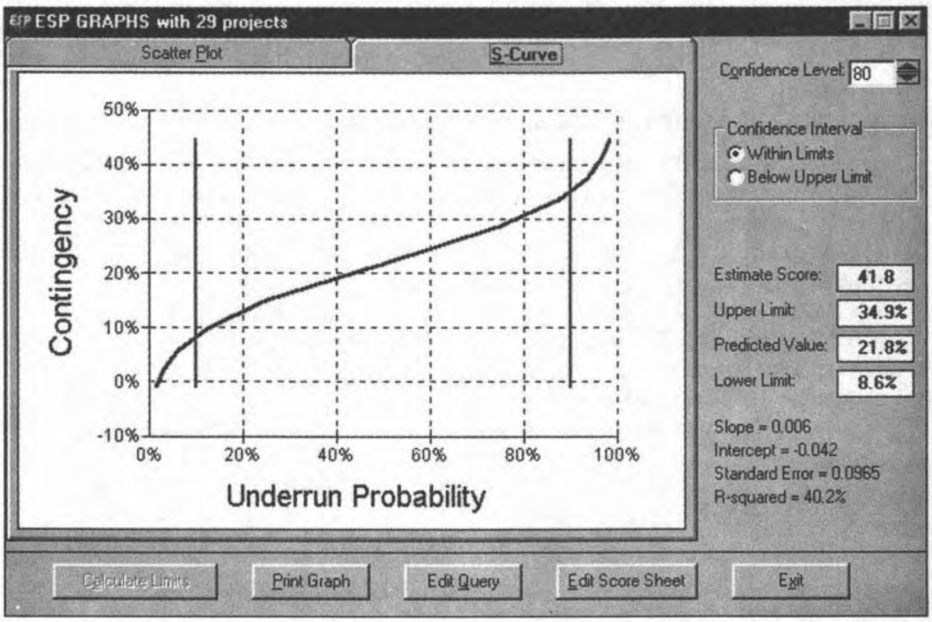


FIGURE 4-12
Scatter Plot from ESP Software Program.

FIGURE 4-13
Cumulative Probability Curve from ESP Software Program.



practices. Feed-back 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 feed-back, 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 a real feed-back 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 project data that is available from completed projects and definitive estimates. The key to success is the establishment of a 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 feed-back is an integral part of the estimating process. It is not an add-on feature. A process for providing feed-back loops is necessary for improving the accuracy of early estimates.

QUESTIONS FOR CHAPTER 4—EARLY ESTIMATES

1 Early estimates are extremely important to the owner. From the perspective of the owner, give examples of problems that may arise if an early estimate is significantly lower than the final actual cost of a project.

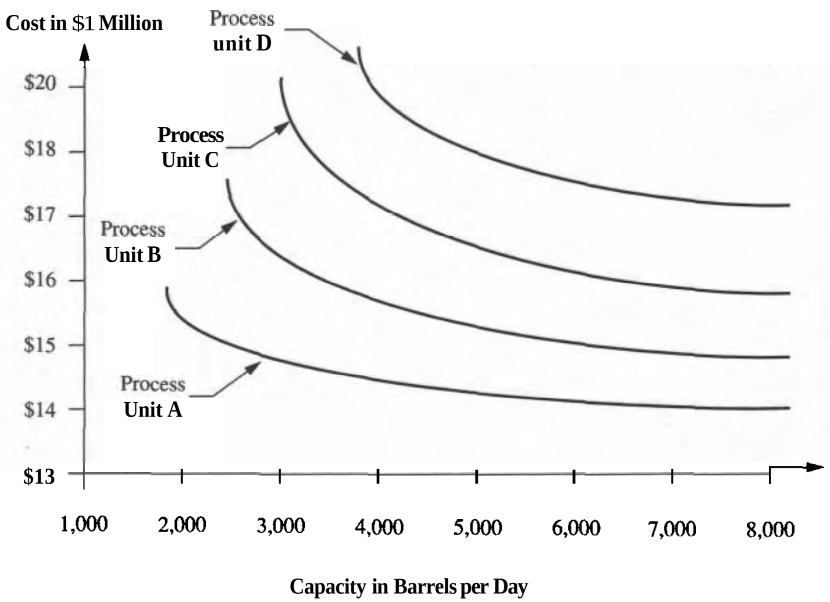
2 From the perspective of the owner, give examples of problems that may arise if an early estimate is significantly lower than the final actual cost of a project.

3 Early estimates are important to the designer. From the perspective of the designer, give examples of problems that may arise if an early estimate is significantly lower than the final cost of a project.

4 Describe the purpose of a kick-off meeting for preparing an early estimate of a project. What are typical items that should be addressed and confirmed before starting estimate preparation?

5 The cost of a 540-ft^3/h process unit is $850,000. From historical cost records, the capacity ratio exponent of a process unit is 0.6. Use the capacity ratios raised to an exponent method to determine the estimated cost of a similar process unit with a capacity of 490 ft^3k.

6 Below are cost-capacity curves for process units in a refinery. What is the estimated cost for a project that has a process unit B with a capacity of 4,000 barrels per day?



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5

PROJECT BUDGETING

PROJECT BUDGETS

The discussion of budgeting in this chapter is an extension of Chapter 4 on preparing early estimates. It is also closely related to Chapter 7 on design proposals, which presents the process of determining the cost of engineering design services for projects. 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 presents an overview of construction costs. A more detailed coverage of estimating construction costs is presented in *Estimating Construction Costs,* 4th ed., published by McGraw-Hill, Inc.

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. Estimating is a prerequisite to project budgeting. Chapter 4 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. Thus, the budget can be considered to be the base estimate plus contingency.

DEVELOPMENT OF PROJECT ESTIMATES FOR BUDGETING

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 for budgeting 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. 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.

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.

Project estimating and budgeting begins with the owner during the study of needs, priorities, and scope. As discussed in Chapter **3,** 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 upon the amount of information that is known about the project when the estimate was prepared. 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 aproject by testing, scrutinizing, and identifying the variances that should be applied to an estimate.

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 this 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, based on 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.

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 during the feasibility study 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 upon 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 +30% to −20%. On completion of detailed design work it may range from +15% to −10%.

For building projects, the detailed estimate is prepared by the construction contractor from a complete set of contract documents 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 resplt 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 is usually 550%.

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 is usually ±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%.

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 government 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 of two sources: cost records from previous projects of similar type and size, or pricing manuals that are published annually by several organizations.

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 5-1 illustrates examples of information that is available for sev-

FIGURE 5-1
Illustrative Examples of Cost-per-Square-Foot Information Available from Pricing Manuals.

Component	Office buildings			Motels		
	Low $/SF	Median $/SF	High $/SF	Low $/SF	Median $/SF	High $/SF
Foundation	3.95	4.00	4.80	0.90	1.40	1.60
Floors on grade	3.10	3.15	3.90	3.95	5.00	5.40
Superstructure	14.90	16.90	20.25	10.95	13.30	21.70
Roofing	0.20	0.25	0.30	2.40	3.40	3.45
Exterior walls	4.90	9.75	13.00	2.80	4.45	5.55
Partitions	4.35	5.30	7.05	2.60	3.65	5.25
Wall finishes	2.35	3.75	5.00	0.75	2.60	2.75
Floor finishes	2.05	3.90	5.15	2.40	3.55	4.55
Ceiling finishes	1.55	2.80	3.75	2.05	4.60	4.90
Conveying systems	5.55	6.70	8.25	1.15	1.80	2.35
Specialties	0.65	0.80	2.65	1.10	1.35	4.00
Fixed equipment	1.05	2.80	3.75	1.15	1.65	1.95
Heat/vent/air cond.	8.85	9.50	12.20	3.10	5.55	6.25
Plumbing	3.50	3.80	4.85	4.45	5.40	6.15
Electrical	4.60	4.75	6.25	4.20	7.45	8.20
Total $/SF	$61.55	$78.10	$101.15	$43.95	$65.15	$84.05

Component	Secondary schools			Hospitals		
	Low $/SF	Median $/SF	High $/SF	Low $/SF	Median $/SF	High $/SF
Foundation	1.35	1.85	2.70	4.35	4.80	6.65
Floors on grade	3.65	4.40	6.00	0.30	0.40	0.60
Superstructure	10.95	12.30	17.25	17.05	18.55	25.50
Roofing	1.70	2.05	2.45	3.25	3.70	5.20
Exterior walls	3.75	5.55	8.00	16.00	18.55	25.10
Partitions	5.90	6.55	8.50	7.20	11.00	24.70
Wall finishes	3.05	3.40	5.15	6.75	7.95	11.10
Floor finishes	3.10	3.95	5.25	2.60	2.75	4.00
Ceiling finishes	3.20	3.65	4.65	2.15	2.20	3.55
Conveying systems	0.00	0.00	0.00	12.95	13.00	19.55
Specialties	1.70	1.90	2.60	3.10	3.25	4.60
Fixed equipment	2.85	3.35	6.00	5.20	5.25	7.65
Heat/vent/air cond.	9.05	10.45	14.45	21.65	25.50	36.05
Plumbing	5.05	6.00	9.20	9.10	10.65	16.45
Electrical	10.25	12.00	16.50	13.45	17.50	24.40
Total $/SF	$69.55	$77.40	$108.70	$125.10	$145.05	$215.10

eral 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 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 of ***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 5.1 can be used for weighting cost data from previous projects:

$$UC = \frac{A + 4B + C}{6} \qquad \text{(Eq. 5.1)}$$

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 5-1 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 5-1

Cost information from eight previously completed parking garage projects is given in the following table.

Project	Total cost	No. cars	Unit cost	
1	$1,387,500	150	$ 9,250	
2	896,000	80	11,200	
3	1,797,000	120	14,975	⟵ highest value
4	1,107,000	90	14,975	
5	590,400	60	12,300	
6	1,903,000	220	8,650	⟵ lowest value
7	889,000	70	12,700	
8	1,615,500	180	8,975	
		Total =	$79,034	
		Average cost per car =	$ 9,879	⟵ average value

From **Eq.** 5.1 the forecast unit cost can be calculated as

$$UC = \frac{\$8{,}650 + 4(\$9{,}879) + \$14{,}975}{6} = \$10{,}524$$

For a project with 135 cars the estimated cost can be calculated as

$$135 \text{ cars @ } \$10{,}524 = \$1{,}420{,}673$$

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 5-2 illustrates the combination of adjustments of cost estimates for size, time, and location. ***Estimating Construction Costs,*** 4th ed., published by McGraw-Hill, Inc., presents a comprehensive discussion of estimating project costs.

Example 5-2

Use the time and location indices below to calculate the forecast cost for a building with 62,700 SF of floor area. The building is to be constructed 3 years from now in city B. A similar type building that cost $2,945,250 and contained 38,500 SF was completed 2 years ago in city D.

Year	Index
3 yr ago	358
2 yr ago	359
1 yr ago	367
Current year	378

Location	Index
City A	1025
City B	1170
City C	1260
City D	1240

An equivalent compound interest can be calculated based on the change in the cost index during the 3-year period:

$$\frac{378}{358} = (1 + i)^3 \rightarrow i = 1.83\%$$

Estimated cost	Previous cost	Time adjustment	Location adjustment	Size adjustment
"	= $2,945,250 ×	$(1 + 0.0183)^5$ ×	(1170/1240) ×	(62,700/38,500)
"	= $2,945,250 ×	1.095 ×	0.944 ×	1.629
"	= $4,959,403			

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 government 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 government project the economic feasibility is usually determined by a **benefit/cost** ratio.

There are three methods that are commonly used by the private sector to evaluate the monetary return on a potential investment: capital recovery, pay back period, and rate of return. Each method uses the fundamental equations of time value of money. There are numerous books that have been published that describe the development and use of these equations for economic analysis. Below is a brief introduction to 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

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 as in the following equation:

$$F = A(1) + A(1 + i) + \dots + A(1 + i)^{n-2} + A(1 + i)^{n-1}$$

Multiplying both sides of the equation by $(1 + i)$ gives the following equation:

$$F(1 + i) = A(1 + i) + A(1 + i)^2 + \dots + A(1 + i)^{n-1} + A(1 + i)^n$$

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:

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

$$= P\left[\frac{i(1 + i)^n}{(1 + i)^n - 1}\right]$$

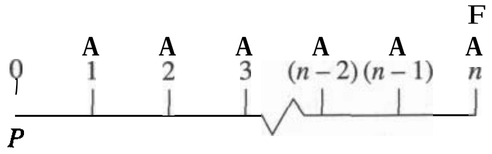
The equation $A = P\{[i(1 + i)^n]/[(1 + i)^n - 1]\}$ gives a uniform series of payments *A* that is equivalent to the present worth of *P*. Again, note that *A* is related to *P* by a factor that depends only on *i* and *n*. This factor, $[i(1 + i)^n]/[(1 + i)^n - 1]$, is called the uniform-series capital recovery. 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 Eqs. *5.2–5.7.*

Fundamental Equations of 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:

Compound Amount $$F = P\left[(1+i)^n\right] = P\left(^{F/P\,i-n}\right) \quad \text{(Eq. 5.2)}$$

Present Worth $$P = F\left[\frac{1}{(1+i)^n}\right] = F\left(^{P/F\,i-n}\right) \quad \text{(Eq. 5.3)}$$

Equal Payment Series:

Compound Amount $$F = A\left[\frac{(1+i)^n - 1}{i}\right] = A\left(^{F/A\,i-n}\right) \quad \text{(Eq. 5.4)}$$

Sinking Fund $$A = F\left[\frac{i}{(1+i)^n - 1}\right] = F\left(^{A/F\,i-n}\right) \quad \text{(Eq. 5.5)}$$

Present Worth $$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = A\left(^{P/A\,i-n}\right) \quad \text{(Eq. 5.6)}$$

Capital Recovery $$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] = P\left(^{A/P\,i-n}\right) \quad \text{(Eq. 5.7)}$$

The factor designation at the right of the preceding interest equations represents an abbreviated form of the equation illustrated in the following:

$\left(^{F/P\,i-n}\right)$ 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,** pay back 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 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 5-3. There may be other considerations that should be evaluated, such as tax advantages, non-uniform generation of revenue, and the disposal of the facility after its useful life. The pay back 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 5-4. 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 5-5. 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 5-3

This example illustrates the capital recovery method for determining economic feasibility. Suppose the feasibility estimate for a project is $7.0M with an expected operating life of 12 years. Annual maintenance and operating expenses are forecast as $560K per year. Using a 10% interest rate, what net annual income must be received to recover the capital investment of the project?

$$\begin{aligned} A &= P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] + \$0.56\text{M} \\ &= \$7.0\text{M}\left[\frac{0.10(1+0.10)^{12}}{(1+0.10)^{12} - 1}\right] + \$0.56\text{M} \\ &= \$1.588\text{M per year} \end{aligned}$$

If the project can be built for $7.0M, operated for $560K per year, and earn $1.5876M per year, the project is economically feasible, neglecting any tax advantages. If the project can be built for less than $7.0M, or can be built to operate more efficiently than $560K per year, it is even more economically attractive.

Example 5-4

This example illustrates the pay back period method for determining the economic feasibility of a project. The initial investment for a project is $18.0M. A net annual profit of $3.5M is anticipated. Using a 15% desired rate of return on the investment, what is the pay back period for the project?

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

$$\$18.0\text{M} = \$3.5\text{M}\left[\frac{(1+0.15)^n - 1}{0.15(1+0.15)^n}\right]$$

$$n = 10.5 \text{ years}$$

Example 5-5

This example illustrates the rate-of-return method for determining the economic feasibility of a project. An initial project investment of $1.05M is being considered for a 5-year study period. It is anticipated the project will be sold after the 5-year period for $560K. Determine the rate of return with the anticipated net profit shown below.

End of year	Net profit ($1,000)
0	0
1	−350
2	−120
3	+420
4	+735
5	+680

Using Eq. 5.2 to transfer the costs from each year to an equivalent present worth: Try $i = 15\%$.

$$P = [-\$350(\overset{P/F\,15-1}{0.8695}) - \$120(\overset{P/F\,15-2}{0.7562}) + \$420(\overset{P/F\,15-3}{0.6575}) + \$735(\overset{P/F\,15-4}{0.5718})$$
$$+ \$680(\overset{P/F\,15-5}{0.4972}) + \$560(\overset{P/F\,15-5}{0.4972})] \times 1{,}000$$

$\$1.05M > \$0.92M$; therefore try a lower rate of return.
Try $i = 10\%$.

$$P = [-\$350(\overset{P/F\,10-1}{0.9090}) - \$120(\overset{P/F\,10-2}{0.8264}) + \$420(\overset{P/F\,10-3}{0.7513}) + \$735(\overset{P/F\,10-4}{0.6830})$$
$$+ \$680(\overset{P/F\,10-5}{0.6209}) + \$560(\overset{P/F\,10-5}{0.6209})] \times 1{,}000$$

$\$1.05M < \$1.17M$; therefore try a higher rate of return.
Try $i = 12\%$.

$$P = [-\$350(\overset{P/F\,12-1}{0.8929}) - \$120(\overset{P/F\,12-2}{0.7972}) + \$420(\overset{P/F\,12-3}{0.7118}) + \$735(\overset{P/F\,12-4}{0.6355})$$
$$+ \$680(\overset{P/F\,12-5}{0.5674}) + \$560(\overset{P/F\,12-5}{0.5674})] \times 1{,}000$$

$\$1.05M \approx \$1.06M$; therefore the rate of return is slightly over 12%.

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 upon 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 6. A design work package, shown in Figure 6-7, can then be prepared for each task. Based upon 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 5-2 illustrates the summary of a design engineering budget. Figure 5-3 shows an example of time distribution for design calculations as well as the development of drawings and specifications for a project. Chapter 7 presents the process of developing design proposals and design budgets. Reference Figures 7-5 and 7-6 for gathering the information necessary to prepare the budget forms shown in Figures 5-2 and 5-3.

DATE:____/____/____

PROJECT BUDGET FORM

Project Name

Dept. Number	Department	HOURS							DOLLARS
		ADMIN	MTGS	SHED	SPECS	CALCS	DWGS	TOTAL	
0100	Project Management							12,000	$840,000
		3,000	2,400	900				6,300	
		1,500	1,200	3,000				5,700	
0200	Architecture		350	100	350	250	800	1,850	$111,000
0300	Mechanical		350		480	360	1,760	2,950	$177,000
0400	Electrical		350		2,100	3,200	7,450	13,100	$786,000
0500	Structural							26,360	$1,581,600
	Project Engineer	2,500	750					3,250	
	CADDS Coord.		160				2,800	2,960	
	Department		550		1,300	6,700	11,600	20,150	
0600	Environmental	400						400	$28,000
0700	Civil							7,140	$428,400
	Turb./Gen. Spec				340			340	
	Department		190	100	1,310	2,000	3,200	6,800	
0800	CADDS		100	100			1,000	1,200	$60,000
0900	Clerical	7,000	400		600			8,000	$200,000
1000	Document Control	1,000			200		800	2,000	$50,000
1100	Reproduction				200		800	1,000	$26,000
1200	Project Control	1,000	200	500				1,700	$102,000
1300	Management	400						400	$36,000
1400	Subcontractor A	100	100		86	114	200	600	$60,000
1500	Subcontractor B	50	100		50		200	400	$40,000
1600	Record Drawings					1,000	2,000	3,000	$150,000
1700	Support Buildings		100		400	500	1,500	2,500	$150,000
WORK–HOUR SUBTOTAL		16,950	7,300	4,700	7,416	14,124	34,110	84,600	$4,826,000

Task #	Description		
1800	Contingency		$500,000
1900	General Expenses		$24,000
2000	Travel		$100,000
2100	Office Budget		$50,000
	EXPENSES SUBTOTAL		$674,000
	TOTAL		$5,500,000

FIGURE 5-2
Illustrative Design Engineering Budget.

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	5,800	2,320	2,320	1,160	11,600
Civil	1,600	640	640	320	3,200
	12,405	4,962	4,962	2,481	24,810

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
Civil	1,400	400	200	2,000
	8,757	2,502	1,251	12,510

DRAWINGS

	25% Drawings	25% Drawing Review	25% Drawing Submittals	25% Final Record	Total
Reproduction	200	200	200	200	800
Doc. Control	200	200	200	200	800
	400	400	400	400	1,600

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
Civil	1,048	262	1,310
Turbine/Gen.	272	68	340
Consultants	108	28	136
Clerical	480	120	600
	5,292	1,324	6,616

SPECIFICATIONS

	50% Specs	50% Review	Total
Reproduction			
Doc. Control	100	100	200
	200	200	400

FIGURE 5-3
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-reimbursablecontracts 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 estimates generally follows a systematic procedure that has been developed by the contractor for his or her unique construction operations. Building contractors organize their estimates in a format that closely follows the Construction Specification Institute's (CSI) masterformat. The CSI masterformat organizes project information into 16 major divisions and is recognized as the industry standard for building construction. Appendix E provides a listing of the CSI Masterformat level 2 titles and numbers. A typical summary of an estimate of a building construction project is shown in Figure 5-4. Each major

FIGURE 5-4
Example of Building Construction Project Bid Summary Using the CSI Organization of Work.

Item	Division	Material	Labor	Subcontract	Total
1	**General requirement**	$ 16,435.00	$ 36,355.00	$ 4,882.00	$ 57.672.00
2	**Site-work**	15,070.00	20,123.00	146,186.00	181,389.00
3	**Concrete**	97,176.00	51,524.00	0.00	148,700.00
4	**Masonry**	0.00	0.00	212,724.00	212,724.00
5	**Metals**	212,724.00	59,321.00	0.00	272,045.00
6	**Woods and plastics**	38,753.00	10,496.00	4,908.00	54,157.00
7	**Thermal and moisture**	0.00	0.00	138,072.00	138,072.00
8	**Doors and windows**	36,821.00	32,115.00	0.00	68,936.00
9	**Finishes**	172,587.00	187,922.00	0.00	360,509.00
10	**Specialties**	15,748.00	11,104.00	9,525.00	36,377.00
11	**Equipment**	0.00	0.00	45,729.00	45,729.00
12	**Furnishings**	0.00	0.00	0.00	0.00
13	**Special construction**	0.00	0.00	0.00	0.00
14	**Conveying systems**	0.00	0.00	0.00	0.00
15	**Mechanical**	0.00	0.00	641,673.00	641,673.00
16	**Electrical**	0.00	0.00	354,661.00	354,661.00
	Total direct costs	$605,314.00	$408,960.00	$1,558,360.00	$2,572,644.00
	Material tax (5%)	30,266.00			2,602,910.00
	Labor tax (18%)		73,613.00		2,676,523.00
	Contingency (2%)			53,530.00	2,730,053.00
	Bonds/Insurance			34,091.00	2,764,144.00
	Profit (10%)			276,414.00	3,040,558.00
				Bid price =	$3,040,558.00

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., as illustrated in Figure 5-5.

Heavy engineering construction contractors generally organize their estimates in a work breakdown structure (WBS) that is unique to the project to be constructed. An example of the WBS organization of an estimate for an electric power construction project is illustrated in Figures 5-6 to 5-8. Each group is subdivided into

FIGURE 5-5
Division 2 Estimate for Site-work.

Cost code	Description	Quantity	Material	Labor	Subcontract	Total
2110	Clearing	L.S.	$0.00	$0.00	$3,694.00	$3,694.00
2220	Excavation	8,800 yd^3	0.00	11,880.00	9,416.00	21,296.00
2250	Compaction	950 yd^3	0.00	2,223.00	722.00	2,945.00
2294	Handwork	500 yd^2	0.00	1,750.00	0.00	1,750.00
2281	Termite control	L.S.	0.00	0.00	3,475.00	3,475.00
2372	Drilled piers	1,632 lin ft	14,580.00	2,800.00	14,525.00	31,904.00
2411	Foundation drains	14 ea.	490.00	1,470.00	0.00	1,960.00
2480	Landscape	L.S.	0.00	0.00	8,722.00	8,722.00
2515	Paving	4,850 yd^2	0.00	0.00	105,633.00	105,633.00
			$15,070.00	$20,123.00	$146,186.00	$181,389.00

FIGURE 5-6
Example of Electric Power Construction Bid Summary Using the WBS Organization of Work.†

Group-level report

No.	Group	Material	Labor and equipment	Subcontract	Total
1100	Switch station	$1,257,295.00	$ 323,521.00	$3,548,343.00	$ 5,128,167.00
2100	Transmission line A	3,381,625.00	1,260,837.00	0.00	4,641,462.00
2300	Transmission line B	1,744,395.00	0.00	614,740.00	2,358,135.00
3100	Substation at spring creek	572,874.00	116,403.00	1,860,355.00	2,549,632.00
4200	Distribution line A	403,297.00	54,273.00	215,040.00	672,610.00
4400	Distribution line B	227,599.00	98,675.00	102,387.00	427,661.00
4500	Distribution line C	398,463.00	21,498.00	113,547.00	532,508.00
		$7,985,548.00	$1,872,215.00	$6,453,412.00	$16,311,175.00

†For large projects the costs are sometimes rounded to the nearest $100 or $1.000. Figures 5-6 to 5-8 show full dollars to illustrate the transfer of costs among the component, division, and group levels of an estimate.

divisions of the work required to construct the group; likewise, each division of that work is subdivided into the components shown in Figures 5-7 and 5-8.

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

FIGURE 5-7
Example of Electric Power Construction Estimate Using the **WBS** Organization of Work.

DIVISION-LEVEL REPORT FOR TRANSMISSION LINE A

Cost item	Description	Material	Labor	Equipment	Total
2100	TRANSMISSION LINE A				
2210	Fabrication of steel towers	$ 692,775.00	$ 0.00	$ 0.00	$ 692,775.00
2370	Tower foundations	83,262.00	62,126.00	71,210.00	216,598.00
2570	Erection of steel towers	0.00	144,141.00	382,998.00	527,139.00
2620	Insulators and conductors	2,605,588.00	183,163.00	274,744.00	3,063,495.00
2650	Shield wire installation	0.00	78,164.00	63,291.00	141,455.00
Total for 2100		$3,381,625.00	$467,594.00	$792,243.00	$4,641,462.00

FIGURE 5-8
Example of Electric Power Construction Estimate Using the WBS Organization of Work.

COMPONENT-LEVEL REPORT FOR TOWER FOUNDATIONS

Cost Item	Description	Quantity	Material	Labor	Equipment	Total
2370	TOWER FOUNDATIONS					
2372	Drilling foundations	4,196 lin ft	$ 0.00	$25,428.00	$44,897.00	$ 70,325.00
2374	Reinforcing steel	37.5 tons	28,951.00	22,050.00	15,376.00	66,377.00
2376	Foundation concrete	870 yd^3	53,306.00	13,831.00	10,143.00	77,280.00
2378	Stub angles	3,142 lb	1,005.00	817.00	794.00	2,616.00
Total for 2370			$83,262.00	$62,126.00	$71,210.00	$216,598.00

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 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%.

QUESTIONS FOR CHAPTER 5—PROJECT BUDGETING

1 Usually each of the three principal parties (the owner, designer, and contractor) prepares a cost estimate at different times during the life of a project. Describe the purpose of each estimate and the impact that estimating errors may have on the other two parties.

2 Why is it important to define the range of accuracy, in percentage, that should be applied to any estimate? Who should set this range and who should be informed of the selected range?

3 Prepare a cost estimate for the construction of a small, high-quality office building that contains 18,525 ft^2 of floor area. Use the data in Figure 5-1 to prepare the estimate. Assume the cost of design for the project is 7% of construction, and a site-work cost of $180,000. What range of percentage of this cost would you recommend to define the level of accuracy?

4 Use the time and location indices in Example 5-2 to estimate the cost of a high-quality office building that contains 64,500 ft^2 of floor area. The building is to be constructed 2 years from now in city A. The cost of a similar type building that contains 95,000 ft^2 was completed last year in city C for a cost of $7,790,000.

5 During the feasibility study of a project, the initial estimated cost for design and construction is $3.7 million. It is anticipated that the cost to maintain and operate the facility after completion of construction will be $250,000 per year. Assuming the owner must obtain a return on the initial investment of 15%, what net annual income must be received to economically justify the project? Assume no salvage value after using the facility for 12 years.

6 The cost estimate of a project is $3.5 million. Annual costs for maintaining and operating the facility are forecast as $250,000 per year. After 8 years, it is anticipated the facility will

be sold for **$2.0** million. If the owner requires a **15%** return on his or her investment, what net annual income must be received to recover the capital investment of the project?

7 The initial investment for a project is **$4.7** million. A net **annual** profit of $1.5 million is anticipated. Using a 12% desired rate of return on the investment, what is the pay back period for the project?

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6

DEVELOPMENT OF WORK PLAN

PROJECT MANAGER'S INITIAL REVIEW

The discussion of developing the project work plan in this chapter is based on handling the project in its early stage of development, prior to 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 during design. 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 in the project to improve quality, cost, or schedule to benefit the owner.

When a project manager is assigned to a project, his or her first duty is to gather all the background material that has been prepared by the sponsoring organization. This includes the owner's study and the contract that has been signed by the project manager's organization. These documents must be thoroughly reviewed to be certain there is a well-defined scope, an approved budget, and a schedule that shows major milestones for the project, in particular the required completion date.

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 6-1.

TABLE 6-1
GUIDELINES FOR PROJECT MANAGER'S INITIAL PROJECT REVIEW

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 & 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?

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.

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 costs. 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. 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 involvement. 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 others 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, and approval process.

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.

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 6-1 through 6-5 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.

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 6-1 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/construction of a project for this company would typically be directed to the engineering department. However, the answers to these questions often

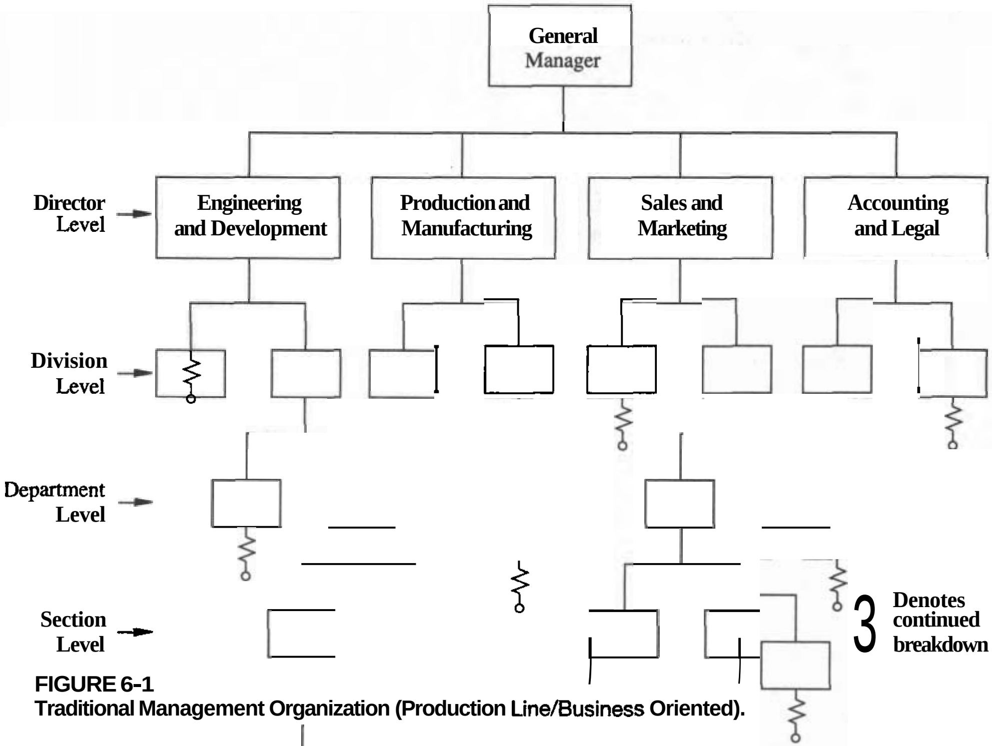

FIGURE 6-1
Traditional Management Organization (Production Line/Business Oriented).

come from the manufacturing department, which in turn may have to obtain input from the marketing group. This requires a channel of communications 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 6-1 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 organization is illustrated by the electrical power company shown in Figure 6-2. The company 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 departments lines can be difficult.

Figure 6-3 shows a typical work environment of a consulting engineering company that provides design services for projects. The company emphasis is discipline

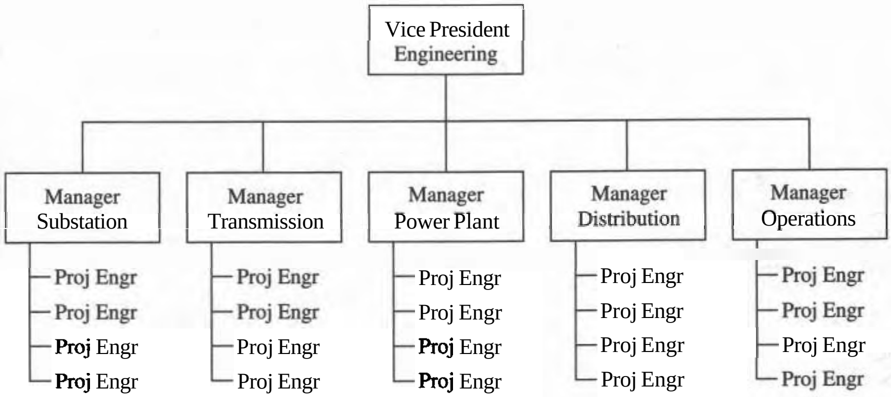

FIGURE 6-2
Functional Organization (Electrical Power Company).

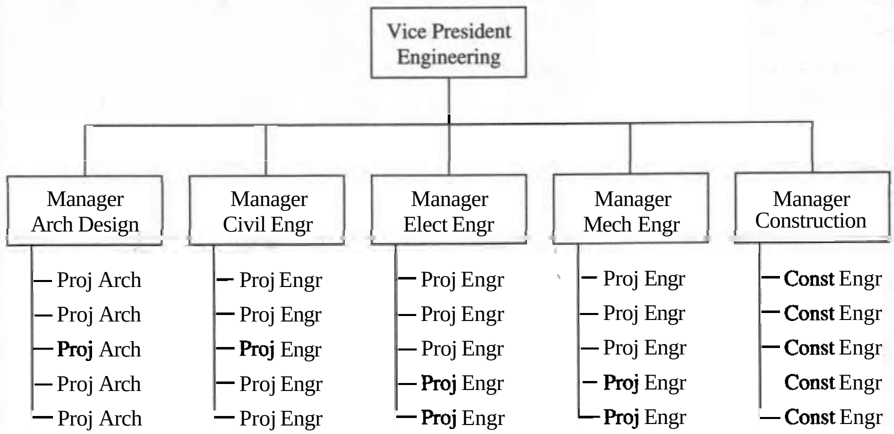

FIGURE 6-3
Discipline Organization (Design Firm).

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 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.

Many consulting engineering companies are organized as shown in Figure 6-3. 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

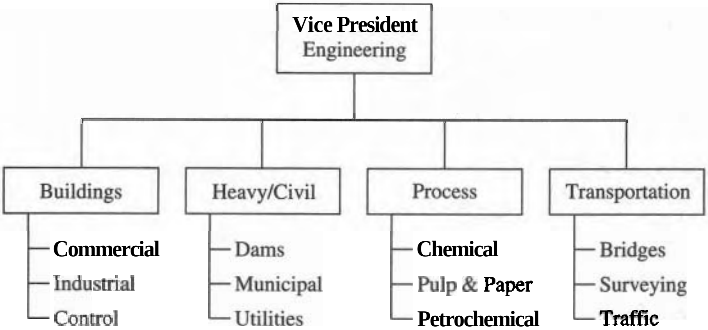

FIGURE 6-4
Functional Organization (Design Firm).

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 what its status is. By the time the project reaches the last discipline there may not be enough budget 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 6-4. 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.

To increase emphasis on project cost, schedule, and general coordination, a matrix organization as shown in Figure 6-5 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.

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

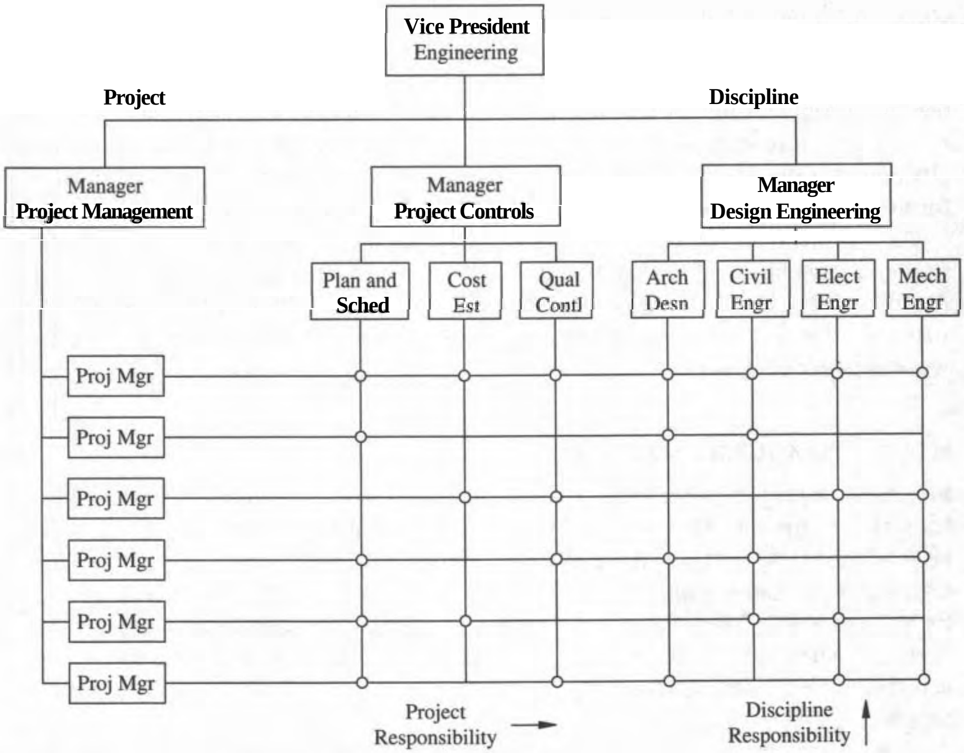

FIGURE 6-5
Matrix Organization (Design Firm).

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 control of and contact with the technical departments. Therefore, there must be a balance between managing the project and providing technical expertise. 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 is 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. Management of the project is best performed in the field, where the actual work is being performed.

WORK BREAKDOWN STRUCTURE

Far any size project, large or small, it is necessary to develop a well-defined work breakdown structure (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 work plan. It defines 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 8 and 9 show how the WBS is used in project scheduling and tracking.

A WBS is a graphical display of the project that shows the division of work in a multi-level system. Figure 6-6 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 upon 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. Development of work packages is discussed later in this chapter.

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

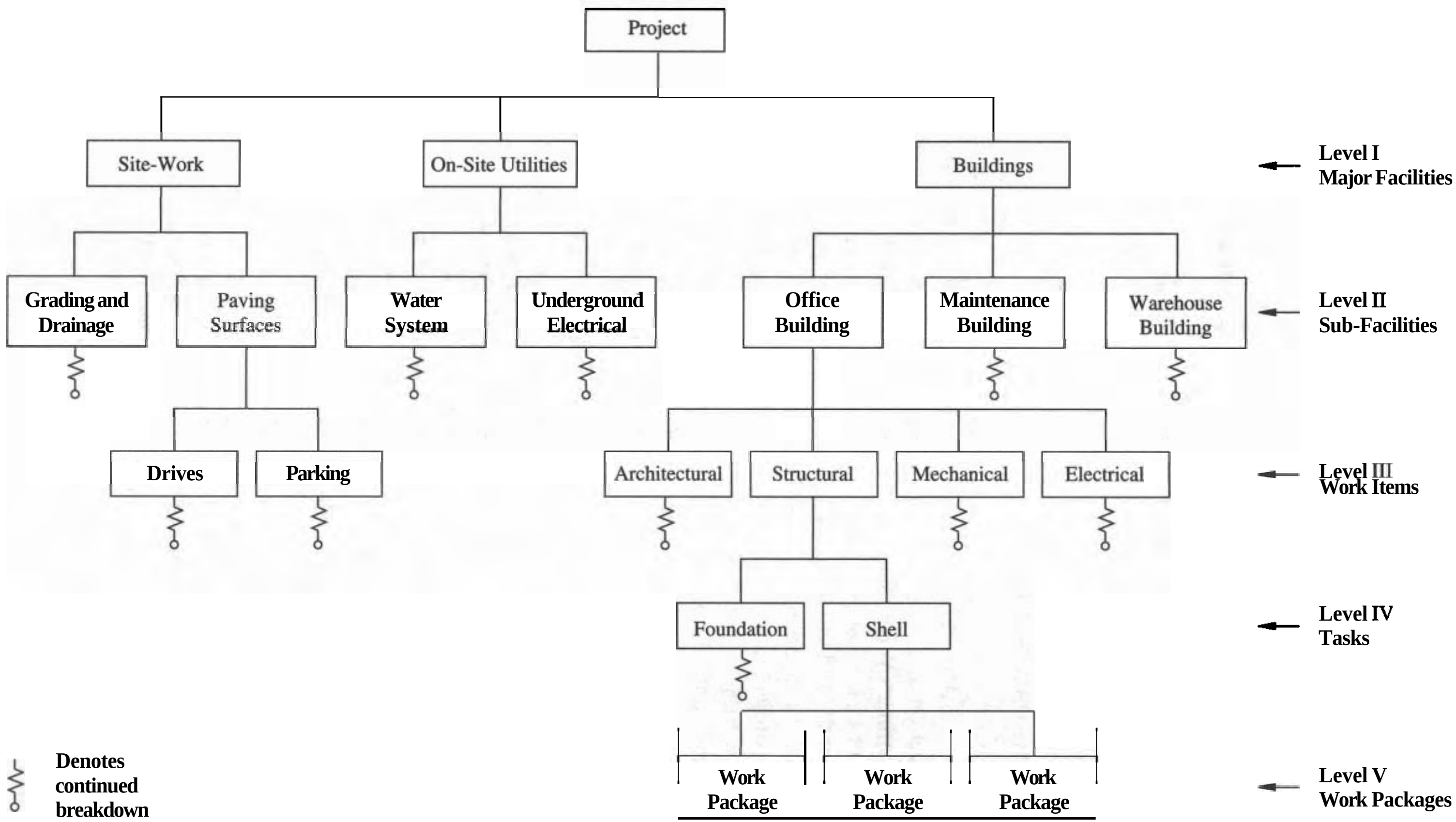

FIGURE 6-6
Illustrative Work Breakdown Structure (WBS).

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. Since 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 and that work is not duplicated. Most importantly, it provides a basis for measurement of performance.

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 tasks that must be performed. A detailed list of tasks should be prepared and grouped into phases that show the sequencing of tasks and the interdependences of work. This provides identity for 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 preproject 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 discipline 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.

The project team consists of members from the various discipline departments (architectural, civil, structural, mechanical, electrical, 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 leader of the team. All team members represent their respective discipline'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 his immediate supervisor and the project manager.

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 discipline 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 rests 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 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 scope, budget, and schedule. These three elements of a project cannot be changed without approval of both the project manager and the owner's representative.

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.

TABLE 6-2
KICK-OFF MEETING CHECK LIST

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, & scope (including guidelines, limitations, problems)
5. Review the project feasibility estimate of the owner & the approved budget for the project team
6. Review the project preliminary schedule & 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 two weeks
10. Establish the next team meeting, write minutes of kick-off meeting, and distribute to each team member and management

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 6-2.

WORK PACKAGES

The project manager is responsible for organizing a work plan for the project; however he or she cannot finalize the project 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 two weeks of the kick-off meeting.

A work package is divided into three categories: scope, budget, and schedule. Figure 6-7 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.

A work package is the lowest level in the WBS and establishes the baseline for project scheduling, tracking, and cost control. 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 6-7, a code account number relates the work to the CBS. Likewise, the schedule section has a code number that relates the work to the OBS. The CBS is used for management of project costs and is further discussed in Chapter 9. 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.

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, computer services, reproduction expenses, travel, expendable supplies, and incidental costs.

Team members must consider their overall work load 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 work breakdown structure 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

Work Package

Title: ____________________

WBS Code: ____________________

1. Scope

Required Scope of Work: ____________________

Services to Be Provided: ____________________

Services not included in this Work Package, but included in another work package: ____________________

Services not included in this Work Package, but will be performed by: ____________________

2. Budget

Personnel Assigned to Job	Work-Hours	$-Cost	CBS Code Acct.	Computer Services Type	Computer Services Hours	Computer Services $-Cost
______	___	___	___	___	___	___
______	___	___	___	___	___	___
______	___	___	___	___	___	___

Total Work-Hours = _____　　Personnel Costs = $ _____

Computer Hours = _____　　Computer Costs = $ _____

Travel Expenses _____ + Reproduction Expenses _____ + Other Expenses _____ = $ _____

Total Budget = $-Labor + $-Computer + $-Other = $ _____

3. Schedule

OBS Code	Work Task	Responsible Person	Start Date	End Date
___	______	______	___	___
___	______	______	___	___
___	______	______	___	___

Work Package: **Start** Date: _____ End Date: _____

Additional Comments: ____________________

Prepared by: ____________________ Date: _____

Approved by: ____________________ Date: _____

FIGURE 6-7
Team Member's Design Work Package.

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 two weeks of the kick-off 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 two 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 work breakdown structure that forms the foundation of the project work plan. After receipt of all information, the project manager can finalize the overall plan to manage the project.

PROJECT WORK PLAN

The project manager must develop a written work plan for each project that identifies 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. The level of detail should be sufficient to allow all project participants to understand what is expected of them in each phase and time period of the project; 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. There must be agreements on priorities, schedule, and budget.

Upon receipt of all the team members' work packages the project manager can assemble the final project work plan. Table **6-3** provides the basic components of a work plan: the directory, tasks, schedule, and budget. The project directory contains all pertinent information, such as project title, number; objectives, and scope. The

TABLE 6-3
COMPONENTS OF A PROJECT WORK PLAN

Directory
- Project title and number
- Project objectives and scope
- Project organizational chart

Tasks
- Detailed listing of tasks
- Grouping of tasks
- Work packages

Schedule
- Sequencing and interdependencies of tasks
- Anticipated duration of each task
- Calendar start and finish dates of tasks

Budget
- Labor-hours and cost of staff for each task
- Other expenses anticipated for each task
- Billing approach and anticipated revenue by month

Measurement
- Accomplishment of tasks
- Completion of work packages
- Number of drawings produced

project organization chart shows all participants, including the owner's representative. The detailed list of tasks, and grouping of tasks, is derived from the work breakdown structure. 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.

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 base for control of all work. Appendix A illustrates the 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 step in organizing a project is development of a WBS. The WBS defines the work to be accomplished, but 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.

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 6-8 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

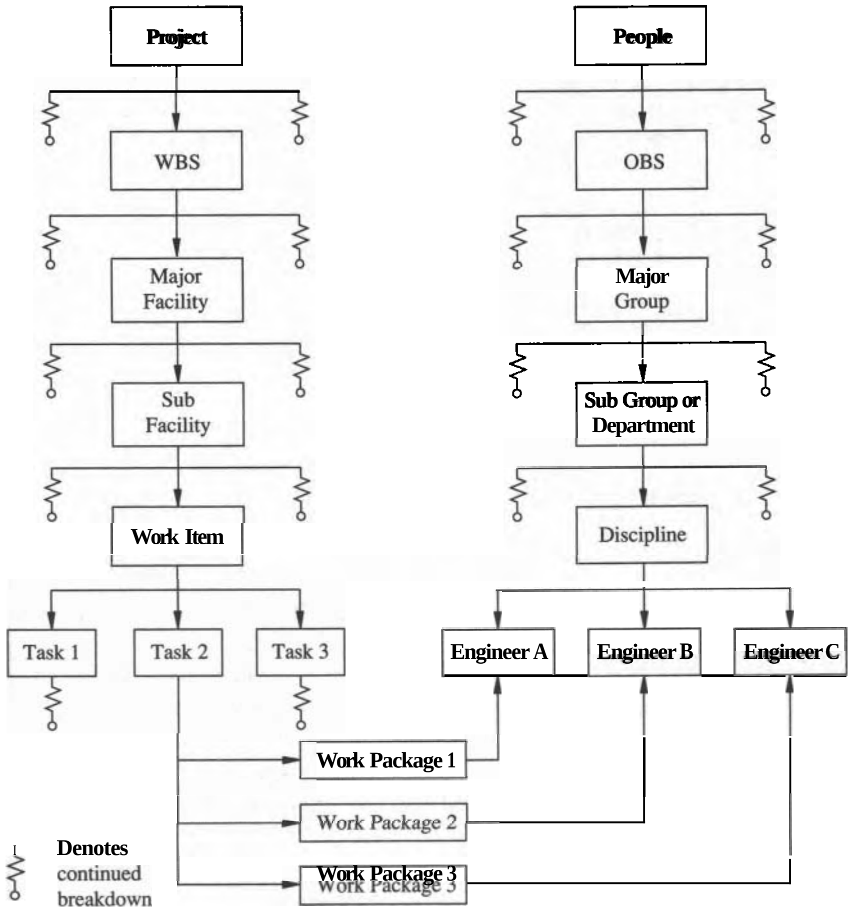

FIGURE 6-8
Linking the WBS and OBS.

then begin the process of selecting individuals from the various discipline departments who will form the project team.

The linking of the WBS and OBS establishes the project framework for management of the project. After the project framework is defined, a project 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. The 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 8.

After completion of the project framework, a coding system, often referred to as a Cost Breakdown System, can be developed to identify each component of the WBS. The coding system provides a common code of accounts used by all participants in

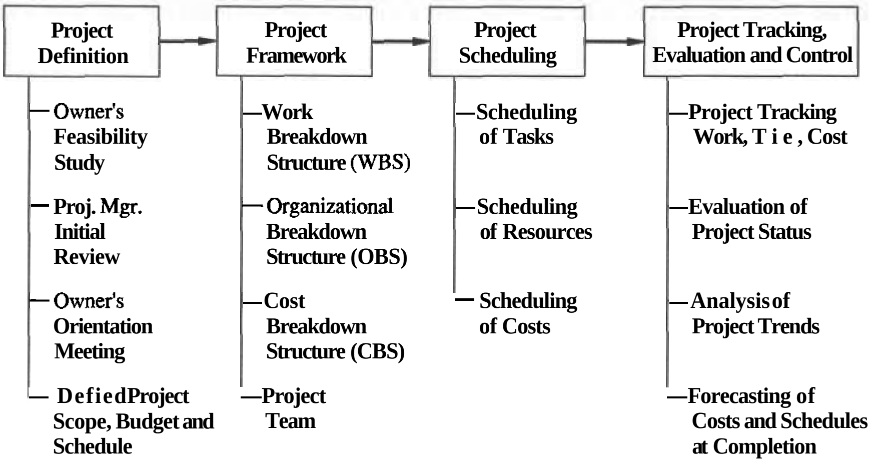

FIGURE 6-9
Phases of Development of Work Plan.

the project because it is directly related to the **WBS,** that is, the work to be performed. Coding systems are discussed in Chapters 8 and 9.

The integration of the **WBS, OBS,** and CPM forms the project plan, which is the base for project tracking and control. A code of accounts can be developed that relates the required work (defined in the **WBS)** to the people (shown on the **OBS)** who will do the work in accordance with the schedule (shown on the CPM) to complete the project. Thus, the **WBS, OBS,** and CPM must be linked together to form an all-encompassing project plan.

To be effective, a system of project management must integrate all aspects of the project; the work to be done, who is going to do it, when it is to be done, and what the cost will be. Actual work can then be compared to planned work, in order to evaluate the progress of a project and to develop trends to forecast at completion costs and schedules.

The development phases of the project work plan are illustrated in Figure 6-9. Topics related to project definition were discussed in Chapters **3** and 5. Project framework is presented in this chapter. Project scheduling and tracking is presented in Chapters 8 and 9, respectively.

QUESTIONS FOR CHAPTER 6—DEVELOPMENT OF WORK PLAN

1 As discussed in this chapter, the work environment of a project manager can have a significant impact on his or her ability to manage projects. Describe factors that may help or hinder the work of a project manager in each of the following organizational structures: functional organization, discipline organization, and matrix organization.

2 You are the project manager of a project that has the following facilities: security entrance, driveways, parking, landscape, small office building, fabrication building, communication

building, and a recreational building. Develop a preliminary work breakdown structure for the project. Identify the engineering disciplines required for the design of the project.

3 Describe the purpose of a kick-off meeting for a project. What are typical items that are presented and discussed during the meeting, including specific assignments that a project manager should ask of team members?

4 Briefly describe the contents of a design work package, who assigns it, when it is assigned, who completes it, and when it should be completed.

5 As the project manager for a project, discuss options that might be considered for one of your team members who is having difficulty completing a design work package. Discuss options for each of the following situations: difficulty in defining the scope of work, difficulty in finding experienced personnel that can be assigned to tasks in the work package, and difficulty in estimating the time that it may take to complete the work.

6 You are the project manager for a project and have just compiled all the design work packages and found that the costs exceed the approved budget. Describe the options that you would consider to manage the discrepancy.

7 The basic contents of a project work plan are shown in Table 6-3. Identify the contents that relate to the fundamental questions of Who? Does what? When? and How much?

8 For the basic components of a project work plan shown in Table 6-3, identify the components that relate to the organization structure, work breakdown structure, cost breakdown structure, and the Critical Path Method for project scheduling.

9 The development of a work plan for a project follows four phases: project definition, framework, schedule, and tracking. Identify and briefly describe the parts that make up each of these four phases.

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7

DESIGN PROPOSALS

EVOLUTION OF PROJECTS

This chapter is written from the perspective of the project manager who is responsible for managing the design effort. 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 6. 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 change as it develops from conception to completion. Because there are perpetual changes in a project, the design project manager should be involved at the beginning of the project and remain with the project until final completion. Continuity of the design project manager is crucial to a successful project. In all instances, the project manager is the prime contact with the sponsor of the project. Changes in a project are a major issue for the design team. Changes occur as a project progresses through the following phases:

- Sponsor's development phase
- Project organization phase
- Engineering phase
- Procurement phase
- Construction phase
- System testing and start-up phase
- Project completion and contract close-out phase

The sponsor's development phase 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 sponsor's goals. Various names are given to the sponsor, including owner, business unit, operating group, client, customer, and end user. Essentially, the sponsor is the organization that requests the work and will use the work when it is completed. 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 sponsor.

PROJECT EXECUTION PLAN

The first step in developing a design proposal is development of the project execution plan to manage the design process. 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. Too often, RFPs have vaguely defined scopes of work that will later cause unforeseen additional work, which adversely impacts the budget and schedule.

The plan must also 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.

PROJECT DEFINITION

Although project definition is primarily the responsibility of the sponsor'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 7-1). 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.

The PDRI consists of 70 elements, grouped into 15 categories, which are further grouped into 3 broad sections (see Figure 7-1). To determine the PDRI, each of the elements are rated on a scale from 1 through 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

I Basis of Project Decision

A. Manufacturing Objectives Criteria
- A1. Reliability Philosophy
- A2. Maintenance Philosophy
- A3 Operating Philosophy

B. Business Objectives
- B1. Products
- B2. Market Strategy
- B3. Project Strategy
- B4. Affordability/Feasibility
- B5. Capacities
- B6. Future Expansion Considerations
- B7. Expected Project Life Cycle
- B8. Social Issues

C. Basic Data Research & Development
- C1. Technology
- C2. Processes

D. Project Scope
- D1. Project Objectives Statement
- D2. Project Design Criteria
- D3. Site Characteristics Available vs. Required
- D4. Dismantling & Demolition Requirements
- D5. Lead/Discipline Scope of Work
- D6. Project Schedule

E. Value Engineering
- E1. Process Simplification
- E2. Design & Material Alternatives Considered/Rejected
- E3. Design for Constructability Analysis

II Front End Definition

F. Site Information
- F1. Site Location
- F2. Surveys & Soil Tests
- F3. Environmental Assessment
- F4. Permit Requirements
- F5. Utility Sources with Supply Conds.
- F6. Fire Protection & Safety Considerations

G. Process/Mechanical
- G1. Process Flow Sheets
- G2. Heat & Material Balances
- G3. Piping & Instrmt Diagrams (P&IDs)
- G4. Process Safety Mgmt. (PSM)
- G5. Utility Flow Diagrams
- G6. Specifications
- G7. Piping System Requirements

G. Process/Mechanical (continued)
- G8. Plot Plan
- G9. Mechanical Equipment List
- G10. Line List
- G11. Tie-in List
- G12. Piping Specialty Items List

H. Equipment Scope
- H1. Equipment Status
- H2. Equipment Location Drawing
- H3. Equipment Utility Requirements

I. Civil, Structural, & Architectural
- I1. Civil/Structural Requirements
- I2. Architectural Requirements

J. Infrastructure
- J1. Water Treatment Requirements
- J2. Loading/Unloading/Storage Facilities Requirements
- J3. Transportation Requirements

K. Instrument & Electrical
- K1. Control Philosophy
- K2. Logic Diagrams
- K3. Electrical Area Classifications
- K4. Substation Requirements/ Power Sources Identified
- K5. Electric Single Line Diagrams
- K6. Instrument & Electrical Specifications

III Execution Approach

L. Procurement Strategy
- L1. Procurement Strategy Equipment & Materials
- L2. Procurement Procedures & Plans
- L3. Procurement Responsibility Matrix

M. Deliverables
- M1. CADD/Model Requirements
- M2. Deliverable Defined
- M3. Distribution Matrix

N. Project Control
- N1. Project Control Requirements
- N2. Project Accounting Requirements
- N3. Risk Analysis

P. Project Execution Plan
- P1. Owner/Approval Requirements
- P2. Engr./Const. Plan & Approach
- P3. Shut Down/Turn-Around Requirements
- P4. Pre-Commissioning Turnover Sequence Requirements
- P5. Startup Requirements
- P6. Training Requirements

FIGURE 7-1 .
Project Definition Rating Index (PDRI)—Sections, Categories, and Elements.
Source: Construction Industry Institute.

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.

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 or managing a business unit in the sponsor'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.

Sometimes the only fixed known information about the project is the amount of money the owner has to spend, with 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 wants to do with the project when it is completed. The designer must assist the owner in separating what he or she needs from what he or she wants. The designer must convert the owner's needs into engineering scope of work and the 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.

High turnover of people is another problem in defining objectives. Many owner organizations frequently promote and reassign personnel. Turnover of people can lead to changing priorities. By the time a project reaches the approval stage, the people who established the initial project definition may no longer be involved. 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 sponsor's organization and the project team.

A well-defined 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 there is a good understanding and agreement of project definition. Getting an early team agreement on definition prevents the project scope from creeping out of control.

DESIGN PROPOSALS

Upon receipt of a request for proposal (RFP) the design project manager should carefully review it to become familiar with the global issues related to environmental and community relations, hazardous waste, bidding strategy, required permits and regulations, 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.

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 sponsor or as informal as a brief outline of scope for expansion of existing work.

During this early stage in project development, the design engineer must convert the sponsor's project definition into an engineering scope of work. However, the design engineer may feel the sponsor's definition is inadequate or may feel there is missing information. The sponsor should be contacted for clarifications. However, sometimes the sponsor 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. It is then mandatory to document and communicate to the sponsor 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 7-2 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.

The design project manager is responsible for managing the overall coordination of the proposal effort. Specific duties include

- 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 sponsor's interview
- Participate in establishing a rate schedule
- Assimilating the list of project deliverables

The discipline managers are responsible for providing technical support for the proposal. This support may include assigning personnel, establishing preliminary designs, reviewing sponsor information, and performing quality-control review of proposal documents. The discipline managers are also responsible for establishing

PROJECT PROPOSAL FORM

☐ Continuation of Existing Work ☐ New Work

PROJECT DATA

Client Name: ____________________

Description of Work: ____________________

Location of Work: ____________________

____

Prepared By: ____________________ Date: __________

DISCIPLINES INVOLVED:

☐ Arch	$ ________	☐ Mechanical	$ ________
☐ civil	$ ________	☐ Structural	$ ________
☐ Electrical	$ ________	☐ Other:	________

ESTIMATE

Fee: $ ____________________ Work-Hours: ____________________

Start Date: ____________________ Completion Date:

Proposal Required: ☐ No ☐ Yes, Due Date: __________

Comments

____

____

____

____

____

____

____

____

____

APPROVAL:

☐ No Further Action Required ☐ Further Discussion Required ☐ Proceed

Date: __________

DISTRIBUTION

President ____________________

Principal-in-Charge ____________________

Project Manager ____________________

Marketer ____________________

Document Control ____________________

FIGURE *7-2*
Project Proposal Form for Design.

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 7-3 illustrates a project proposal check list. The project data can be the same as listed on the project proposal form. Prior to the sponsor'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, such as Power-point.

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 sponsor requirements, can be attached to the form. The completed form, plus attachments, is submitted to management prior to preparation of the proposal.

ENGINEERING ORGANIZATION

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. 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 7-4 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.

SCOPE BASELINE FOR BUDGET

Project proposal detail sheets as illustrated in Figure 7-5 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 PROPOSAL CHECK LIST

Project Manager: ____________ Marketer: ____________

PROJECT DATA

Client Name: ____________
Description of Work: ____________
Location of Work: ____________

Estimated Cost to Prepare Proposal: $ ____________

Estimated Work-Hours ____________

PROPOSAL SUPPORT DOCUMENTATION

- ☐ Organization Chart
- ☐ Rate Schedule
- ☐ List of Projects to Include
- ☐ List of Employee Resumes
- ☐ List of Special Graphics
- ☐ List of Travel Expenses
- ☐ Proposal Sheets
- ☐ Other: ____________

CLIENT INTERVIEW

Date of Interview: ____________ Rehearsal Date: ____________

- ☐ List of Attendees
- ☐ Presentation Materials List
- ☐ Agenda
- ☐ Other: ____________

GENERAL SCOPE OF WORK

____
____
____
____
____
____
____
____

- ☐ Drawing List
- ☐ Special Requirements List
- ☐ Specifications List
- ☐ Other: ____________

APPROVAL:

____________ Date: ____________
President

____________ Date: ____________
Principal-in-Charge

FIGURE 7-3
Proposal Check List for Design.

Project Manager

- A. Project Engineer
- B. Schedule and Control 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. 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. Clerical Personnel
- F. Document Control Personnel
- G. Reproduction Personnel
- H. Contract Administration

FIGURE 7-4
Illustrative Example of Expertise Required for Design.

project. Thus, the project proposal detail sheet forms the basis for setting up and managing the project.

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 sponsoring 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 7-5 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

PROJECT PROPOSAL DETAIL. SHEET

Discipline: ____________________

PROJECT DATA

Project Manager: ____________________ Marketer: ____________________
Proposal Number: ____________
Client Name: ____________________
Description of Work: ____________________
Location of Work: ____________________
Estimated Department Budget: ____________________ Work-Hours: ____________

SCOPE DEFINITION

CLIENT REFERENCES AND ATTACHMENTS

PERSONNEL CATEGORIES REQUIRED WITH WORK-HOURS

	ADMIN	SPECS	ENGR	DRWGS
Department Manager				
Lead Engineer				
Senior Engineer				
Junior Engineer				
CADD/Drafting Coord.				
Total				

Do not include Clerical, Reproduction, or Other Disciplines. Return to PM by: ________

OUTSIDE COORDINATION / OTHER REQUIREMENTS

☐ Specification List

☐ Drawing List Total Number of Drawings: ____________

☐ **Other:** ____________________

Prepared by: ____________________ Date: ________

FIGURE *7-5*
Detail Sheet for Design Proposal.

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 7-5. The completed form, plus all supporting documentation, is returned to the project manager. An example of this completed form is given in Figure 5-3.

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 7-6 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 5-2.

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 accounting 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 upon data from past projects can be made to prevent significant errors in the design budget.

The design project manager must also communicate with the design managers of the various disciplines 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 work load expected of 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.

DATE: ___/___/___

PROJECT PROPOSAL BUDGET FORM

Project Name: ____

		RESOURCE HOURS								
		RATE								
Dept. Number	Department	ADMIN	MTGS	SHED	SPECS	ENGR CALCS	DRWGS	RCD DRWG	TOTAL	DOLLARS
	Project Management								0	$0
	Architecture								0	$0
	Mechanical								0	$0
	Electrical								0	$0
	Structural								0	$0
	Environmental								0	$0
	Civil								0	$0
	CADDS								0	$0
	Clerical								0	$0
	Document Control								0	$0
	Reproduction								0	$0
	Project Control								0	$0
	Management								0	$0
RESOURCE-HOUR SUBTOTAL		0	0	0	0	0	0	0	0	0
FEE SUBTOTAL		$ -	$ -	$ -	$ -	$ -	$ -	$ -		0

Task #	Description		
	Contingency		
	General Expenses		
	Travel		
	Office Budget		
	EXPENSES SUBTOTAL		$0
	TOTAL		$0

FIGURE 7-6
Budget Form for Design Proposal.

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 sketches that are hand drawn on 8%X 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 7-7 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.

Design schedules, such as the room finish schedule, 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 referred to, 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 are 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.

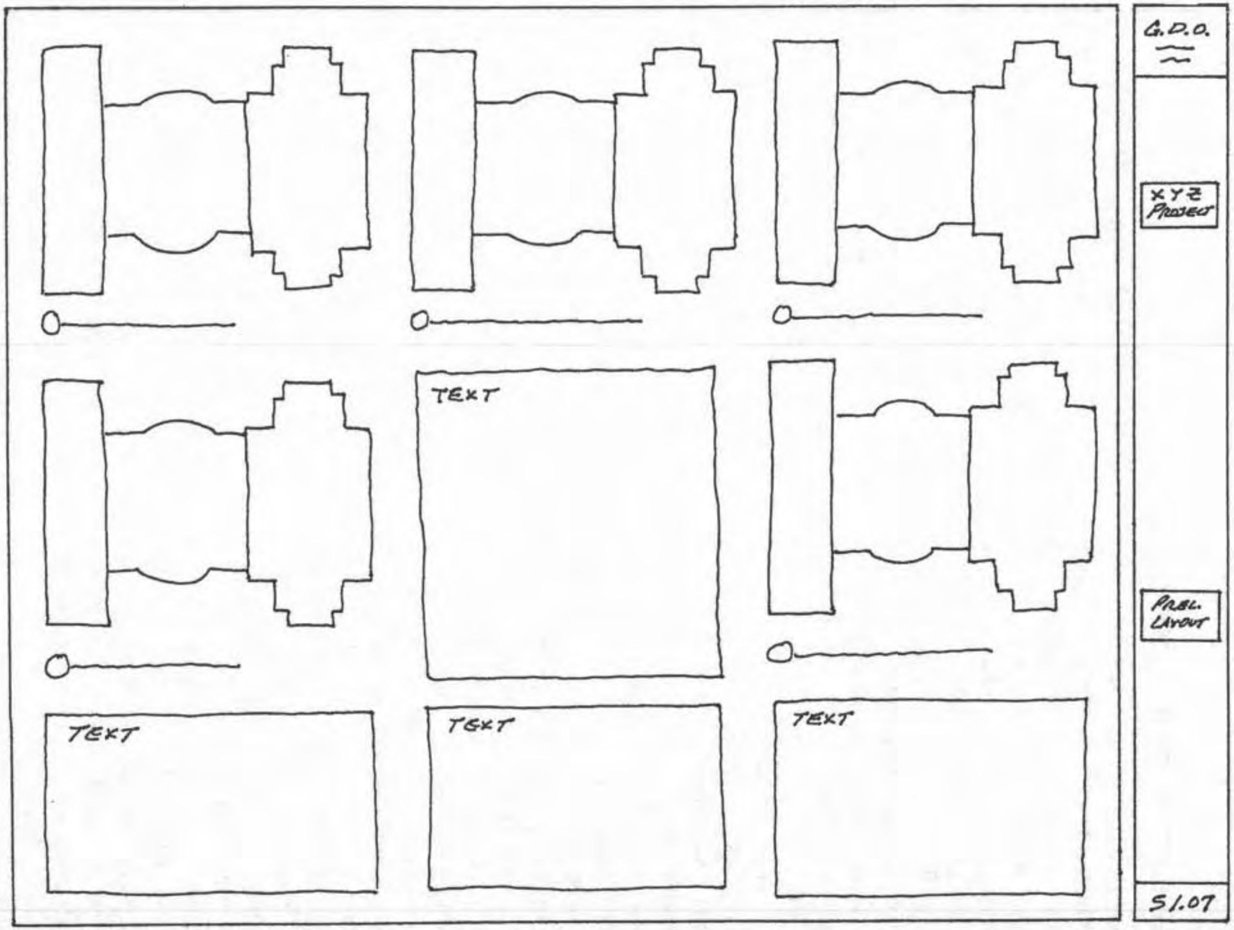

FIGURE 7-7
Illustrative Example of Mini-Drawing.

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 sponsor's organization. Typical examples include design calculations, writing specifications, preparing drawings, conducting tests, or providing inspection. Many sponsoring 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 helps also 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 sponsoring 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 8 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 8 presents a discussion and example of CPM scheduling for engineering design, and Chapter 9 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 sponsoring organization's special requirements, applicable codes, and regulatory agencies. The schedule should also show key progress reviews, 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 most costly 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.

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 time cards. 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.

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. Sponsors 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 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 sponsor's organization. The adverse impact of late changes in scope must be communicated to the sponsor.

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 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 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. 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 completion 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 work breakdown structure, and used in determining the budget for design. Table 7-1 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 9.

Measuring progress of design is difficult because design is a creative process. Sometimes considerable time may be expended in the design effort without seeing

TABLE 7-1
EXAMPLE PROGRESS MEASUREMENT SYSTEM FOR ENGINEERING DESIGN WORK PACKAGES

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%
Drawing 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%

TABLE 7-1
EXAMPLE PROGRESS MEASUREMENT SYSTEM FOR ENGINEERING DESIGN WORK PACKAGE —continued

C: Progress Measurement of Structural Engineering Design Work Packages—continued

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%

Specifications: 4 total, 1 hour per specification

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%

TABLE 7-1
EXAMPLE PROGRESS MEASUREMENT SYSTEM FOR ENGINEERING DESIGN WORK PACKAGES-continued

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%
Drawings 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 drawing issued	20%
	Total = 100%
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	

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 sponsors 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 sponsor. There must be agreement between the sponsor 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 9 presents methods of measuring design progress.

QUESTIONS FOR CHAPTER 7—DESIGN PROPOSALS

1 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 sponsor. As a project manager of the design team, discuss methods you would use to ensure a clear understanding of the project requirements and expectations of the project sponsor.
2 The purpose of a design proposal is to identify the scope and develop the budget and schedule for preparing the design. Discuss methods you would use to convert the owner's needs and expectations into engineering scope, budget, and schedule.
3 A common mistake in the development of design schedules is the failure to include adequate contingency in the project schedule. List steps you would use to ensure adequate contingency is incorporated into a design schedule.
4 Excessive use of computers can lead to overdesigning, overwriting, and overdrafting. As a project manager of the design team, what methods would you use to control excessive use of computers during the design effort?
5 Changes in scope are a common problem during the design. As project manager of the design team, what methods would you use to monitor and control scope during the design process?

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8

PROJECT SCHEDULING

PROJECT PLANNING AND PROJECT SCHEDULING

Project planning is the process of identifying all the activities necessary to successfully complete the project. Project scheduling is the process of determining the sequential order of the planned activities, assigning realistic durations to each activity, and determining the start and finish dates for each activity. Thus, project planning is a prerequisite 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 because planning and scheduling are performed interactively. For example, a specific list of activities may be planned and scheduled for a project. Then, after the schedule is reviewed, it may be decided that additional activities should be added or some activities should be rearranged in order to obtain the best schedule of events for the project.

Planning is more difficult to accomplish than scheduling. The real test of the project planner/scheduler is his or her ability to identify all the work required to complete the project. 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 6 results in a list of activities that must be performed to complete a project.

After the activities are identified, it is relatively easy 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 non-workable due to too much emphasis on getting a computer-generated schedule. The planner/scheduler must give adequate time and think through the 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 good project schedule.

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 8-1).

Planning is the first step to project scheduling. Planning is a process and not a discrete activity. As changes occur, additional planning is required to incorporate the changes into the schedule. There are many situations or events that can arise that can impact a project schedule. 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 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 a lack of 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.

TABLE 8-1
DESIRED RESULTS OF PROJECT PLANNING AND SCHEDULING

1. Finish the project on time
2. Continuous (uninterrupted) flow of work (no delays)
3. Reduced amount of rework (least amount of changes)
4. Minimize confusion and misunderstandings
5. Increased knowledge of status of project by everyone
6. Meaningful and timely reports to management
7. You run the project instead of the project running you
8. Knowledge of scheduled times of key parts of the project
9. Knowledge of distribution of costs of the project
10. Accountability of people, defined responsibility/authority
11. Clear understanding of who does what, when, and how much
12. Integration of all work to ensure a quality project for the owner

Another common complaint of many designers is the amount of rework they must do because of changes in the project. This also leads to confusion and misunderstandings that further hinder productive work. Planning should include a clear description of the required work before the work is started. However, it must be recognized that changes are a necessary part of project work, especially in the early development phases. 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.

Project planning and scheduling can serve as an effective means of preventing 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.

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.

To develop an integrated total project plan, the project must be broken down into well-defined units of work that can be measured and managed. 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. 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 plan can be developed.

The project plan and schedule must clearly define individual responsibilities, schedules, budgets, and anticipated problems. The project manager should prepare formal agreements with appropriate parties whenever there is a change in the project. There should be equal concern given to schedule and budget, and the two must be linked. Planning, scheduling, and controlling begin at the inception of the project and are continuous throughout the life of the project until completion. Table 8-2 lists key principles for planning and scheduling.

TABLE 8-2
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 and scheduling process
3. Include all aspects of the project: scope, budget, schedule, and quality
4. Build flexibility into the plan, include allowance for changes and time for reviews and approvals
5. Remember the schedule is the plan for doing the work, and it will never be precisely correct
6. Keep the plan simple, eliminate irrelevant details that prevent the plan from being readable
7. Communicate the plan to all parties; any plan is worthless unless it is known

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 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 very 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 work load. 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.

TECHNIQUES FOR PLANNING AND SCHEDULING

The technique used for project scheduling will vary depending upon the project's size, complexity, duration, personnel, and owner requirements. The project manager must choose a scheduling technique that is simple to use and is easily interpreted by all project participants. There are two general methods that are commonly used: the bar chart (sometimes called the Gantt chart) and the Critical Path Method (sometimes called CPM or network analysis system).

The bar chart, developed by Henry L. Gantt during World War I, is a graphical time-scale 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 may occur at times on some projects. However, if these situations exist on every project, it is likely that the projects are not well planned, managed, or controlled.

The Critical Path Method (CPM) was developed in 1956 by the DuPont Company, with Rernington Rand as consultants, as a deterministic approach to scheduling. The CPM method 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.

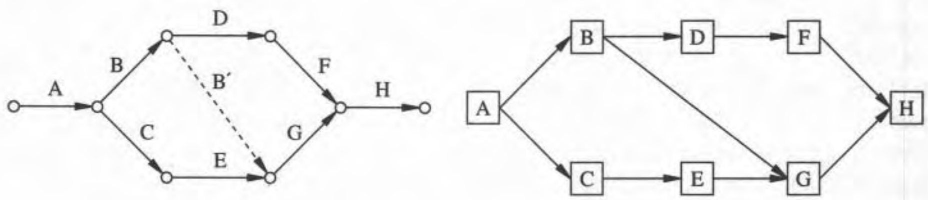
Although the CPM technique requires more effort than a bar chart, it provides more detailed information that is required for effective project management. Using a network schedule to plan a project forces the project team to break a project down into identifiable tasks and to relate the tasks to each other in a logical sequence in much greater detail than a bar chart. This up-front planning and scheduling helps the project team to identify conflicts in resources before they occur. The project manager must use his or her own judgement and select the method of scheduling that best defines the work to be done and that communicates project requirements to all participants.

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 8-1 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.

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 and 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.

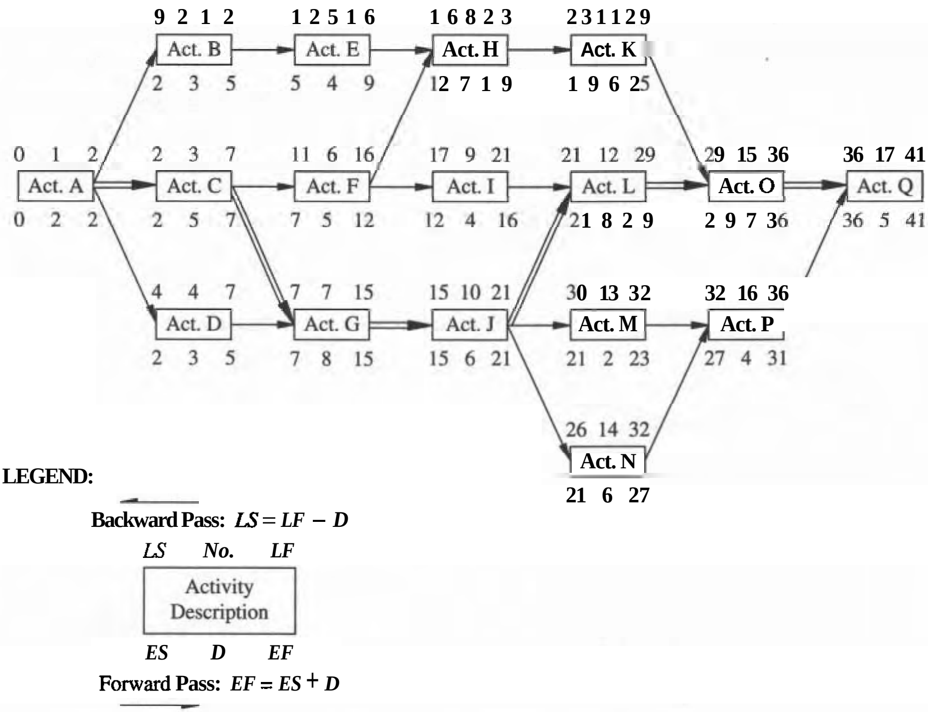
FIGURE 8-1
Basic Definitions for CPM.

For project management the CPM is the most commonly used NAS method. The concept is simple, the computations only require basic arithmetic; and 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 8-2 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.

FIGURE 8-2
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 upon 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 8-2, 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.

Table **8-3** lists the basic steps to guide the process of developing a CPM diagram for project planning and scheduling. 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 CPM DIAGRAM FROM THE WBS

Table 8-3 provided the list of basic steps that can be used to guide the process of developing a network analysis system for project planning and scheduling. The development of the WBS is an important first step that is often neglected. Attempting to draw the CPM diagram without a WBS usually leads to numerous revisions to the diagram.

Figure 8-3 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. A discussion of a typical owner's study for this type of project was presented in Chapter 3. To handle this

TABLE 8-3
STEPS IN PLANNING AND SCHEDULING

1. Develop a work breakdown structure (WBS) that identifies work items (activities)
   a. Consider activities that require time
   b. Consider activities that require cost
   c. Consider activities that you need to arrange
   d. Consider activities that you want to monitor
2. 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
3. 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
4. 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
5. 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
6. 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

project the contracting strategy is to use in-house personnel to design the on-site 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 employee's office building.

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.

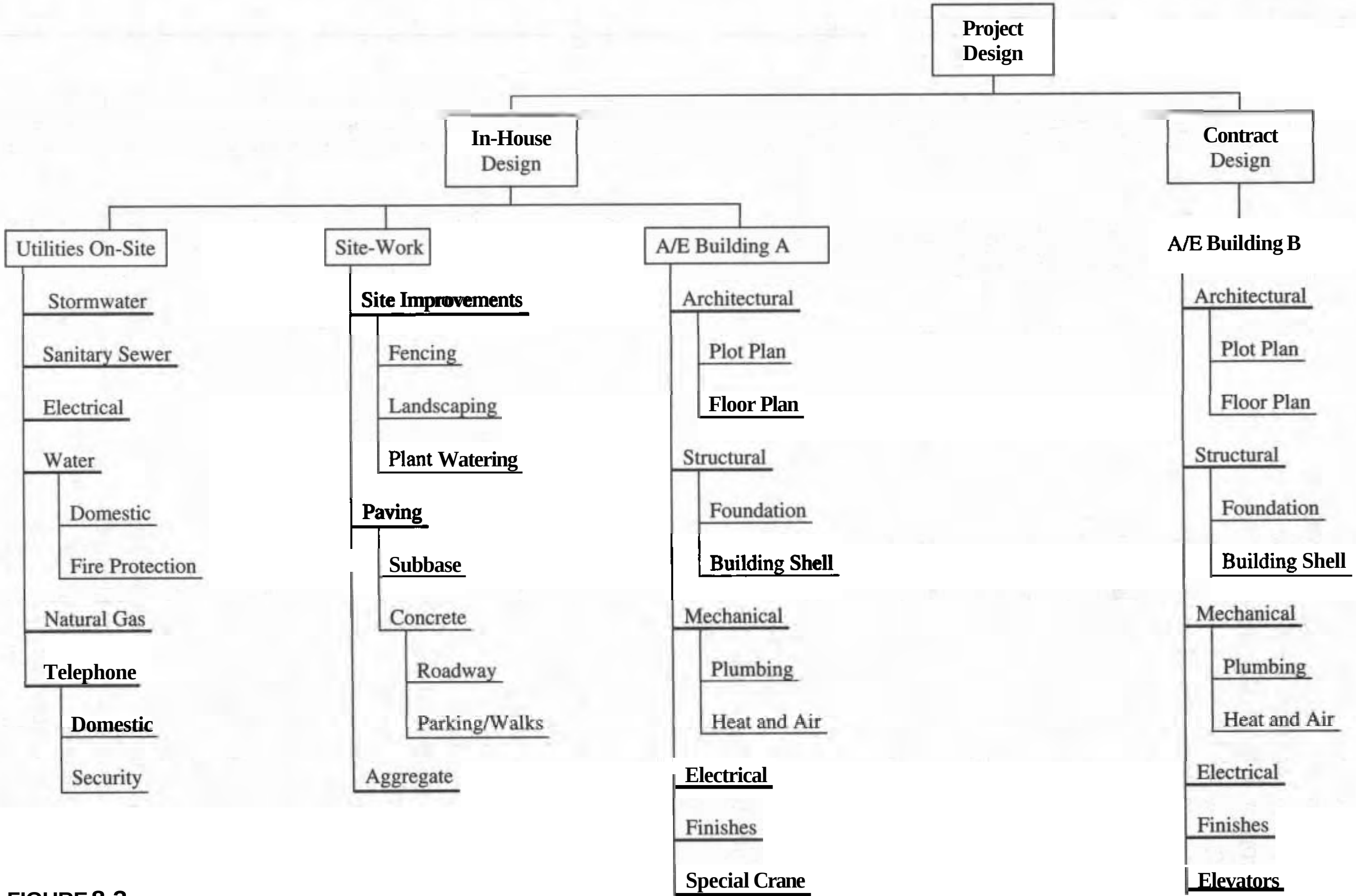


FIGURE 8-3
Work Breakdown Structure for Design of Service Facility Project.

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 simple terms, a person must tell a draftsman, or the computer, how to draw the diagram. An efficient way to accomplish this task is to record each activity on a 3 × 5 index card and to use a tack to post all activities on a bulletin board or office wall. The activities can then be easily rearranged and reviewed by key participants before development of the formal diagram.

Figure 8-4 is a CPM diagram that was developed from the **WBS** shown in Figure 8-3. 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.

The purpose of CPM is to plan the work to guide the progress of a project and provide a baseline for project control. Chapter 9 discusses linking the **WBS** to the CPM for project control by expanding Figures 8-3 and 8-4 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 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

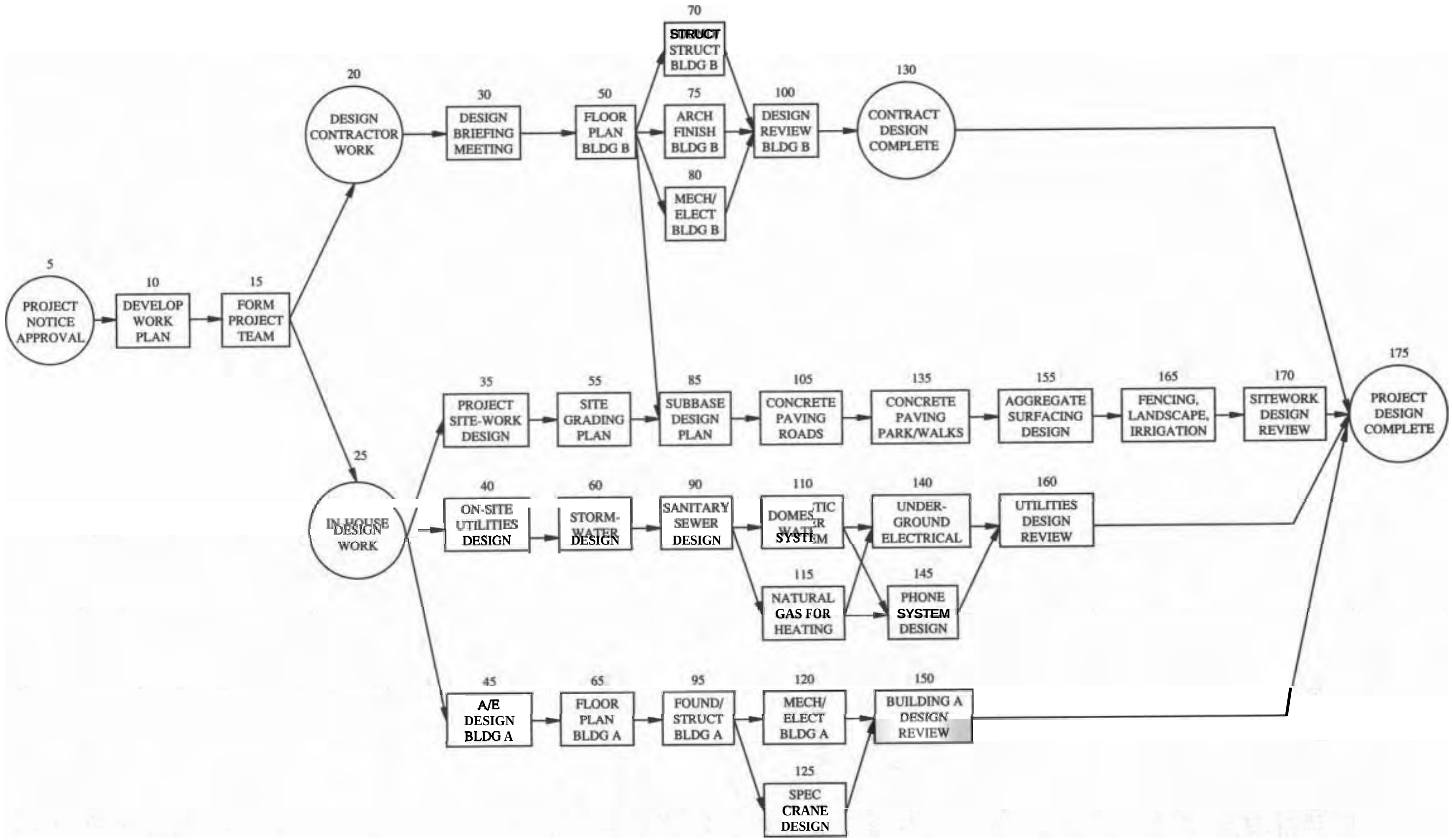


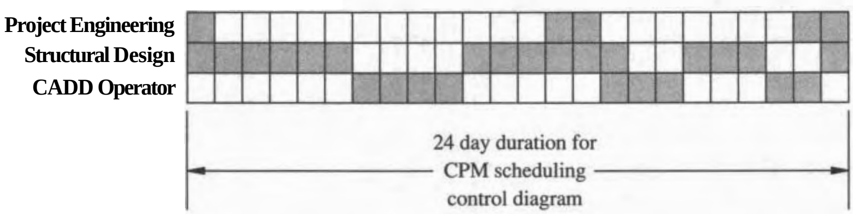
FIGURE 8-4
CPM Diagram for Design Engineering.

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 Operator	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.

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 are 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 8-5 and 8-6. Figure 8-5 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 8-5 is shown with its time and cost 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 8-5 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 8-6.

For this project, two surveying crews are available, which allows 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 8-6. 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 is shown above the activity list, and the project start date is shown at the end of the sequence list.

Figure 8-7 shows the activity schedule report for the project that is typically available from a CPM computer program. Both calendar and work days are shown. 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. The letter "C" at the left of an activity denotes it is a critical activity; that is, it has zero total and free float.

SCHEDULE CODING SYSTEM

One of the advantages of CPM scheduling by computer methods is the ability 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 8-4 is a simple 4-digit coding system to illustrate sorting capabilities for the sewer and water lines project that is shown in Figure 8-5. 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 4-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 4-digit code number for

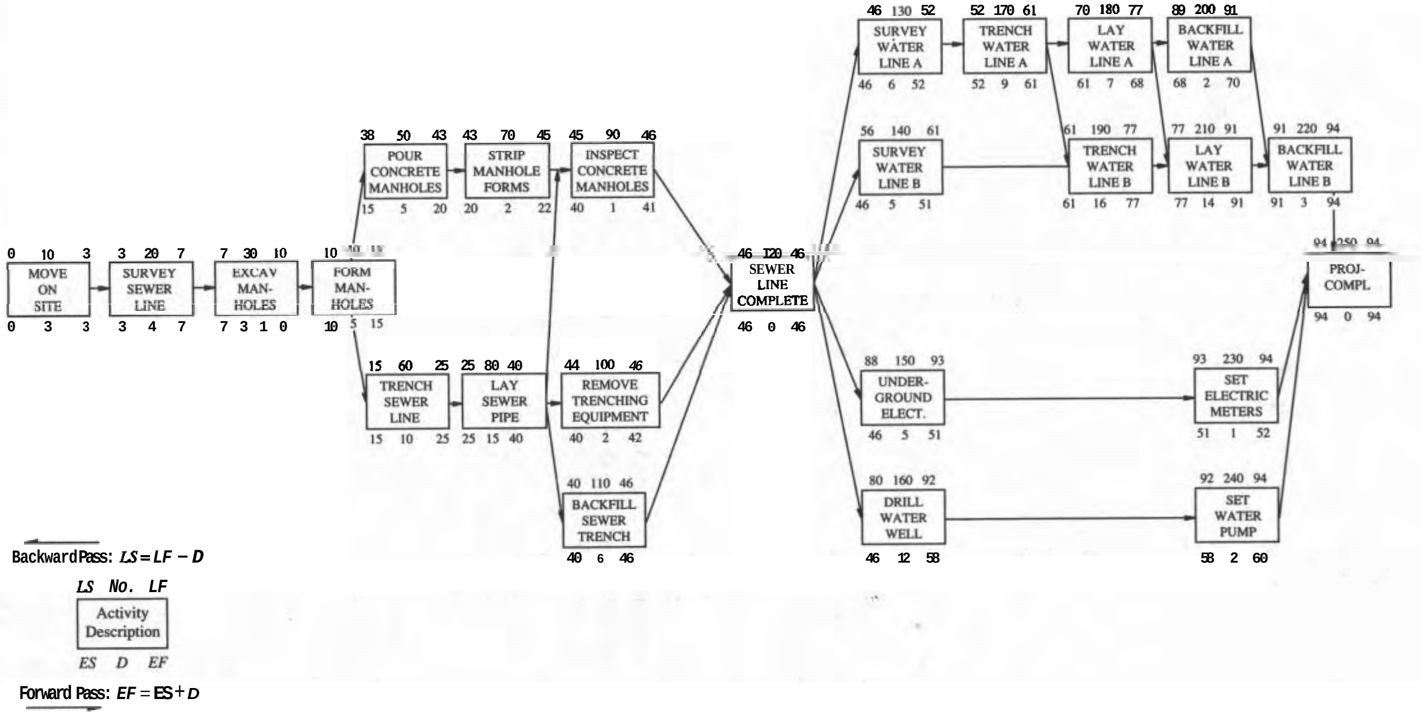


FIGURE *8-5*
CPM Diagram for Construction Phase of Sewer and Water Lines Project.

****
** INPUT DETAILS **
****

PROJECT: SEWER & WATER LINE

ACTIVITY LIST:

NUMBER	CODE	DESCRIPTION	DURATION	COST	ASSIGNED START
10	5000	MOVE ON SITE	3	1400.	
20	1100	SURVEY SEWER LINES	4	2700.	
30	1200	EXCAVATE FOR MANHOLES	3	3500.	
40	1200	INSTALL MANHOLE FORMWORK	5	6000.	
50	1200	PLACE CONCRETE MANHOLES	5	4700.	
60	1300	TRENCH SEWER LINE	10	12600.	
70	1200	STRIP MANHOLE FORMWORK	2	2100.	
80	1400	LAY SEWER PIPE	15	11250.	
90	1200	INSPECT MANHOLES	1	800.	
100	1300	REMOVE TRENCHING EQUIPMENT	2	1400.	
110	1500	BACKFILL SEWER TRENCH	6	3600.	
120	5000	SEWER LINE COMPLETE	0	0.	
130	2110	SURVEY WATER LINE A	6	4000.	
140	2120	SURVEY WATER LINE B	5	3400.	
150	3000	UNDERGROUND ELECTRICAL	5	2500.	
160	4000	DRILL WATER WELL	12	7000.	
170	2310	TRENCH WATER LINE A	9	8800.	
180	2410	LAY PIPE FOR WATER LINE A	7	16800.	
190	2320	TRENCH WATER LINE B	16	15600.	
200	2510	BACKFILL WATER LINE A	2	900.	
210	2420	LAY PIPE FOR WATER LINE B	14	33600.	
220	2520	BACKFILL WATER LINE B	3	2850.	
230	3000	INSTALL WATER METERS	1	600.	
240	4000	SETWATERPUMP	2	1400.	
250	5000	PROJECT COMPLETE	0	0.	

SEQUENCE OF ACTIVITIES:

FROM	TO
10	20
20	30
30	40
40	50
40	60
50	70
60	80
70	90
80	90
80	110
80	100
90	120
100	120
110	120
120	130
120	160
120	150
120	140
130	170
140	190
150	230
160	240
170	180
170	190
180	200
180	210
190	210
200	220
210	220
220	250
230	250
240	250

PROJECT START DATE: APRIL 1, 2002
FIVE-DAY WORK WEEK
NO ASSIGNED HOLIDAYS

FIGURE 8-6
Computer Input Data File for Sewer and Water Lines Project.

** ACTIVITY SCHEDULE **

PROJECT: SEWER AND WATER LINES
SCHEDULE FOR ALL ACTIVITIES

** PAGE 1 **
ACTIVITY SCHEDULE

	ACTIVITY NUMBER	ACTIVITY DESCRIFTION	DURA- TION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT	FREE FLOAT
C	10	MOVE ON SITE	3	1APR2002 1	3APR2002 3	1APR2002 1	3APR2002 3	0	0
C	20	SURVEY SEWER LINES	4	4APR2002 4	9APR2002 7	4APR2002 4	9APR2002 7	0	0
C	30	EXCAVATE FOR MANHOLES	3	10APR2002 8	12APR2002 10	10APR2002 8	12APR2002 10	0	0
C	40	INSTALL MANHOLE FORMWORK	5	15APR2002 11	19APR2002 15	15APR2002 11	19APR2002 15	0	0
	50	PLACE CONCRETE MANHOLES	5	22APR2002 16	26APR2002 20	23MAY2002 39	29MAY2002 43	23	0
C	60	TRENCH SEWER LINE	10	22APR2002 16	3MAY2002 25	22APR2002 16	3MAY2002 25	0	0
	70	STRIP MANHOLE FORMWORK	2	29APR2002 21	30APR2002 22	30MAY2002 44	31MAY2002 45	23	18
C	80	LAY SEWER PIPE	15	6MAY2002 26	24MAY2002 40	6MAY2002 26	24MAY2002 40	0	0
	90	INSPECT MANHOLES	1	27MAY2002 41	27MAY2002 41	3JUN2002 46	3JUN2002 46	5	5
	100	REMOVE TRENCHING EQUIPMENT	2	27MAY2002 41	28MAY2002 42	31MAY2002 45	3JUN2002 46	4	4
C	110	BACKFILL SEWER TRENCH	6	27MAY2002 41	3JUN2002 46	27MAY2002 41	3JUN2002 46	0	0
C EVENT	120	SEWER LINE COMPLETE	0	4JUN2002 47	4JUN2002 47	4JUN2002 47	4JUN2002 47	0	0
C	130	SURVEY WATER LINE A	6	4JUN2002 47	11JUN2002 52	4JUN2002 47	11JUN2002 52	0	0
	140	SURVEY WATER LINE B	5	4JUN2002 47	10JUN2002 51	18JUN2002 57	24JUN2002 61	10	10
	150	UNDERGROUND ELECTRICAL	5	4JUN2002 47	10JUN2002 51	1AUG2002 89	7AUG2002 93	42	0
	160	DRILL WATER WELL	12	4JUN2002 47	19JUN2002 58	22JUL2002 81	6AUG2002 92	34	0
	230	INSTALL WATER METERS	1	11JUN2002 52	11JUN2002 52	8AUG2002 94	8AUG2002 94	42	42
C	170	TRENCH WATER LINE A	9	12JUN2002 53	24JUN2002 61	12JUN2002 53	24JUN2002 61	0	0
	240	SET WATER PUMP	2	20JUN2002 59	21JUN2002 60	7AUG2002 93	8AUG2002 94	34	34
	180	LAY PIPE FOR WATER LINE A	7	25JUN2002 62	3JUL2002 68	8JUL2002 71	16JUL2002 77	9	9
C	190	TRENCH WATER LINE B	16	25JUN2002 62	16JUL2002 77	25JUN2002 62	16JUL2002 77	0	0
	200	BACKFILL WATER LINE A	2	4JUL2002 69	5JUL2002 70	2AUG2002 90	5AUG2002 91	21	21
C	210	LAY PIPE FOR WATER LINE B	14	17JUL2002 78	5AUG2002 91	17JUL2002 78	5AUG2002 91	0	0
C	220	BACKFILL WATER LINE B	3	6AUG2002 92	8AUG2002 94	6AUG2002 92	8AUG2002 94	0	0
C EVENT	250	PROJECT COMPLETE	0	8AUG2002 94	8AUG2002 94	8AUG2002 94	8AUG2002 94	0	0

END OF SCHEDULE

FIGURE *8-7*
Computer-Generated Activity Schedule for Sewer and Water Lines Project.

each activity in the sewer and water lines project is shown in the activity list of Figure 8-6.

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 8-8. A project manager may also print a bar chart for these activities as shown in Figure 8-9. 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

TABLE 8-4
CODING SYSTEM FOR SEWER AND WATER LINES PROJECT

Code Number X X X X

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 Lines	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

that have a second code digit number that is greater than "2" and less than "5" (reference Table 8-4).

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 8-5 illustrates the early start cost analysis calculations for the sewer and water lines project shown in Figure 8-5. 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.

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. A small microcomputer can perform all the calculations for cost analysis of a project with several hundred activities in less than two seconds.

```
****************************
**   ACTIVITY  SCHEDULE   **
****************************
```

PROJECT: SEWER AND WATER LINES
SCHEDULE FOR SEWER LINE ACTIVITIES ONLY

** PAGE 1 **
ACTIVITY SCHEDULE

	ACTIVITY NUMBER	ACTIVITY DESCRIPTION	DURA-TION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT	FREE FLOAT
C	20	SURVEY SEWER LINES	4	4APR2002 4	9APR2002 7	4APR2002 4	9APR2002 7	0	0
C	30	EXCAVATE FOR MANHOLES	3	10APR2002 8	12APR2002 10	10APR2002 8	12APR2002 10	0	0
C	40	INSTALLMANHOLEFORMWORK	5	15APR2002 11	19APR2002 15	15APR2002 11	19APR2002 15	0	0
	50	PLACE CONCRETE MANHOLES	5	22APR2002 16	26APR2002 20	23MAY2002 39	29MAY2002 43	23	0
C	60	TRENCH SEWER LINE	10	22APR2002 16	3MAY2002 25	22APR2002 16	3MAY2002 25	0	0
	70	STRIP MANHOLE FORMWORK	2	29APR2002 21	30APR2002 22	30MAY2002 44	31MAY2002 45	23	18
C	80	LAY SEWER PIPE	15	6MAY2002 26	24MAY2002 40	6MAY2002 26	24MAY2002 40	0	0
	90	INSPECT MANHOLES	1	27MAY2002 41	27MAY2002 41	3JUN2002 46	3JUN2002 46	5	5
	100	REMOVE TRENCHING EQUIPMENT	2	27MAY2002 41	28MAY2002 42	31MAY2002 45	3JUN2002 46	4	4
C	110	BACKFILL SEWER TRENCH	6	27MAY2002 41	3JUN2002 46	27MAY2002 41	3JUN2002 46	0	0

********** END OF SCHEDULE **********

FIGURE 8-8
Computer Printout of Sewer Line Activities Only (Sort of Activities List by Code Digit #1 Equal to One).

```
                              ********************
                              **   BAR  CHART   **
                              ********************

PROJECT: SEWER AND WATER LINES                                                                    **  PAGE 1  **
SCHEDULE FOR SEWER LINE ACTIVITIES ONLY                                                             BAR CHART

                                                  1        10        20        30        40        50        60
 ACTIVITY    DESCRIPTION               DURATION  1APR2002 12APR2002 26APR2002 10MAY2002 24MAY2002 7JUN2002 21JUN2002
                                                   +.........+.........+.........+.........+.........+.........+
 C     20    SURVEY SEWER LINES               4        *XXX
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
 C     30    EXCAVATE FOR MANHOLES            3            *XX
                                                   .    .    .    .    .    .    .    .    .    .    .    .
 C     40    INSTALL MANHOLE FORMWORK         5               *XXXX
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
       50    PLACE CONCRETE MANHOLES          5                    XXXXX-----------------------*----
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
 C     60    TRENCH SEWER LINE               10                    *XXXXXXXXX
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
       70    STRIP MANHOLE FORMWORK           2                         XX--------------------*-
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
 C     80    LAY SEWER PIPE                  15                              *XXXXXXXXXXXXXX
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
       90    INSPECT MANHOLES                 1                                             X----*
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
      100    REMOVE TRENCHING EQUIPMENT       2                                             XX--*-
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .
 C    110    BACKFILL SEWER TRENCH            6                                             *XXXXX
                                                   .    .    .    .    .    .    .    .    .    .    .    .    .

                                                   +.........+.........+.........+.........+.........+.........+
                                  WORK DAYS       1        10        20        30        40        50        60
                             CALENDAR DATES  1APR2002 12APR2002 26APR2002 10MAY2002 24MAY2002 7JUN2002 21JUN2002
```

FIGURE 8-9
Computer-Generated Bar Chart for Sewer Line Activities Only.

TABLE 8-5
CALCULATIONS FOR PROJECT COSTS PER DAY ON AN EARLY START BASIS
TOTAL PROJECT DURATION = 94 WORKING DAYS
TOTAL PROJECT COST = $147,500.00

Day	%-Time	Activities In progress		Project cost/day	Cumulative project cost	% Cost
1	1.06%	Act. 10	$1,400/3 = $466.67/Day	$466.67	$466.67	0.32%
2	2.12%	" "	" = "	"	$933.33	0.63%
3	3.19%	" "	" = "	"	$1,400.00	0.95%
4	4.25%	Act. 20	$2,700/4 = $675.00/Day	$675.00	$2,075.00	1.41%
5	5.32%	" "	" = "	"	$2,750.00	1,86%
6	6.38%	" "	" = "	"	$3,425.00	2.32%
7	7.45%	" "	" = "	"	$4,100.00	2.78%
8	8.51%	Act. 30	$3,500/3 = $1,167.67/Day	$1,167.67	$5,267.67	3.57%
9	9.57%	" "	" = "	"	$6,433.33	4.36%
10	10.63%	" "	" = "	"	$7,600.00	5.15%
11	11.70%	Act. 40	$6,000/5 = $1,200.00/Day	$1,200.00	$8,800.00	5.97%
12	12.77%	" "	" = "	"	$10,000.00	6.78%
13	13.83%	" "	" = "	"	$11,200.00	7.59%
14	14.89%	" "	" = "	"	$12,400.00	8.41%
15	15.96%	" "	" = "	"	$13,600.00	9.22%
16	17.02%	Act. 50	$4,700/5 = $940.00/Day			
		Act. 60	$12,600/10 = $1,260.00/Day	$2,200.00	$15,800.00	10.71%
17	18.09%	" "	" = "	"	$18,000.00	12.20%
18	21.70%	" "	" = "	"	$20,200.00	13.69%
19	20.21%	" "	" = "	"	$22,400.00	15.19%
20	21.28%	" "	" = "	"	$24,600.00	16.68%
21	22.34%	Act. 60	$12,600/10 = $1,260.00/Day			
		Act. 70	$2,100/2 = $1,050.00/Day	$2,310.00	$25,910.00	18.24%
⋮	⋮				⋮	⋮
94	100.0%				$147,500.00	100.0%

Figure 8-10 is a computer printout of the daily distribution of costs for the calculations illustrated in Table 8-5. 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 8-10, 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.

A tabular format of the distribution of costs on an early start, late start, and target basis is presented in Figure 8-11. The target scheduled costs are average values between the early and late start schedules. The right hand two columns of Figure 8-11 show the percentage-cost and percentage-time values for the target schedule. As shown in the figure there is a non-linear relationship between the time and cost for a 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

```
*********************************
**  COST EVERY DAY HISTOGRAM  **
*********************************

PROJECT :SEWER AND WATER LINES                                   **  PAGE 1  **
DISTRIBUTION OF PROJECT COSTS                                 - For all activities -
BASIS: EARLY START
```

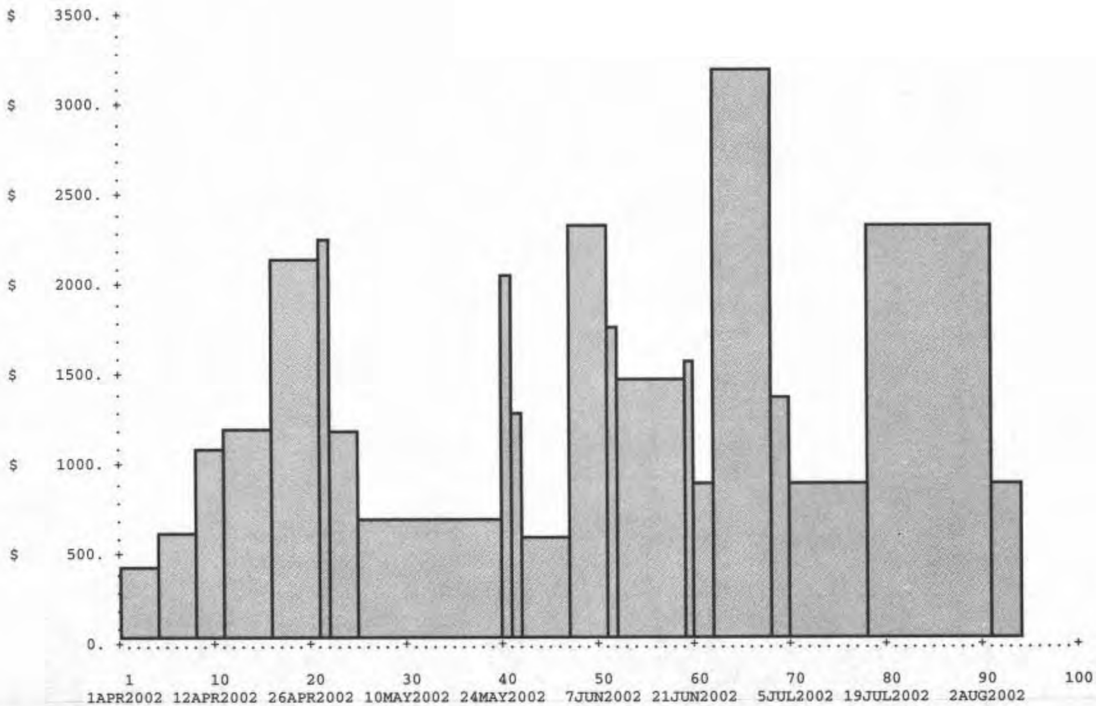


FIGURE 8-10
Computer Printout of Daily Distribution of Costs for Sewer and Water Lines Project.

** DAILY COST SCHEDULE **

PROJECT: SEWER AND WATER LINES
DAILY DISTRIBUTION OF COST FOR ALL ACTIVITIES
START DATE: 1 APR 2002 FINISH DATE: 8 AUG 2002

** DAILY COST SCHEDULE FOR ALL ACTIVITIES **
** EARLY START - LATE START - TARGET **

WORK DAY	CALENDAR DATE	EARLY START		LATE START		TARGET SCHEDULE			
		COSTIDAY	CUMULATIVE COST	COST/DAY	CUMULATIVE COST	COST/DAY	CUMULATIVE COST	%TIME	%COST
1	1APR2002	$ 467.	$ 467.	$ 467.	$ 467.	$ 467.	$ 467.	1.1%	.3%
2	2APR2002	$ 467.	$ 933.	$ 467.	$ 933.	$ 467.	$ 933.	2.1%	.6%
3	3APR2002	$ 467.	$ 1400.	$ 467.	$ 1400.	$ 467.	$ 1400.	3.2%	.9%
4	4APR2002	$ 675.	$ 2075.	$ 675.	$ 2075.	$ 675.	$ 2075.	4.3%	1.4%
5	5APR2002	$ 675.	$ 2750.	$ 675.	$ 2750.	$ 675.	$ 2750.	5.3%	1.9%
6	8APR2002	$ 675.	$ 3425.	$ 675.	$ 3425.	$ 675.	$ 3425.	6.4%	2.3%
7	9APR2002	$ 675.	$ 4100.	$ 675.	$ 4100.	$ 675.	$ 4100.	7.4%	2.8%
8	10APR2002	$ 1167.	$ 5267.	$ 1167.	$ 5267.	$ 1167.	$ 5267.	8.5%	3.6%
9	11APR2002	$ 1167.	$ 6433.	$ 1167.	$ 6433.	$ 1167.	$ 6433.	9.6%	4.4%
10	12APR2002	$ 1167.	$ 7600.	$ 1167.	$ 7600.	$ 1167.	$ 7600.	10.6%	5.2%
11	15APR2002	$ 1200.	$ 8800.	$ 1200.	$ 8800.	$ 1200.	$ 8800.	11.7%	6.0%
12	16APR2002	$ 1200.	$ 10000.	$ 1200.	$ 10000.	$ 1200.	$ 10000.	12.8%	6.8%
13	17APR2002	$ 1200.	$ 11200.	$ 1200.	$ 11200.	$ 1200.	$ 11200.	13.8%	7.6%
14	18APR2002	$ 1200.	$ 12400.	$ 1200.	$ 12400.	$ 1200.	$ 12400.	14.9%	8.4%
15	19APR2002	$ 1200.	$ 13600.	$ 1200.	$ 13600.	$ 1200.	$ 13600.	16.0%	9.2%
16	22APR2002	$ 2200.	$ 15800.	$ 1260.	$ 14860.	$ 1730.	$ 15330.	17.0%	10.4%
17	23APR2002	$ 2200.	$ 18000.	$ 1260.	$ 16120.	$ 1730.	$ 17060.	18.1%	11.6%
18	24APR2002	$ 2200.	$ 20200.	$ 1260.	$ 17380.	$ 1730.	$ 18790.	19.1%	12.7%
19	25APR2002	$ 2200.	$ 22400.	$ 1260.	$ 18640.	$ 1730.	$ 20520.	20.2%	13.9%
20	26APR2002	$ 2200.	$ 24600.	$ 1260.	$ 19900.	$ 1730.	$ 22250.	21.3%	15.1%
21	29APR2002	$ 2310.	$ 26910.	$ 1260.	$ 21160.	$ 1785.	$ 24035.	22.3%	16.3%
↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
85	26JUL2002	$ 2400.	$ 130250.	$ 2983.	$ 120767.	$ 2692.	$ 125508.	90.4%	85.1%
86	29JUL2002	$ 2400.	$ 132650.	$ 2983.	$ 123750.	$ 2692.	$ 128200.	91.5%	86.9%
87	30JUL2002	$ 2400.	$ 135050.	$ 2983.	$ 126733.	$ 2692.	$ 130892.	92.6%	88.7%
88	31JUL2002	$ 2400.	$ 137450.	$ 2983.	$ 129717.	$ 2692.	$ 133583.	93.6%	90.6%
89	1AUG2002	$ 2400.	$ 139850.	$ 3483.	$ 133200.	$ 2942.	$ 136525.	94.7%	92.6%
90	2AUG2002	$ 2400.	$ 142250.	$ 3933.	$ 137133.	$ 3167.	$ 139692.	95.7%	94.7%
91	5AUG2002	$ 2400.	$ 144650.	$ 3933.	$ 141067.	$ 3167.	$ 142858.	96.8%	96.9%
92	6AUG2002	$ 950.	$ 145600.	$ 2033.	$ 143100.	$ 1492.	$ 144350.	97.9%	97.9%
93	7AUG2002	$ 950.	$ 146550.	$ 2150.	$ 145250.	$ 1550.	$ 145900.	98.9%	98.9%
94	8AUG2002	$ 950.	$ 147500.	$ 2250.	$ 147500.	$ 1600.	$ 147500.	100.0%	100.0%

END OF DAILY COST SCHEDULE

FIGURE 8-11
Computer Printout of Daily Costs for All Activities of Sewer and Water Lines Project.

over which costs may be distributed for the project (reference Figure 8-12). 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 9 discusses linking accomplished work to the S-curve.

The type of reports presented in this section are typical examples of the reports that can be obtained from the many computer software programs that are available.

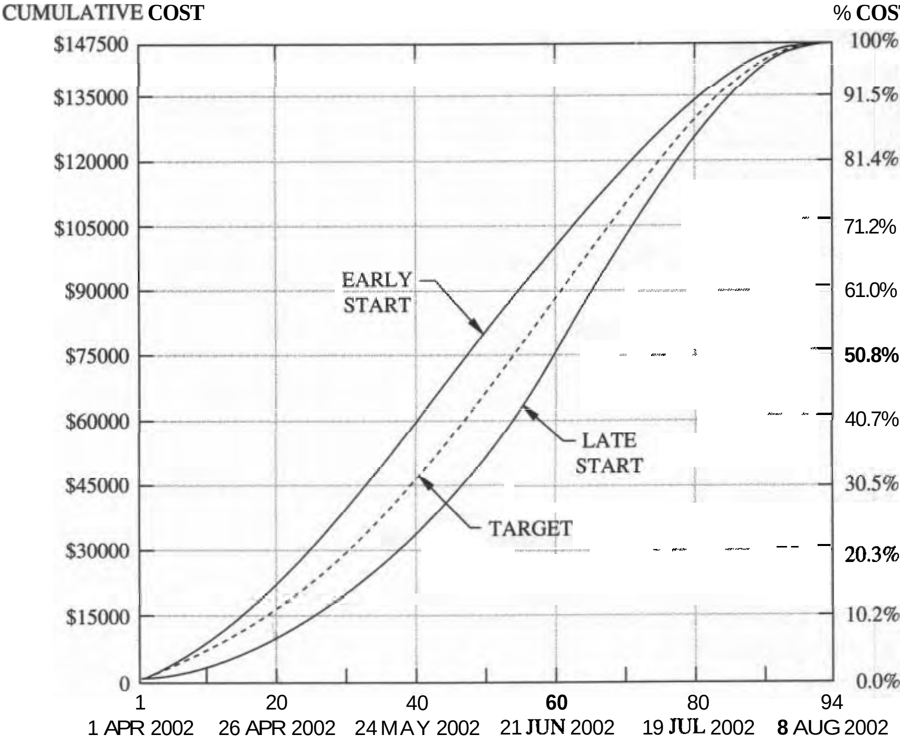


FIGURE 8-12
Illustrative S-Curve for Cumulative Cost Curve on an Early Start, Late Start, and Target Basis.

The only input data that a project manager must prepare, to obtain the described analyses, are shown in Figure 8-6.

RESOURCE ALLOCATIONS FOR DESIGN

Efficient utilization of resources is critical to successful 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 the correct expertise is available when needed. Ge'nerally, 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 plan 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 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 job-site 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 plan should include material and equipment required by the construction work force.

Labor represents a major cost of construction. The labor force on the job operates construction equipment and installs the materials. A resource allocation plan is required to ensure high efficiency and productivity during construction. The project manager can resource load the project plan 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 resource plan can be used as a tool to ensure a relatively uniform distribution of labor on the project. Figure 8-13 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 8-13 shows irregularity in the distribution of workers per day during the middle of the project.

Figure 8-14 illustrates the same project as Figure 8-13, except Activity F is started one day later and Activity H is started two days earlier. The lower portion of Figure 8-14 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 distribution 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 8-14.

PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT)

In the Critical Path Method 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 four weeks, the time to perform a soil investigation to gather and test soil samples may be two weeks, or the time to erect forms for concrete may be three 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 a 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.

Activity Number	Duration in Days	Numbers 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	6	8	6														
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	6	3	6														18	18	18	18	18	18	18	18				
I	11	2	4														8	8	8	8	8	8	8	6	6	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	35	35	38	38	26	26	35	35	17	17	11	3

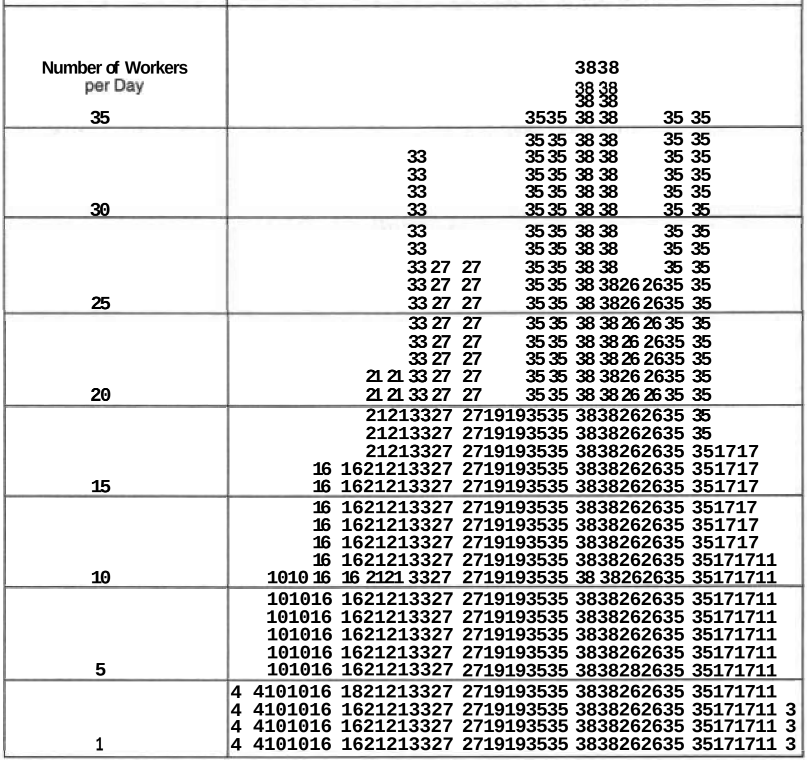


FIGURE 8-13
Irregular Distribution of Labor.

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												16	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	21	27	27	37	37	38	38	38	38	38	26	17	17	17	17	11	3

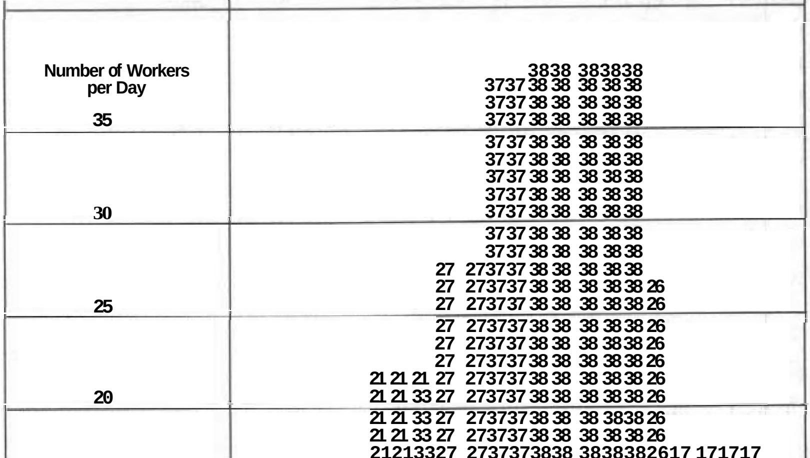


FIGURE 8-14
Distribution of Labor after Starting Activity F Two Days Later and Activity H Two Days Earlier.

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 **a.** 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:

$$\nu = \sigma^2 = \left(\frac{(b - a)}{6}\right)^2$$

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 **a** is the square root of the sum of the activities ahead of the event. Thus, the **a** 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 **a** is calculated with the following equation:

$$\sigma_{TE} = \sqrt{\nu_{1\text{-}2} + \nu_{2\text{-}3} + \nu_{3\text{-}4} + \cdots + \nu_{i\text{-}j}}$$

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.

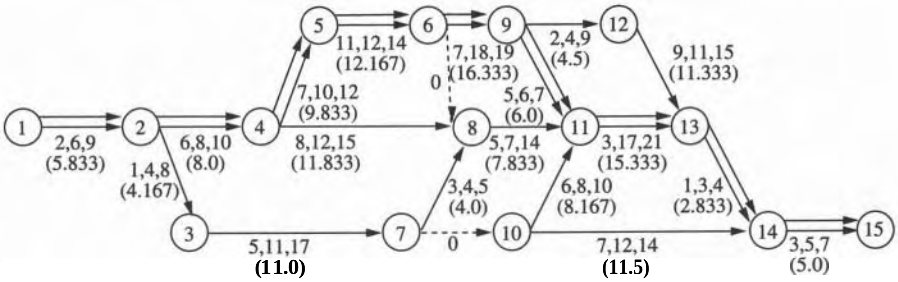
TABLE 8-6
PERT PROBABILITY TABLE

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 8-6 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.

Example 8-1

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 optimistic 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 a of event 15. The value of a 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:

$$\sigma_{TE} = \sqrt{\nu_{1\text{-}2} + \nu_{2\text{-}4} + \nu_{4\text{-}5} + \nu_{5\text{-}6} + \nu_{6\text{-}9} + \nu_{9\text{-}11} + \nu_{11\text{-}13} + \nu_{13\text{-}14} + \nu_{14\text{-}15}}$$

$$= \sqrt{\left(\frac{9-2}{6}\right)^2 + \left(\frac{10-6}{6}\right)^2 + \left(\frac{12-7}{6}\right)^2 + \left(\frac{14-11}{6}\right)^2 + \left(\frac{19-7}{6}\right)^2 + \left(\frac{7-5}{6}\right)^2 + \left(\frac{21-3}{6}\right)^2 + \left(\frac{4-1}{6}\right)^2 + \left(\frac{7-3}{6}\right)^2}$$

$$= \sqrt{1.3611 + 0.4444 + 0.6944 + 0.2500 + 4.0000 + 0.1111 + 9.0000 + 0.2500 + 0.4444}$$

$$= \sqrt{16.5554}$$

$$= 4.07$$

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, **i.e.,** later that 81.3 days. The probability of completing the project by the eighty-fourth day can be calculated as follows:

$$z = \frac{T_S - T_E}{\sigma_{TE}}$$

$$= \frac{84.0 - 81.3}{4.07}$$

$$= 0.663$$

From Table 8-6, 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 eighty-fourth 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:

$$z = \frac{T_S - T_E}{\sigma_{TE}}$$

$$= \frac{78.0 - 81.3}{4.07}$$

$$= -0.811$$

From Table 8-6, 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 seventy-eighth 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 8-6 is 0.5333:

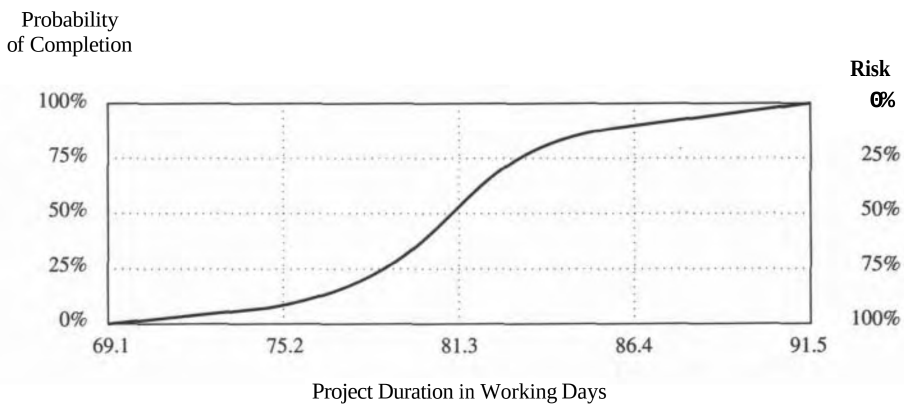
$$z = \frac{T_S - T_E}{\sigma_{TE}}$$

$$0.533 = \frac{T_S - 81.3}{4.07}$$

$$T_S = 83.5 \text{ days}$$

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.



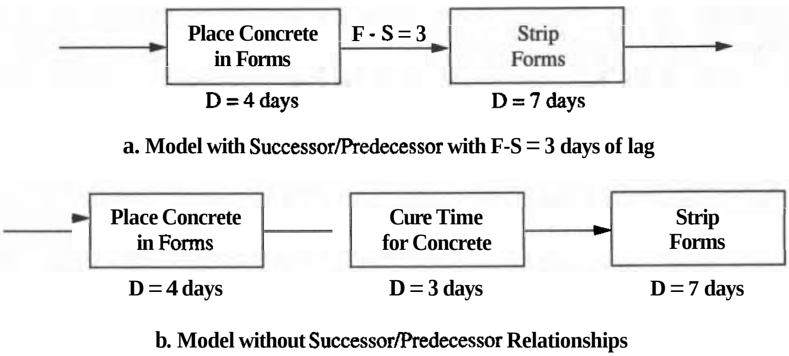
This analysis is based on a **a** for event **15** based on the critical path activities. A full analysis is more complex if all near-critical paths are analyzed. For example, it is possible to have another path through the PERT diagram that is near critical, which would yield a shorter T_E for event 15 and a higher value for **a** due to larger variances in the activities in the non-critical path.

SUCCESSOWPREDECESSOR 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 two-day lag means the start of



a. Model with Successor/Predecessor with F-S = 3 days of lag

b. Model without Successor/Predecessor Relationships

FIGURE 8-15
Comparison of CPM Diagrams with and without a Finish-to-Start (F-S) Successor/Predecessor Relationship.

the successor activity cannot occur until two 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.

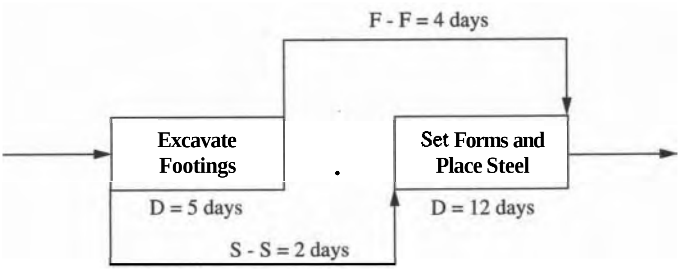
A model of the F-S with lag relationship is illustrated in Figure 8-15*a*. An alternative of this model is shown in Figure 8-15*b*, which shows the same results without using the F-S with lag relationship. Thus, adding one intermediate activity between the successor and predecessor activities clearly produces the same results as the F-S relationship.

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 8-16a illustrates S-S and F-F with lag relationships between two activities. Figure 8-16b 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.

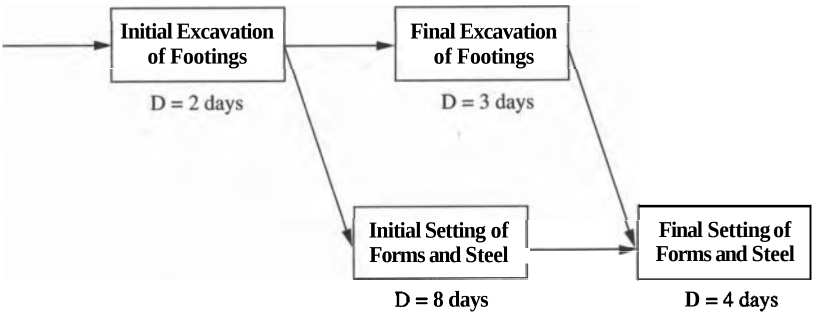
As previously stated, there is no practical application of the S-F relationship in the engineering and construction industry. Some computer scheduling software packages do not allow the use of the S-F relationship.

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



a. Model with SuccessorlPredecessor S - S = 2 days and F - F = 4 days of lag



b. Model without SuccessorlPredecessorRelationships

FIGURE 8-16
Comparison of CPM Diagrams with and without a Start-to-Start (S-S) Successor/Predecessor Relationship.

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 8-17 illustrates problems that can occur in calculating the start and finish dates when modeling multiple successor/predecessor activity relationships. Each

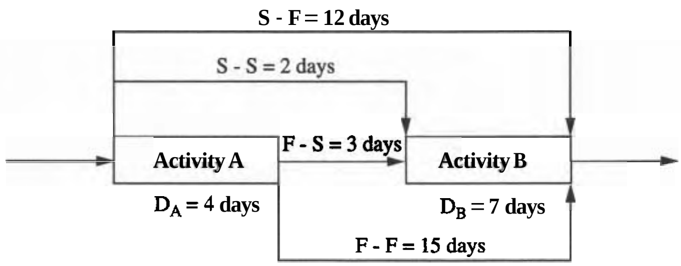


FIGURE 8-17
Example of Multiple Successor/Predecessor Activity Relationships.

successorlpredecessorpath must be evaluated to determine start and finish times. A forward pass for the activities in Figure 8-17 shows Activity B can start as early as two days or as late as seven days after the start of Activity A, depending on the path chosen. Also, depending on the successorlpredecessorpath 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 8-18 is a **CPM** diagram with successorlpredecessorrelationships of construction work related to foundation construction work. Figure 8-19 is a pure **CPM** diagram, without successorlpredecessor activity relationships, for the same construction work. These figures are presented to illustrate the complexity of successorlpredecessorcalculations. As shown in Figure 8-18, 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.

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 8-18 indicates that all the activities are critical, **although** that is not the case. Figure 8-19 is a pure **CPM** diagram for the same work shown in Figure 8-18. Figure 8-19 eliminates the S-S and F-F relationships by splitting activities to show the actual sequencing of work. As shown in Figure 8-19 much of the work is actually non-critical, compared to that of Figure 8-18. For example, the network of Figure 8-19 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 8-19 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 successor1 predecessor activity relationships.

Unfortunately, there is no industry standard to define how to finalize the **early/late** starts and finishes using successorlpredecessors relationships with lags. Each computer software developer defines the algorithm used by his or her software

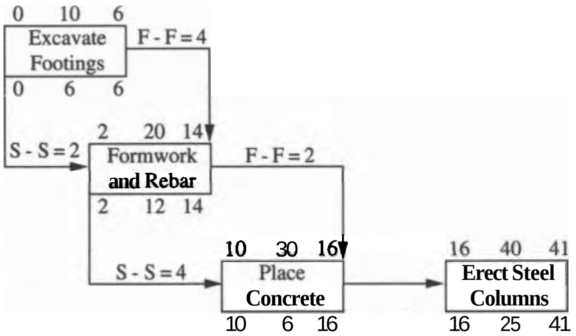


FIGURE 8-18
Successor/Predecessor Activity Relationships. (Note all activities appear critical.)

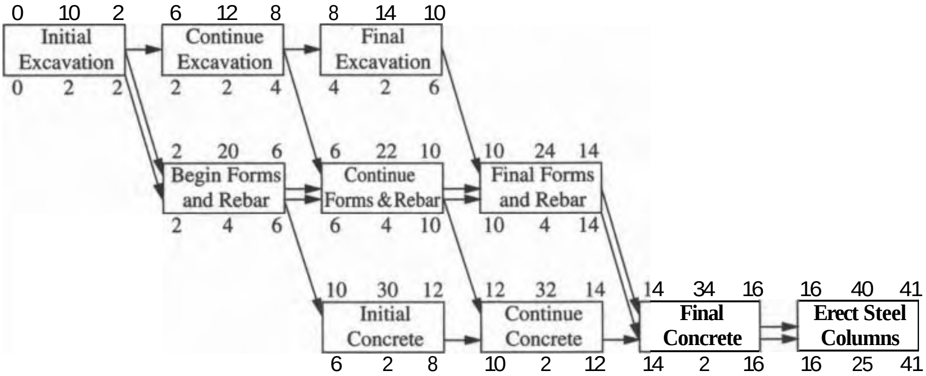


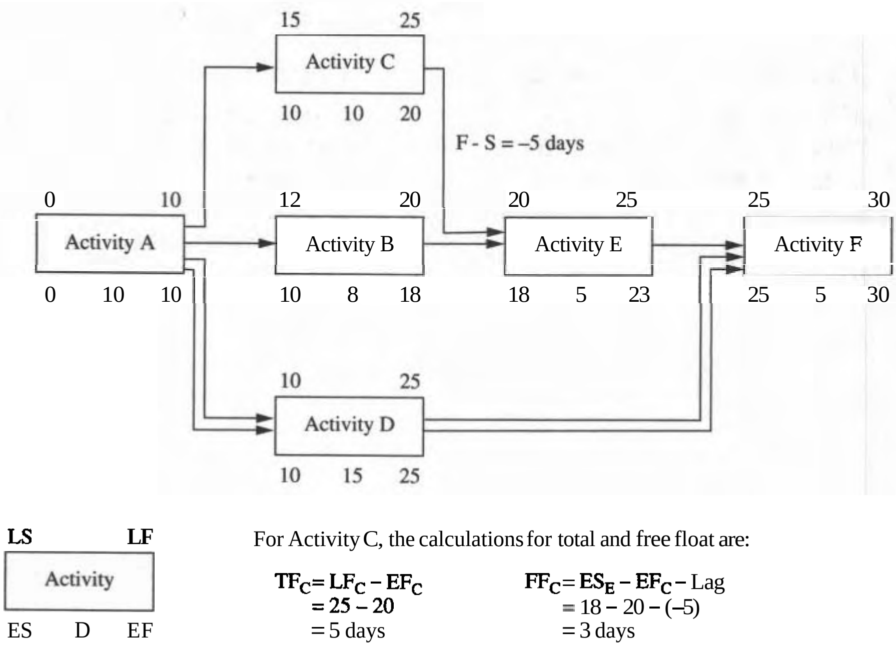
FIGURE 8-19
Pure CPM Diagram without Successor/Predecessor Activity Relationships. (Double arrows denote path of critical activities: 10, 20, 22, 24, 34, and 40.)

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. Therefore, take extreme caution when using successor/predecessor activity relationships because serious problems can arise. To prevent these problems, a pure CPM diagram can be developed without successor/predecessor relationships by simply adding additional activities. Although additional activities may appear as a disadvantage, adding additional activities provides a clear understanding of the sequence of work, thus preventing confusion and misunderstandings of the project schedule.

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 8-2: Finish-to-Start Activity Relationships

Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activity 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 calculations 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

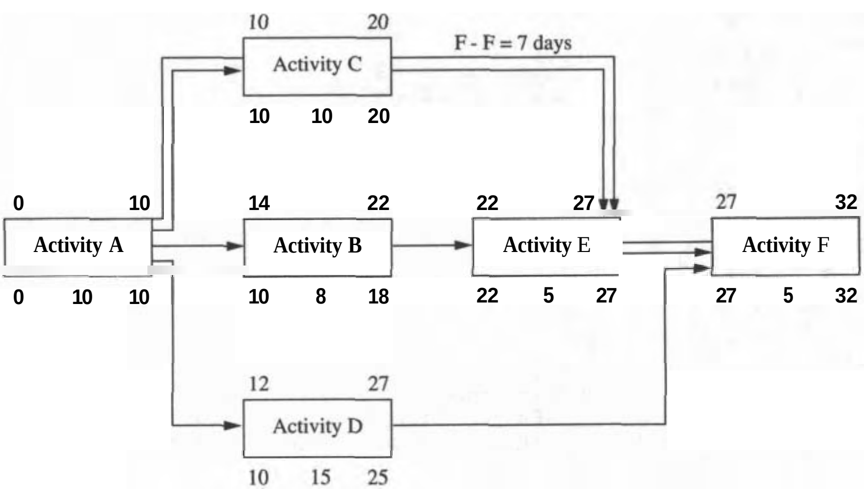
*Denotes critical activities.

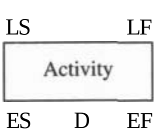
Based on the forward and backward pass calculations, the critical path is through Activities A, D, and F. Note the impact on the schedule and possible confusion due to the F-S relationship with five days of negative lag between Activity C and E. The EF_C is 20 days (governed by the equation $EF_C = ES_C + D = 10 + 10 = 20$). 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. Acomputer 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 $FF_C = ES_E - EF_C - \text{Lag} = 18 - 20 - (-5) = 3$ days. However, a review of the diagram shows the $EF_C = 20$, which is greater than the $ES_E = 18$. Thus, the use of F-S relationships with negative lag is not recommended.

Example 8-3: Finish-to-Finish Activity Relationships

Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activity 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 calculations for total and free float are:

$$TF_C = LF_C - EF_C = 20 - 20 = 0 \text{ days}$$

$$FF_C = LF_E - LF_C - \text{Lag} = 27 - 20 - 7 = 0 \text{ days}$$

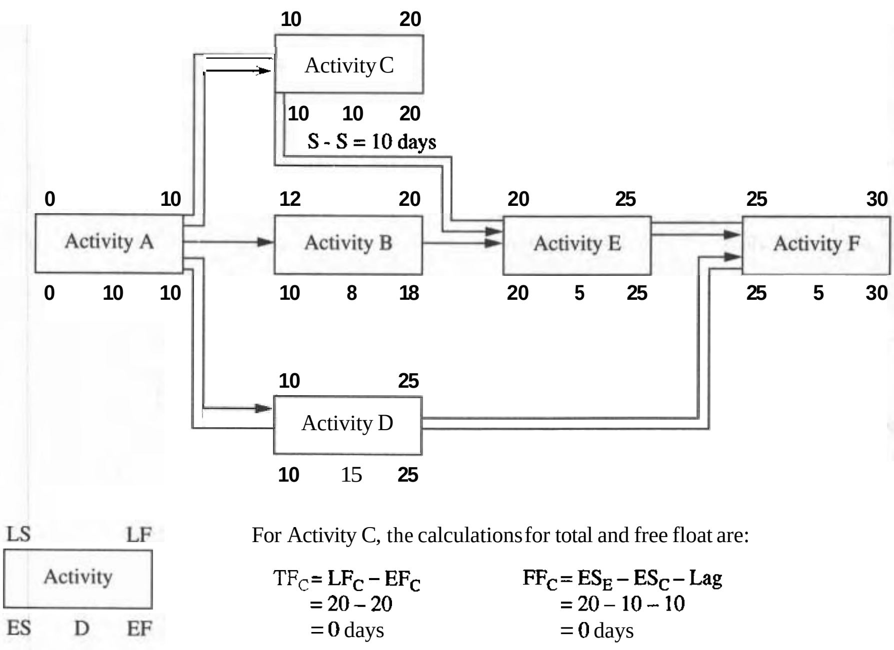
Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	14	22	4	4
C*	10	10	20	10	20	0	0
D	15	10	25	12	27	2	2
E*	5	22	27	22	27	0	0
F*	5	27	32	27	32	0	0

'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 8-4: Start-to-Start Activity Relationships

Calculate the start, finish, and float for each activity in the following CPM precedence network diagram. Activity 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 calculations for total and free float are:

$$TF_C = LF_C - EF_C = 20 - 20 = 0 \text{ days}$$

$$FF_C = ES_E - ES_C - Lag = 20 - 10 - 10 = 0 \text{ days}$$

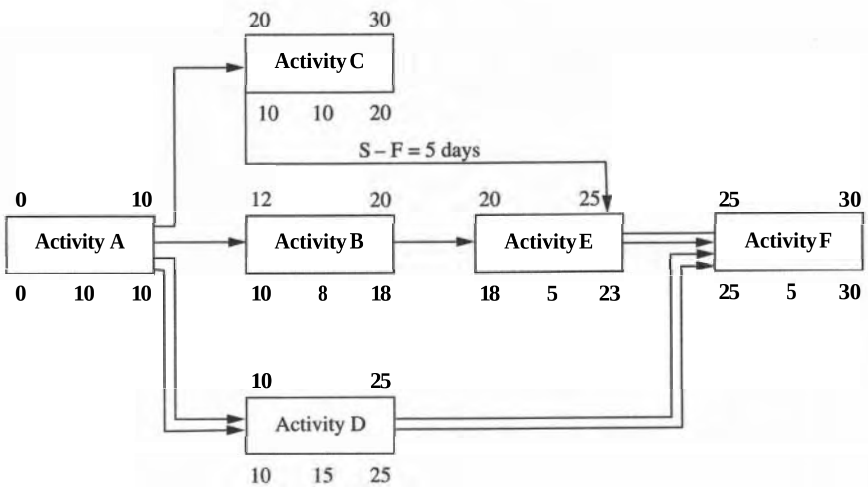
Activity	Duration	Early start	Early finish	Late start	Late finish	Total float	Free float
A*	10	0	10	0	10	0	0
B	8	10	18	12	20	2	2
C*	10	10	20	10	20	0	0
D*	15	10	25	10	25	0	0
E*	5	20	25	20	25	0	0
F*	5	25	30	25	30	0	0

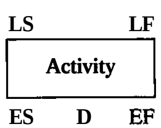
***Denotes critical activities.**

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 Activity C and E.

Example 8-5: 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 Activity 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 calculations 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.

QUESTIONS FOR CHAPTER 8—PROJECT SCHEDULING

1 One of the obvious purposes of project planning and scheduling is to complete a project on time. Identify other benefits that can be derived from good project planning. Also describe typical problems that can be prevented by good planning and scheduling.

2 A list of activities that are required to complete a project is shown below. Draw a CPM precedence diagram for the project and calculate the project schedule. Provide the schedule in a tabular form, showing early/late starts and finishes as well as the total and free float for each activity. Denote the critical path on the network.

Activity	Duration	Cost	Preceded by	Followed by
A	2 days	$500	None	B, C, D
B	3 days	$900	A	E
C	4 days	$1,600	A	F
D	5 days	$500	A	G
E	7 days	$1,400	B	H
F	7 days	$1,500	C	I, L
G	8 days	$2,400	D	J, K
H	4 days	$800	E	L
I	2 days	$1,000	F	N
J	12 days	$3,600	G	M, O
K	5 days	$2,000	G	P
L	6 days	$1,200	F, H	Q
M	2 days	$900	J	N
N	2 days	$700	I, M	S
O	6 days	$1,800	J	R, T
P	4 days	$1,200	K	T
Q	4 days	$2,000	L	U
R	4 days	$1,600	O	S
S	2 days	$1,400	N, R	V
T	9 days	$1,800	O, P	V
U	2 days	$1,200	Q	V
V	3 days	$300	S, T, U	None

3 Perform a cost analysis based on an early start and late start schedule for the project in Question 2. Plot the S-curve for the early and late start costs. Show costs on the left-hand ordinate and percent costs on the right-hand. Along the abscissa, show the time in working days and in percentage of project duration.

4 Describe advantages and disadvantages of each of the two basic techniques of project scheduling: bar charts and CPM networks. Include situations most appropriate for each of the two techniques.

5 Provide a brief summary of the responsibilities of the owner, designer, and contractor related to project planning and scheduling. Describe how the schedule of each party should be related, including the advantages and disadvantages of maintaining one common schedule for a project.

6 A project manager is usually assigned the responsibility of either managing a single large project or many small projects at a time. Describe the different approaches to planning and scheduling that must be used by these two types of project managers.

7 Describe the purpose and use of a coding system for activities in a CPM project schedule. Include factors that should be considered in the development of the coding system and describe how the coding system can relate to the work breakdown structure, organizational breakdown structure, and the cost breakdown structure.

8 The data for the CPM diagram for a project are shown below. Perform a cost analysis for the project and present the results in tabular form showing the daily distribution costs on an early start, late start, and target schedule. Plot the three S-curves on one graph to show the results of your analysis.

Activity	Duration	Cost	Preceded by	Followed by
A	2 days	$1,200	None	B, C, D
B	3 days	$3,300	A	E
C	8 days	$12,000	A	F
D	6 days	$18,000	A	F, G, H
E	8 days	$8,000	B	J
F	9 days	$27,000	C, D	K
G	12 days	$7,200	D	K, L, M
H	5 days	$5,000	D	I
I	3 days	$12,000	H	M
J	2 days	$1,600	E	N, R
K	5 days	$6,000	F, G	R
L	1 day	$1,500	G	O
M	2 days	$4,000	G, I	P, R
N	2 days	$8,000	J	Q
O	2 days	$1,200	L	R
P	4 days	$5,200	M	S
Q	2 days	$6,000	N	T
R	7 days	$7,000	J, K, M, O	V
S	2 days	$2,800	P	U
T	1 day	$5,000	Q	V
U	3 days	$3,000	S	V
V	5 days	$10,000	R, T, U	None

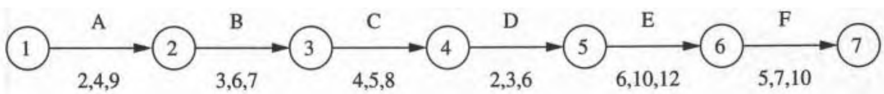
9 The bar chart shown on the next page is the original baseline schedule for a project that must be completed in 25 working days. The schedule was developed without regard to the distribution of labor on the project. The number of crews and the number of workers in each crew are shown for each activity.

a Evaluate the allocation of labor by preparing a histogram of the distribution of labor, similar to Figure **8**-13.

b Assume that the completion date of **25** working days cannot be changed and that the start of Activity A and finish of Activity K cannot be changed. The start time for the remaining activities can be delayed a maximum of **2** days. Reschedule the project to reduce any irregularity in the distribution of labor, as illustrated in Figures **8-13** and **8-14.**

Activity Number	Duration in Days	Workers 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	3	1	4	X X X				
B	7	2	3	X X	X X X X X			
C	9	1	2	X	X X X X X	X X X		
D	7	2	5	X	X X X X X	X		
E	8	1	4		X X X X	X X X X		
F	10	3	4		X X	X X X X X	X X X	
G	9	1	5		X	X X X X X	X X X	
H	8	3	6			X X	X X X X X	X
I	11	2	4			X X	X X X X X	X X X X
J	4	3	2				X	X X X
K	6	1	3				X	X X X X X

10 Below are the critical activities of a PERT diagram. The optimistic time ***(a)***, most likely time (m), and pessimistic time (b) are shown at the bottom of each activity. Calculate the most likely time (t_e) for each activity. What is the optimistic, pessimistic, and expected time for completing the project? What is the probability that this project can be completed in **37** days? What is the probability that this project will be completed by the thirty-second day? For a **99%** probability, what is the expected number of days for completion? For a 1% probability, what is the expected number of days for completion?



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9

TRACKING WORK

CONTROL SYSTEMS

Effective project management requires planning, measuring, evaluating, forecasting, and controlling all aspects of a project: quality and quantity of work, costs, and schedules. An all encompassing project plan must be defined before starting a project; otherwise there is no basis for control. 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 plan must be developed with input from people who will be performing the work, and it must be communicated to all participants. The tasks, costs, and schedules of the project plan establish the benchmarks and check-points that are necessary for comparing actual accomplishments to planned accomplishments, so the progress of a project can be measured, evaluated, and controlled.

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.

To be effective, a project control system 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 interpret the results that are obtained, or they are too limited 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 to all participants in a project; so it will serve as a tool for project improvement rather than reporting flaws that irritate people.

Since the introduction of small personal computers in the early 1980s, the automation of the concept of an integrated project control system has become widely discussed. Many papers have been written that describe different, but similar, approaches to integrated project control systems. Common among the approaches is development of a well-defined work breakdown structure (WBS) as a starting point in the system. 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 Critical Path Method (CPM) is used to develop the overall project schedule from the WBS by integrating and sequencing the work in accordance with the work packages. A coding system is designed that identifies each component of the WBS so information from the WBS can be related to the project control system. To control costs the WBS is linked to the cost breakdown structure (CBS) by the code of accounts. Likewise, the WBS is linked to the organizational breakdown structure (OBS) to coordinate personnel to keep the project on schedule. A coding system allows 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 develop 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 upon the completeness of the WBS.

The products of design are production drawings and specifications. As discussed in Chapter 8, 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 9-1 is used to develop the CPM diagram in Figure 9-2. This EPC project is an expansion of the design project presented in Chapter 8, 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.

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 9-2, 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.

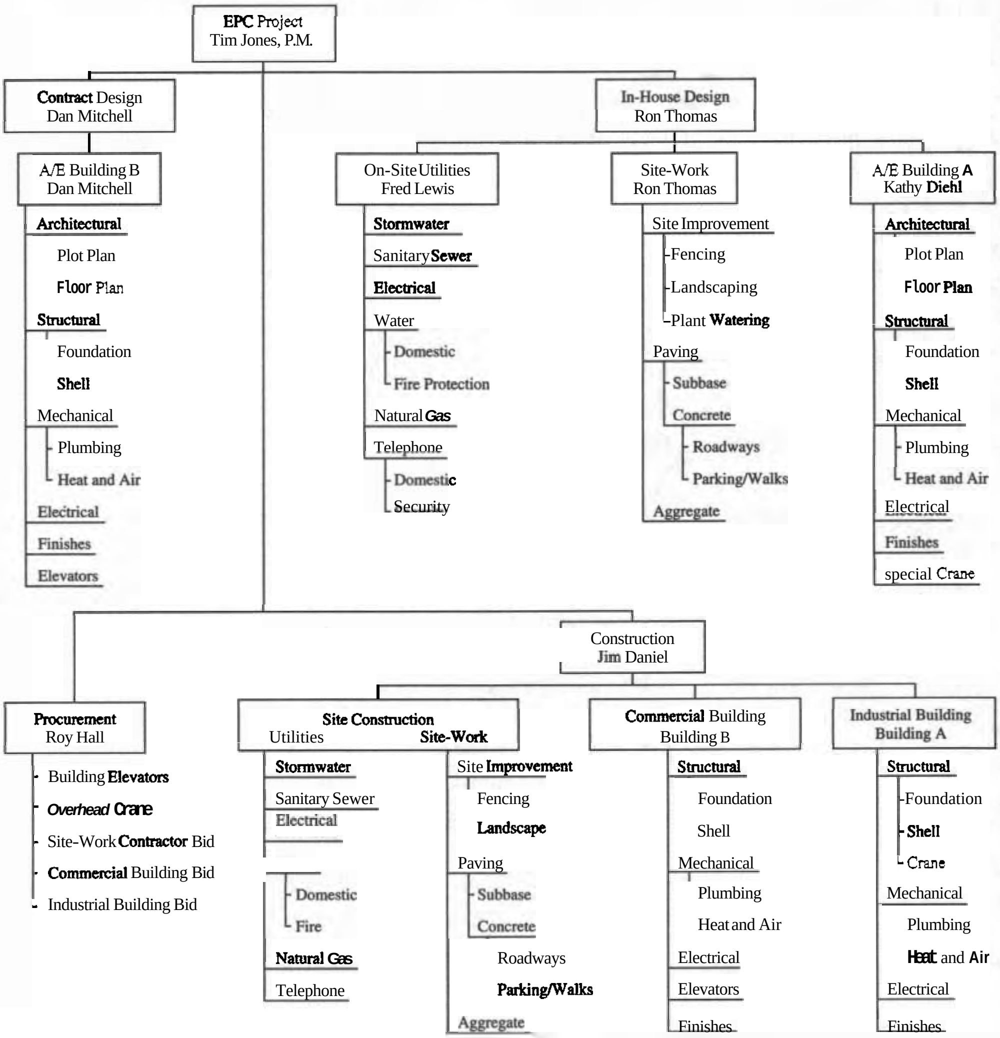


FIGURE 9-1
WBS for EPC of Service Facility Project.

CODING SYSTEM FOR PROJECT REPORTS

A coding system can be developed that identifies each component of a project to allow the sorting of information in order to produce a variety of reports for project monitoring and control. 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 9-1 is an illustrative example of a simple 4-digit coding system for the project shown in Figure 9-2.

TABLE 9-1
CODING SYSTEM FOR THE PROJECT IN FIGURE 9-2

Code Number X X X X

Digit 1 – Project phases	Digit 2 – Facilities	Digit 3 – Disciplines	Digit 4 – Team Members
0 Unassigned	0 Unassigned	0 Unassigned	0 Unassigned
1 In-house engineering	1 Grading/subbase	1 Architectural	1 Tim Jones
2 Contract design	2 Concrete paving	2 Civil	2 Dan Mitchell
3 Vendor procurement	3 Aggregate parking	3 Structural	3 Ron Thomas
4 Contract procurement	4 Stormwater sewer	4 Mechanical	4 Fred Lewis
5 Site-work construction	5 Sanitary sewer	5 Electrical	5 Kathy Diehl
6 Office Building	6 Underground utilities	6 Landscape	6 Roy Hall
7 Industrial building	7 Building A	7 Project engineering	7 Jim Daniel
8 Unassigned	8 Building B	8 Unassigned	8 Unassigned
9 Unassigned	9 Landscape	9 Unassigned	9 Unassigned
WBS		OBS	

Table 9-1 can be used to assign a code number that is unique to each activity in the CPM diagram of Figure 9-2 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 Kathy Diehl. Table 9-2 is a list of the code numbers assigned to each activity in the project.

Using the coding system of Table 9-1, 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 4-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 27 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 alpha-numeric 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.

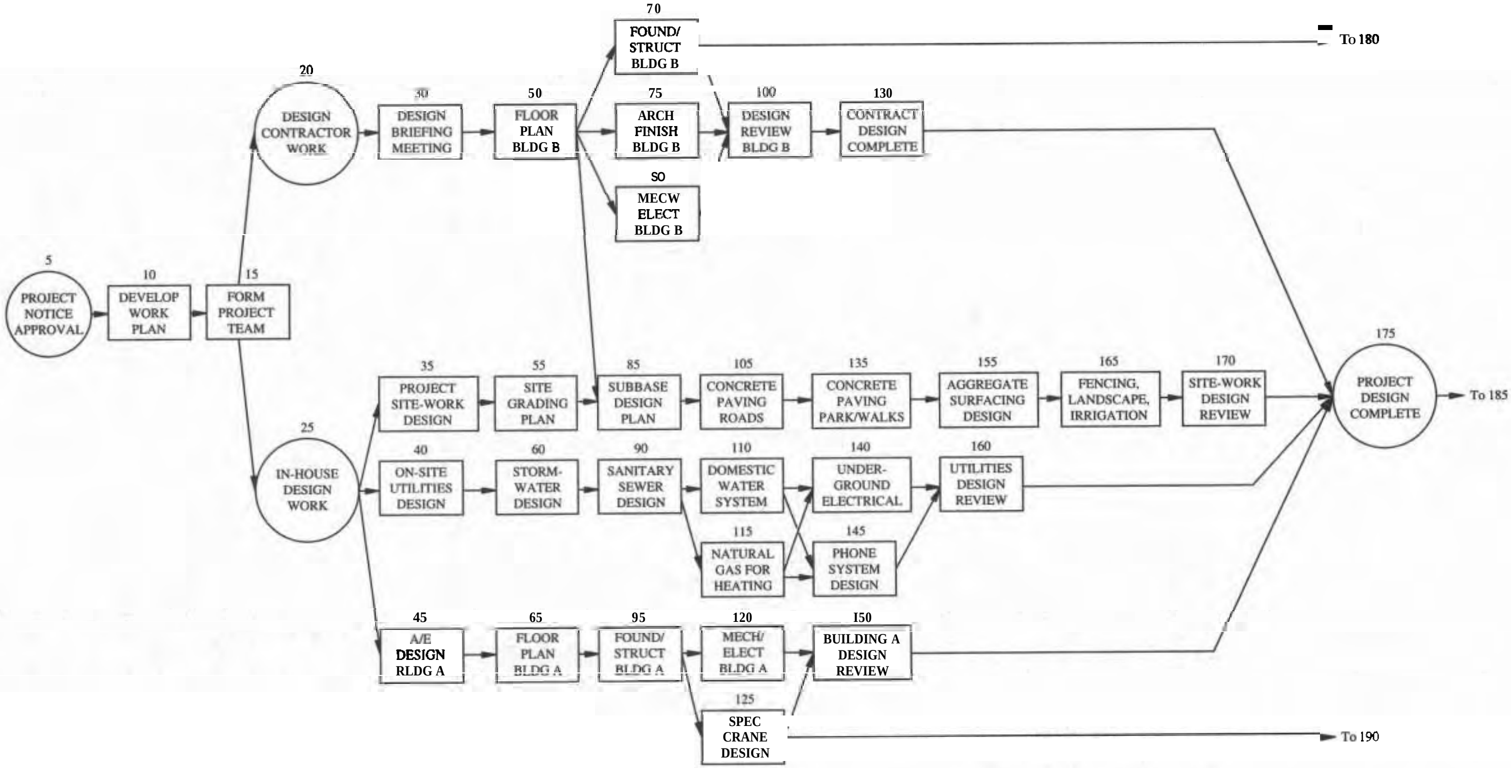


FIGURE 9-2
CPM Diagram for EPC Project (continued on following page).

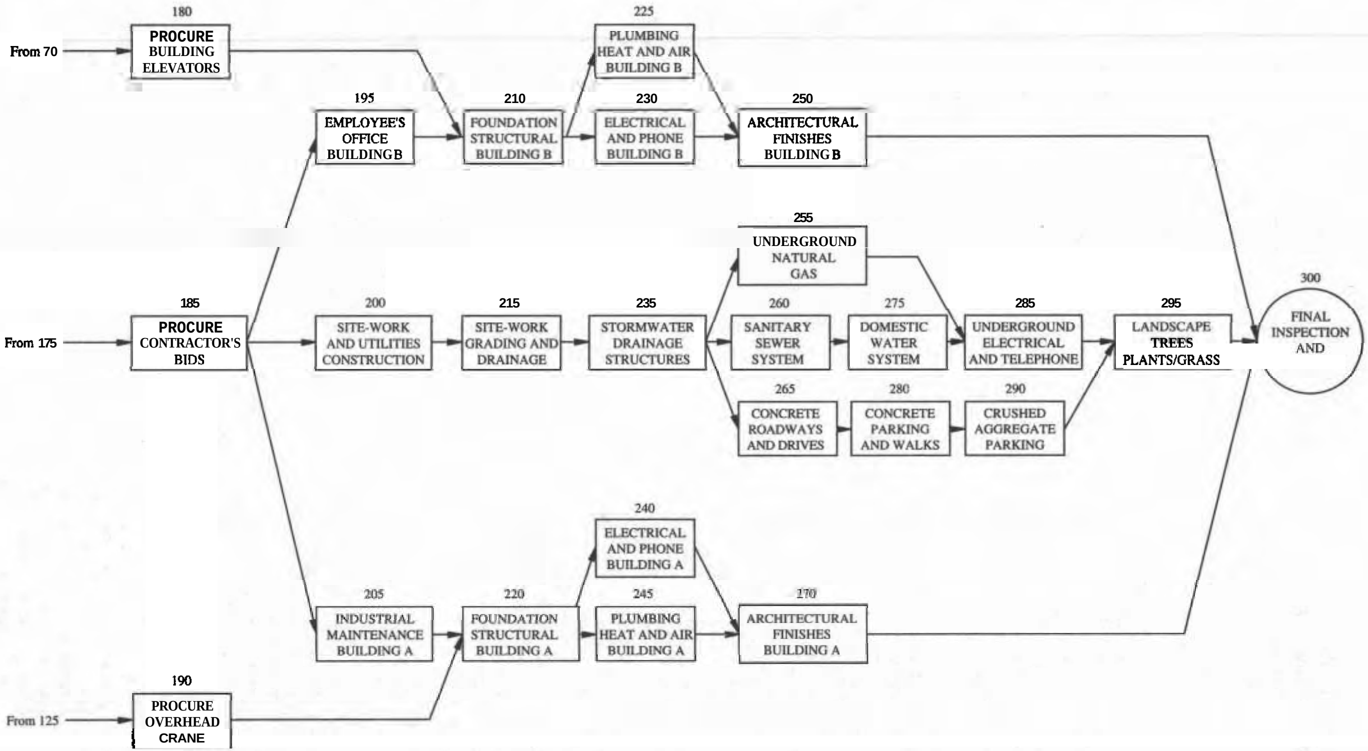


FIGURE 9-2 (Continued)
CPM Diagram for EPC Project (continued from previous page).

TABLE 9-2
EPC PROJECT ACTIVITY LIST
EXAMPLE EPC MAINTENANCE FACILITY PROJECT

NO.	CODE	ACTIVITY DESCRIPTION	DURATION	COST	TEAM MEMBER
5	0071	PROJECT NOTICE APPROVAL	3	500.	TIM JONES
10	0071	DEVELOP WORK PLAN	7	12000.	TIM JONES
15	0071	FORM PROJECT TEAM	5	850.	TIM JONES
20	2872	DESIGN CONTRACTOR'S WORK	2	3000.	DAN MITCHELL
25	1073	IN-HOUSE DESIGN WORK	3	1500.	RON THOMAS
30	2872	DESIGN BRIEFING MEETING	1	1200.	DAN MITCHELL
35	1073	PROJECT SITE-WORK DESIGN	1	1400.	RON THOMAS
40	1624	ON-SITE UTILITIES DESIGN	1	1200.	FRED LEWIS
45	1715	A/E DESIGN BUILDING A	1	1500.	KATHY DIEHL
50	2812	FLOOR PLAN BUILDING B	10	9900.	DAN MITCHELL
55	1123	SITE GRADING PLAN	12	14000.	RON THOMAS
60	1424	STORMWATER DESIGN	10	2000.	FRED LEWIS
65	1715	FLOOR PLAN BUILDING A	15	26000.	KATHY DIEHL
70	2832	FOUND/STRUCT BUILDING B	45	31200.	DAN MITCHELL
75	2812	ARCH FINISHES BUILDING B	30	49500.	DAN MITCHELL
80	2842	MECH/ELECT BUILDING B	45	37300.	DAN MITCHELL
85	1123	SUBBASE DESIGN PLAN	5	4000.	RON THOMAS
90	1524	SANITARY SEWER DESIGN	10	12000.	FRED LEWIS
95	1735	FOUND/STRUCT BUILDING A	30	92700.	KATHY DIEHL
100	2871	DESIGN REVIEW BUILDING B	10	8000.	TIM JONES
105	1223	CONCRETE PAVING ROADS	20	12000.	RON THOMAS
110	1624	DOMESTIC WATER SYSTEM	7	9000.	FRED LEWIS
115	1624	NATURAL GAS SYSTEM	8	6000.	FRED LEWIS
120	1745	MECH/ELECT BUILDING A	30	22200.	KATHY DIEHL
125	1735	SPECIAL OVERLOAD CRANE	11	10800.	KATHY DIEHL
130	2872	CONTRACT DESIGN COMPLETE	1	1000.	DAN MITCHELL
135	1223	CONCRETE PAVING PARKING/WALKS	10	7000.	RON THOMAS
140	1654	UNDERGROUND ELECTRICAL	14	12000.	FRED LEWIS
145	1654	UNDERGROUND TELEPHONE SYSTEM	4	3000.	FRED LEWIS
150	1771	BUILDING A DESIGN REVIEW	3	5000.	TIM JONES
155	1323	AGGREGATE SURFACING DESIGN	8	6000.	RON THOMAS
160	1677	UTILITIES DESIGN REVIEW	1	1100.	TIM JONES
165	1963	FENCING/LANDSCAPE/IRRIGATION	14	28000.	RON THOMAS
170	1071	SITE-WORK DESIGN REVIEW	5	7000.	TIM JONES
175	0071	PROJECT DESIGN COMPLETE	1	1000.	TIM JONES
180	3876	PROCURE BUILDING ELEVATORS	25	95000.	ROY HALL
185	4076	PROCURE CONTRACTORS' BIDS	20	7000.	ROY HALL
190	3776	PROCURE OVERHEAD CRANE	40	55000.	ROY HALL
195	6887	EMPLOYEE'S OFFICE BUILDING B	3	1000.	JIM DANIEL
200	5087	SITE-WORK/UTILITIES CONSTRUCTION	4	1500.	JIM DANIEL
205	7787	INDUSTRIAL/MAINTENANCE BLDG A	2	1400.	JIM DANIEL
210	6882	FOUND/STRUCT BUILDING B	45	195000.	DAN MITCHELL
215	5083	SITE-WORK/GRADING/DRAINAGE	18	85000.	RON THOMAS
220	7785	FOUND/STRUCT BUILDING A	110	390000.	KATHY DIEHL
225	6882	PLUMBING, HEAT, & AIR BLDG B	75	285000.	DAN MITCHELL
230	6882	ELECTRICAL/PHONE BUILDING B	60	215000.	DAN MITCHELL
235	5484	STORMWATER/DRAINAGE STRUCTURES	15	22000.	FRED LEWIS
240	7785	ELECTRICAL/ PHONE BUILDING A	65	167000.	KATHY DIEHL
245	7785	PLUMBING, HEAT, & AIR BLDG A	85	192000.	KATHY DIEHL
250	6882	ARCH FINISHES BUILDING B	50	260000.	DAN MITCHELL
255	5684	UNDERGROUND NATURAL GAS	5	10500.	FRED LEWIS
260	5584	SANITARY SEWER SYSTEM	21	33200.	FRED LEWIS
265	5283	CONCRETE PAVING ROADS & DRIVES	60	185000.	RON THOMAS
270	7785	ARCH FINISHES BUILDING A	30	175000.	KATHY DIEHL
275	5684	DOMESTIC WATER SYSTEM	7	13200.	FRED LEWIS
280	5283	CONCRETE PARKING & WALKWAYS	15	35000.	RON THOMAS
285	5684	UNDERGROUND ELECT & PHONE	14	47000.	FRED LEWIS
290	5383	CRUSHED AGGREGATE PARKING	40	76000.	RON THOMAS
295	5983	LANDSCAPE TREES/PLANTS/GRASS	20	62000.	RON THOMAS
300	9977	FINAL INSPECTION & APPROVAL	3	3500.	TIM JONES

CONTROL SCHEDULES FOR TIME AND COST

The CPM network diagram shows the sequencing of activities that represent 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 9-2, Table 9-2 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 costs and durations.

The total cost for the project includes the direct costs (from the previous paragraph) plus indirect costs, contingency reserve, 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 monitorihg 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 9-3 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.

For the example of Figure 9-3, 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 would be a drawing list that included all drawings for electrical work. The number of work-hours (WI-I) for each drawing and the number of 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 **8** 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

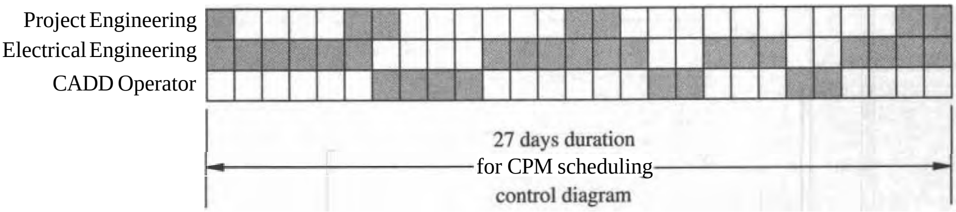
Engineering Budget Matrix

FUNCTION \ ACTIVITY OR COST ELEMENT		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 9-3
Engineering Cost Breakdown Structure and Work Breakdown Structure.
Source: Construction Industry Institute, Publication No. 6-1.

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	7 days
Electrical Engineering	19 days
CADD Operator	8 days
Total Budgeted Days =	34 days



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 9-4 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.

The general superintendent who will be responsible for the project on the construction job-site 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.

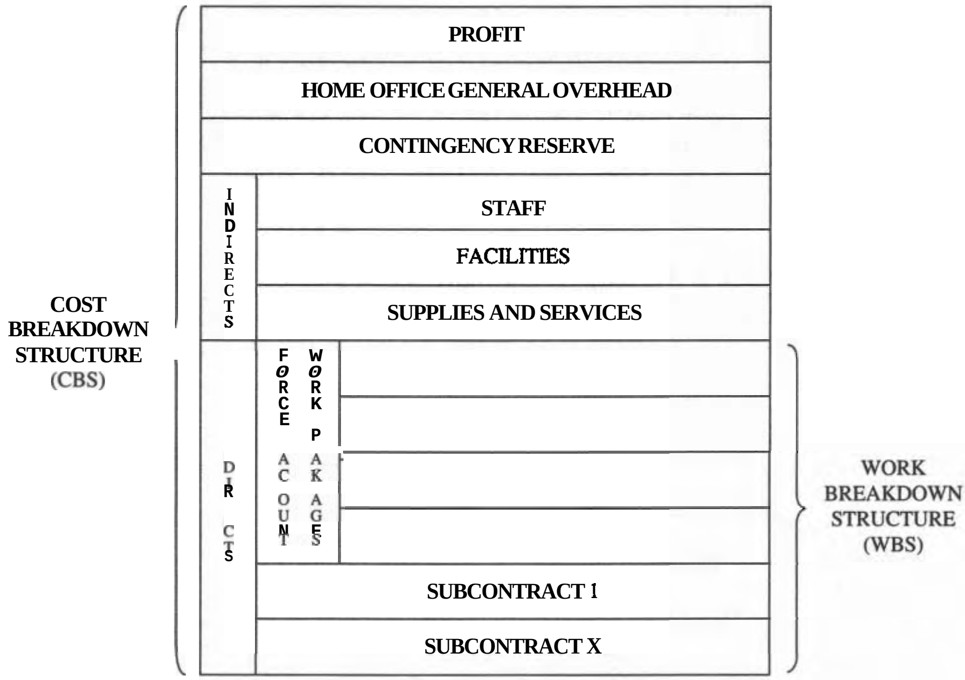


FIGURE 9-4
WBS vs. CBS.
Source: Construction Industry Institute, Publication No. 6-4.

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 material 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 9-2. 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, an S-curve, see Figure 9-5, can be produced that shows the distribution of costs for all design work. This curve is obtained using the coding system of Table 9-1, by selecting all activities in which the first digit of their code is greater than zero and less than 3.

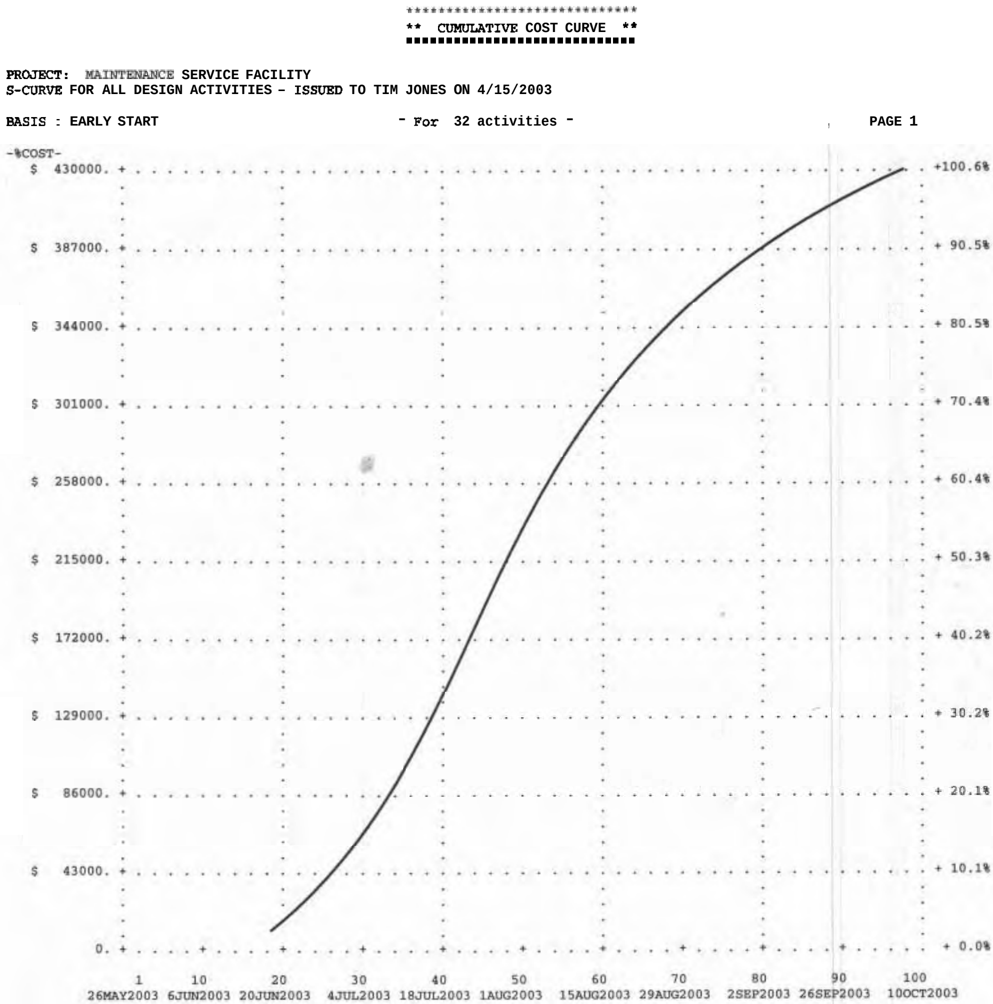


FIGURE 9-5
S-Curve for All Design Work (Sort by Code Digit 1 Greater Than 0 and Less Than 3).

Additional reports can be computer generated as discussed in Chapter 8. For example, Figure 9-6 shows the graph of daily cost for all in-house 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.

Table 9-3 is a partial listing of the project control 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 the letter " C at the left of the activity number. Major milestone events are also noted

```
**********************************
**  COST EVERY DAY HISTOGRAM  **
**********************************

PROJECT: SERVICE MAINTENANCE FACILITY
DISTRIBUTION OF COSTS FOR ALL DESIGN ACTIVITIES - ISSUED TO TIM JONES ON 4/15/2003
                                                                          PAGE 1
BASIS : EARLY START                                              - For 32 activities -
```

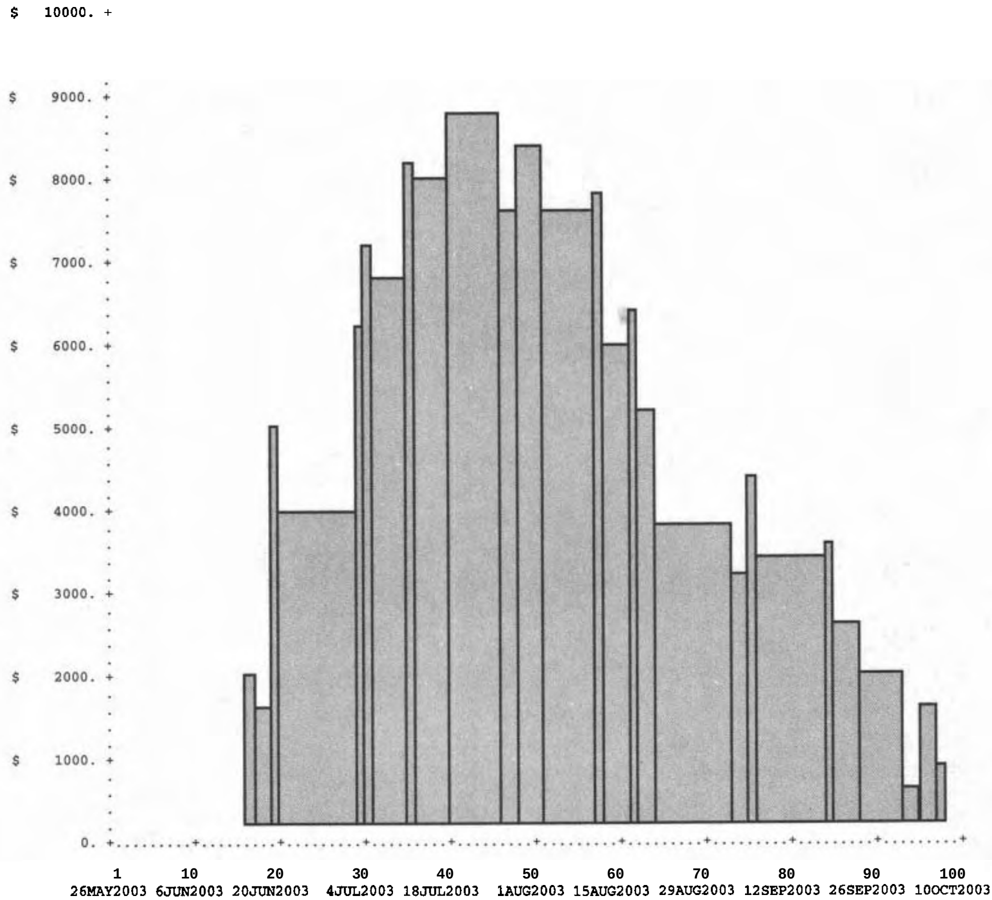


FIGURE 9-6
Distribution of Daily Costs for All In-House Design Work.

on the schedule. This schedule is a summary-level schedule report that integrates engineering, procurement, and construction.

Table **9-4** is a monthly cost schedule for the entire project. The distribution of costs are 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 non-linear distribution between costs and time. For example, at the end of the sixth month, which represents **33.0%** of the time of completion, only **17.9%** of the costs are anticipated to be expended. However, at the end of the eleventh month, 64.1% of the time, **54.3%** of the costs are expected to be expended.

TABLE 9-3
SCHEDULE OF ALL ACTIVITIES

****
** ACTIVITY SCHEDULE **
****

PROJECT: SERVICE MAINTENANCE FACILITY — ** PAGE 1 **
SCHEDULE FOR ALL ACTIVITIES - ISSUED TO TIM JONES ON 4/15/2003 — ACTIVITY SCHEDULE

	ACTIVITY NUMBER	DESCRIFTION	DURA-TION	EARLY START	EARLY FINISH	LATE START	LATE FINISH	TOTAL FLOAT	FREE FLOAT
C	5	PROJECT NOTICE APPROVAL	3	26MAY2003 1	28MAY2003 3	26MAY2003 1	28MAY2003 3	0	0
C	10	DEVELOP WORK PLAN	7	29MAY2003 4	6JUN2003 10	29MAY2003 4	6JUN2003 10	0	0
C	15	FORM PROJECT TEAM	5	9JUN2003 11	13JUN2003 15	9JUN2003 11	13JUN2003 15	0	0
	20	DESIGN CONTRACTOR'S WORK	2	16JUN2003 16	17JUN2003 17	25JUN2003 23	26JUN2003 24	7	0
C	25	IN-HOUSE DESIGN WORK	3	16JUN2003 16	18JUN2003 18	16JUN2003 16	18JUN2003 18	0	0
	30	DESIGN BRIEFING MEETING	1	18JUN2003 18	18JUN2003 18	27JUN2003 25	27JUN2003 25	7	0
	35	PROJECT SITE-WORK DESIGN	1	19JUN2003 19	19JUN2003 19	25JUN2003 23	25JUN2003 23	4	0
	40	ON-SITE UTILITIES DESIGN	1	19JUN2003 19	19JUN2003 19	7AUG2003 54	7AUG2003 54	35	0
C	45	AIE DESIGN BUILDING A	1	19JUN2003 19	19JUN2003 19	19JUN2003 19	19JUN2003 19	0	0
	50	FLOOR PLAN BUILDING B	10	19JUN2003 19	2JUL2003 28	30JUN2003 26	11JUL2003 35	7	3
	55	SITE GRADING PLAN	12	20JUN2003	7JUL2003	26JUN2003	11JUL2003	4	0
			10	20JUN			UG2003	35	0
	[illegible]	STORM-WAT R DESIGN		20JUN2003	3J L2003	8A 2003	21A 64	35	
	260	SANITARY SEWER SYSTEM	21	29DEC2003 156	26JAN2004 176	24JUN2004 284	22JUL2004 304	128	0
	265	CONCRETE PAVING ROADS & DRIVES	60	29DEC2003 156	19MAR2004 215	15MAR2004 211	4JUN2004 270	55	0
	225	PLUMBING, HEAT. & AIR BLDG B	75	13JAN2004 167	26APR2004 241	29MAR2004 221	9JUL2004 295	54	0
	230	ELECTRICAL/PHONE BUILDING B	60	13JAN2004 167	5APR2004 226	19APR2004 236	9JUL2004 295	69	15
	275	DOMESTIC WATER SYSTEM	7	27JAN2004 177	4FEB2004 183	23JUL2004 305	2AUG2004 311	128	0
	285	UNDERGROUND ELECT & PHONE	14	5FEB2004 184	24FEB2004 197	3AUG2004 312	20AUG2004 325	128	73
	280	CONCRETE PARKING AND WALKWAYS	15	22MAR2004 216	9APR2004 230	7JUN2004 271	25JUN2004 285	55	0
	240	ELECTRICAL/PHONE BUILDING A	65	12APR2004 231	9JUL2004 295	10MAY2004 251	6AUG2004 315	20	20
C	245	PLUMBING, HEAT. & AIR BLDG A	85	12APR2004 231	6AUG2004 315	12APR2004 231	6AUG2004 315	0	0
	290	CRUSHED AGGREGATE PARKING	40	12APR2004 231	4JUN2004 270	28JUN2004 286	20AUG2004 325	55	0
	250	ARCH FINISHES BUILDING B	50	27APR2004 242	5JUL2004 291	12JUL2004 296	17SEP2004 345	54	54
	295	LANDSCAPE TREES/PLANTS/GRASS	20	7JUN2004 271	2JUL2004 290	23AUG2004 326	17SEP2004 345	55	55
C	270	ARCH FINISHES BUILDING A	30	9AUG2004 316	17SEP2004 345	9AUG2004 316	17SEP2004 345	0	0
C	300	FINAL INSPECTION & APPROVAL	3	20SEP2004 346	22SEP2004 348	20SEP2004 346	22SEP2004 348	0	0

******************** END OF SCHEDULE ********************

TABLE 9-4
MONTHLY COST DISTRIBUTION FOR ALL ACTIVITIES IN THE PROJECT

** MONTHLY COST SCHEDULE **

PROJECT: SERVICE MAINTENANCE FACILITY
SCHEDULE FOR ALL ACTMTIES - ISSUED TO TIM JONES ON 4/15/2003
START DATE: 26 MAY 2003 FINISH DATE: 22 SEP 2004

MONTHLY COST SCHEDULE
- For all activities -

NO.	MONTH YEAR	EARLY START COST/MON	EARLY START CUMULATIVE COST	LATE START COST/MON	LATE START CUMULATIVE COST	TARGET SCHEDULE COST/MON	TARGET SCHEDULE CUMULATIVE COST	%TIME	%COST
1	MAY2003	$ 3929.	$ 3929.	$ 3929.	5 3929.	$ 3929.	$ 3929.	1.4%	.I%
2	JUN 2003	$ 48841.	$ 52770.	$ 34645.	5 38573.	$ 41743.	$ 45672.	7.5%	1.5%
3	JUL 2003	$ 177261.	$ 230031.	$ 101204.	$ 139778.	$ 139233.	$ 184904.	14.1%	6.1%
4	AUG 2003	5 130583.	$ 360614.	$ 130838.	$ 270616.	$ 130711.	$ 315615.	20.1%	10.3%
5	SEP 2003	$ 166931.	5 527545.	$ 160525.	$ 431141.	$ 163728.	$ 479343.	26.4%	15.7%
6	OCT 2003	$ 69255.	$ 596800.	$ 63784.	$ 494925.	$ 66519.	$ 545863.	33.0%	17.9%
7	NOV 2003	$ 180187.	$ 776987.	$ 62507.	$ 557432.	$ 121347.	$ 667210.	38.8%	21.9%
8	DEC 2003	$ 247116.	$ 1024103.	$ 111945.	$ 669377.	$ 179531.	$ 846740.	45.4%	27.7%
9	JAN 2004	$ 324067.	$ 1348170.	$ 180933.	$ 850311.	$ 252500.	$ 1099240.	51.7%	36.0%
10	FEB 2004	$ 332900.	$ 1681070.	$ 235742.	$ 1086053.	$ 284321.	$ 1383561.	57.5%	45.3%
11	MAR 2004	$ 316279.	$ 1997348.	$ 234362.	$ 1320415.	$ 275320.	$ 1658882.	64.1%	54.3%
12	APR 2004	$ 242022.	$ 2239371.	$ 245967.	$ 1566382.	$ 243995.	$ 1902877.	70.4%	62.3%
13	MAY 2004	$ 250489.	$ 2489860.	$ 308343.	$ 1874725.	$ 279416.	$ 2182293.	76.4%	71.5%
14	JUN 2004	$ 284017.	$ 2773877.	$ 329589.	$ 2204314.	$ 306803.	$ 2489096.	82.8%	81.5%
15	JUL 2004	$ 89479.	$ 2863356.	$ 322710.	$ 2527024.	$ 206094.	$ 2695190.	89.1%	88.3%
16	AUG 2004	$ 110461.	$ 2973817.	$ 338893.	$ 2865917.	$ 224677.	$ 2919867.	95.4%	95.6%
17	SEP 2004	$ 79333.	$ 3053150.	$ 187233.	$ 3053150.	$ 133283.	$ 3053150.	100.0%	100.0%

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 9-5 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 9-5 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 upon the availability of personnel. This information can be compiled from a summary of the individual design work packages.

To manage the overall design effort a work/time curve can be developed from the information in Table 9-5, see Figure 9-7. The upper portion of Figure 9-7 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 9-7 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.

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.

TABLE 9-5
ILLUSTRATIVE WEIGHT MULTIPLIERS FOR DESIGN WORK

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	

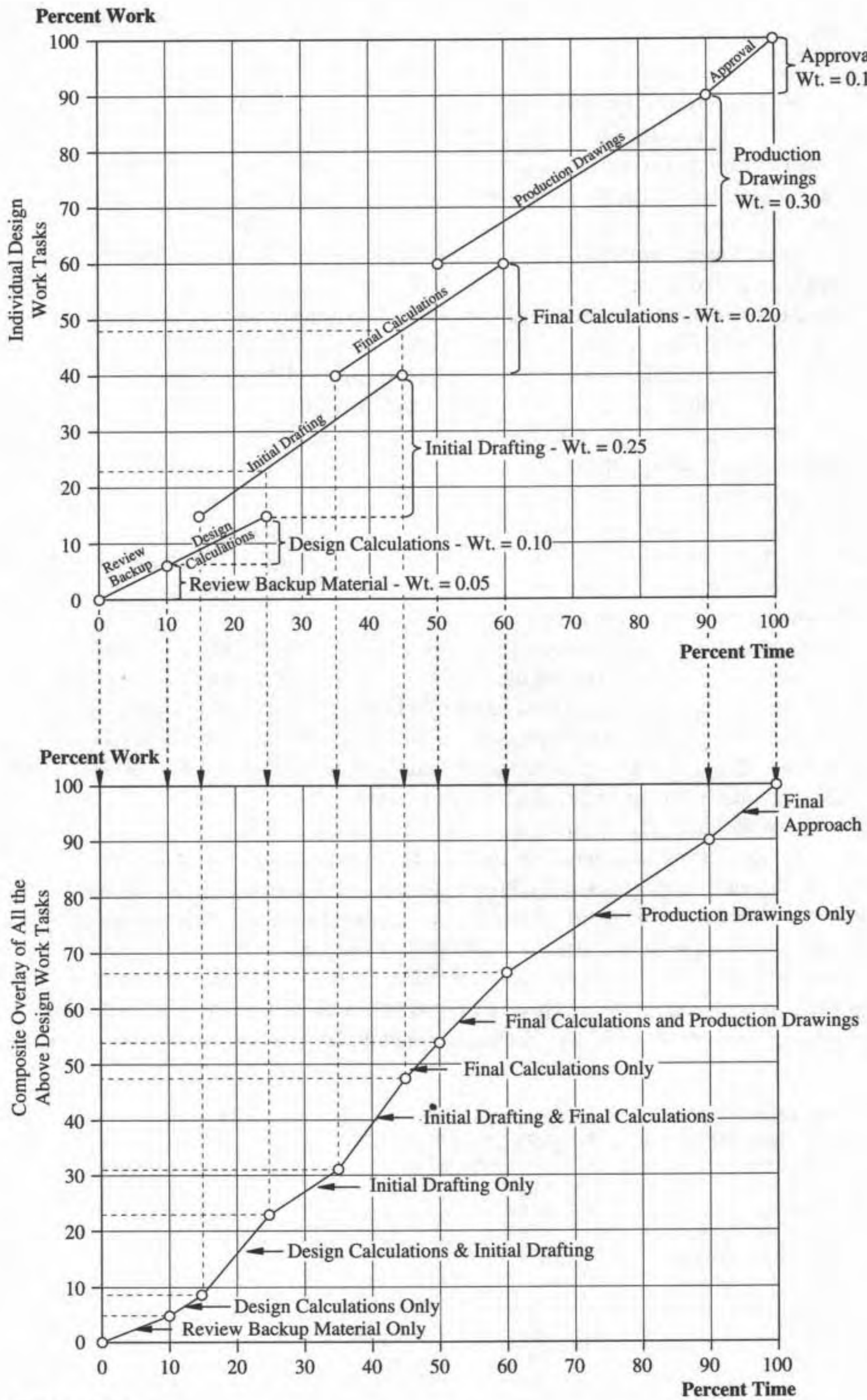


FIGURE 9-7
Work/Time Relationship for All Design Work.

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 preengineered metal building. A weight multiplier can be applied to each of the three major facilities, along with their planned sequence of occurrence (reference Table 9-6).

Table 9-6 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.

Figure 9-8 shows the composite of the planned accomplishment of work. The upper portion of Figure 9-8 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.

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 upon 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 job-site, 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 is 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

TABLE 9-6
ILLUSTRATIVE WEIGHT MULTIPLIER FOR 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	

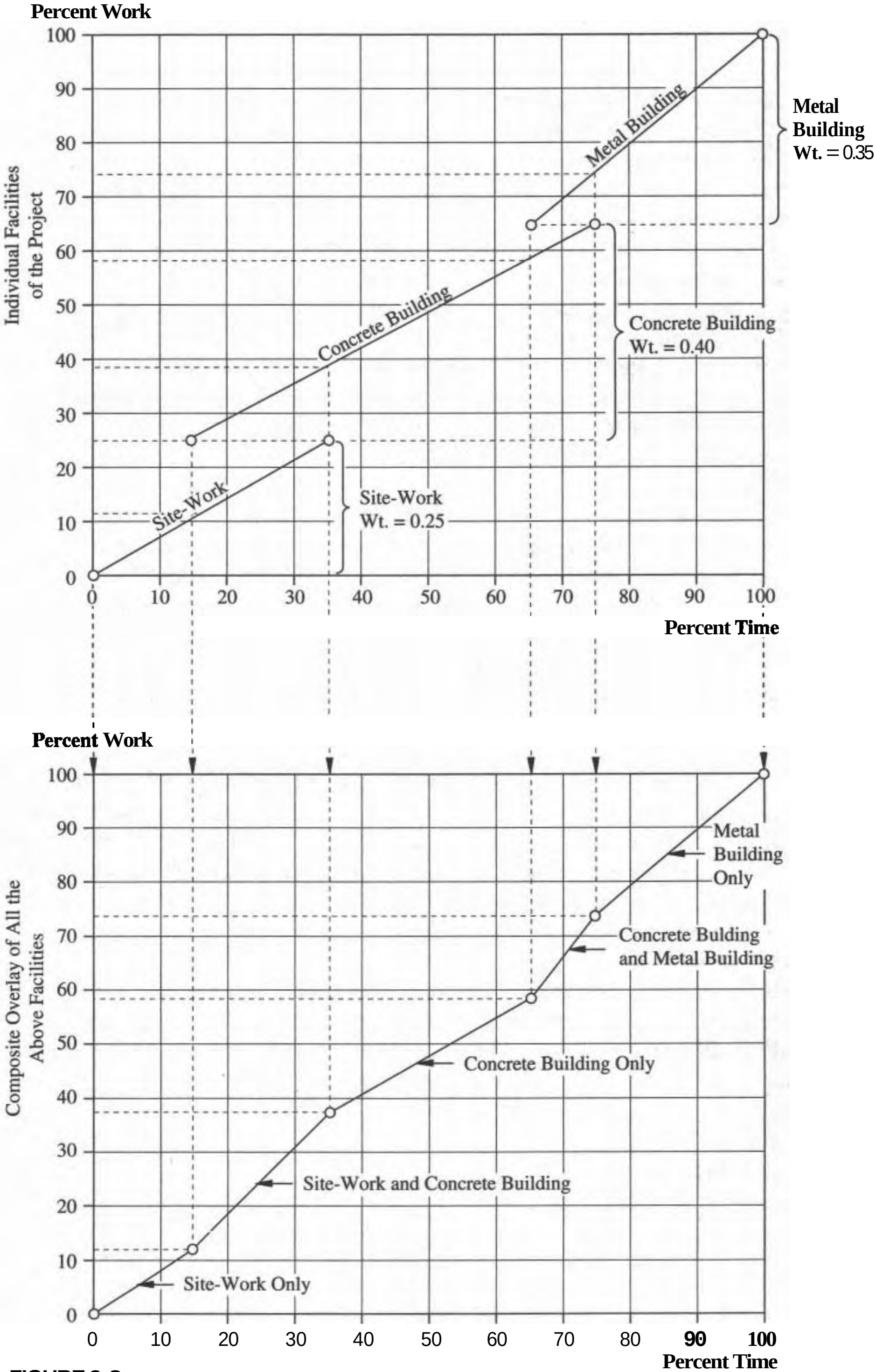


FIGURE 9-8
Work/Time Relationship for Construction of the Entire Project.

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 mid-point 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 afterwards. The status of a project can then be determined and corrective actions taken when corrections can be made at the least cost.

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 9-9 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.

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 upon good judgement, and should be determined as a joint effort by key participants of the project team.

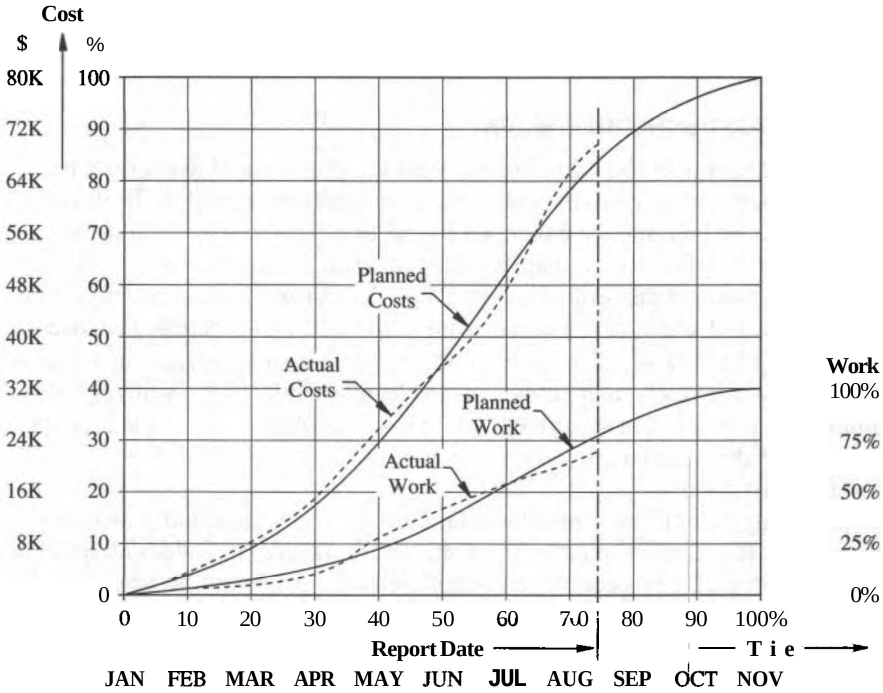


FIGURE 9-9
Integrated Cost/Schedule/Work Graph.

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 9-10*a*. 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 9-10*b* to 9-10*d*.

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 upon the complexity of the project and the level of control desired by the project manager.

PERCENT COMPLETE MATRIX METHOD

A very simple 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 upon the budget for each work package in a project. The budget can be measured as any one of three