

construction project scheduling and control

SECOND EDITION

SALEH MUBARAK





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Construction Project Scheduling and Control

Construction

Project Scheduling

and Control

Second Edition

Saleh Mubarak



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To the soul of my father, a brilliant scholar and a noble person.

He taught me the importance of knowledge, the art of teaching, and the spirit of giving. Best of all, he was a wonderful role model for me, being dedicated, altruistic, and humble.

To my mother, who always showed me the value of education and discipline.

To my wife, for her relentless encouragement, support, and patience during the years it took me to finish this book.

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Preface

Five years have passed since my book *Construction Project Scheduling and Control* came out. The response was more than encouraging. I received correspondence from several countries—comments, suggestions, requests for solutions, and simple complements. The simplicity was the most praised trait of the book. I was so happy and proud when the language editor (of the first edition) corrected me regarding an activity's *total float* in an example in the book. She was not a technical person but learned the Critical Path Method while linguistically reviewing my book.

During the past five years, I used my book in my seminars and college classes. I discussed it with my friends, colleagues, and students. I kept a log of all suggestions and corrections. I was thinking of the second edition just after the first one came out in 2004, just like a basketball coach thinking of the next season while in the current season. Although I was very happy and content with the way the book came out and was received, I discovered that there is no such thing as perfect human product. Imperfection is part of our nature as human beings, but we should think positively about it; there is always room for improvement. I had to combine satisfaction with ambition in completing this second edition with a strong conviction that the third edition is coming out in a few years.

One experience has added to my knowledge and the book—the overseas job I have held since July 2008. I could not imagine the pace and amount of construction in such a small place as Qatar. There are more tower cranes than you can count. Professional people came from all over the world, like a huge bouquet of flowers, with their diversity in education, culture, race, and language. Communications has been a challenge to say the least. Even though English is the official business language in the organization where I work, one soon realizes that English is not English! Forget about the difference in pronunciation and accents, forget about spelling of labor or

labour and program or programme; there are differences in the interpretation of technical terms and in the way we conduct business. To make it interesting, none of these ways is wrong. This situation is the cure for what I call the *background paradigm*, in which everyone believes he is right just because he was brought up this way! Then our cultures and ways of doing business clash and everyone believe the others are wrong! In many of these situations, there is no right and wrong; there are different ways. However, in a project management team, all must sing together with one common tune; what a challenge! Believe it or not, I enjoy every minute of this “clash of cultures” . . . I think of it like this: “one cubic meter of concrete mix, \$100; one ton of steel, \$600; one workday with 30 different nationalities, priceless!”

This edition contains many additions in almost every chapter and part of the book. Two new chapters have been added. One is on the Dynamic Minimum Lag (DML), a concept for a new logical relationship in CPM scheduling I recently developed. The other new chapter is on risk management in scheduling and project control.

Since the first edition, I have observed more qualitative interest in project scheduling in the professional and academic worlds. In particular, the Project Management Institute (PMI) has created a subsidiary in 2004 called College of Scheduling (PMI-COS), entirely dedicated to project scheduling issues—research, best practices, and standardization. In addition, the PMI recently created a new certification track in scheduling (Scheduling Professional, PMI-SP). I was invited to be in the committee that wrote its exam questions. Other organizations such as the Association for the Advancement of Cost Engineering, International AACEi, the American Institute of Architecture (AIA), the Construction Management Association of America (CMAA), the Associated General Contractors (AGC), and many others inside and outside the United States have also showed increased interest in scheduling and project control issues. This is coupled with the increasing role of CPM scheduling in delay and other claims, which made it an essential part of the required knowledge for judges, lawyers, and arbitrators. This is a clear indication of the importance of scheduling and project control in today’s bigger and more complicated projects.

It was a grace from God to be able to finish this work. There are a lot of people to whom I owe a lot of gratitude. I would like to thank my friend and colleague Chris Carson for his tremendous help in the new risk chapter. My thanks also to attorney Barry Bramble for his help in updating and improving the claims chapter, which he originally co-authored, and to Mr. Earl Glenwright for his valuable input. Thanks to my colleagues Dr. Gui Ponce de Leon, Dr. Fredrick Plotnick, and Dr. Gunnar Lucko for their contributions to the “Other Scheduling Methods” chapter. Big thanks to Consolidated Contractors Company (CCC) of Athens, Greece, and its Qatar Director Mazen Karam, for providing me with nice pictures from their projects all over the world.

To all my readers—construction and other professionals, educators, and students: I would like to hear from you. If you have a question, suggestion, comment, or correction, please drop me an e-mail at CPMXPERT@gmail.com. I promise to make every effort to read and respond to every e-mail I receive. Such communications will elevate us in the pursuit of perfection.

Preface to the First Edition

The art of teaching requires two important components: knowledge of the subject and the ability to convey this knowledge to students. Having a love of the subject is a bonus that allows a teacher to take the classroom to an even higher level.

During my career as a structural engineer, as a construction professional, and as a professor, I have had to play many roles and wear many hats. There is no question that the different roles and different positions have provided me with rounded knowledge and a panoramic view of the construction industry. However, no subject has been more interesting and intriguing to me than scheduling and project control. During my teaching career, I acquired many books on this subject. Many of them are good or excellent books, but none has fulfilled my exact need. Some lack the detailed step-by-step approach, some have few examples and exercises, some are written by academics with little real-world experience, and some deal with the subject of scheduling and project control as if it were still the 1970s or 1980s.

I was searching for a book that does the following:

- Addresses the need of the average student and details all steps clearly and without shortcuts
- Includes many solved and unsolved exercises that cover all the subjects in the book
- Relates to computer software programs used in the construction industry without making them the center of attention or overshadowing the theoretical principles
- Deals with precedence networks as the main and only viable CPM scheduling method, having coverage of arrow networks only as part of the evolution of scheduling
- Focuses on scheduling as part of the overall project management effort (rather than as just one chapter in a project management book)

Not having found such a book and after having taught scheduling for several years using four textbooks, I decided to write my own book. I started writing from scratch in early 2001. I also began living it: in my office, at home, when going to bed, in the shower, while driving the car, almost every waking moment. As ideas would come to mind, I would write them on a piece of paper or record them on my digital tape recorder. I did not want to let any idea escape me. Several experts also reviewed this book and provided me with invaluable critiques, and I made additional changes and improvements every time I read the text. Following is an outline of this textbook.

In chapter 1, planning, scheduling, and project control are defined, and the steps needed to build a schedule are described. In chapter 2, bar (Gantt) charts, the most common method used to display and report schedules, are introduced. This topic is revisited in chapter 9. Networks and the critical path method (CPM) are covered in the next four chapters. Chapter 3 covers arrow and node networks and their history, concepts, and structure. Chapter 4 addresses the CPM and its calculations. Chapter 5 covers precedence networks, an advanced form of node networks with its own calculations and concepts. I realize that this subject can become more complicated than field personnel or students can (or like to) handle. As a result, in this chapter, I offer two approaches: the simplistic approach, which leads to bottom-line results without becoming bogged in the details, and the detailed approach, for those who want to study the subject thoroughly. I further distinguish between continuous and interruptible activities, a subject I have not seen discussed clearly and sufficiently elsewhere in the literature.

Chapter 6 deals with resource allocation and leveling. This concept is explained clearly, more so in English than in mathematical terms. The mathematical model or algorithm for resource leveling is not discussed because it is complicated and unnecessary and because most schedulers never refer to it. Powerful computers and software have made this function feasible and practical.

Scheduling would be worthless without updating and project control, so chapter 7 covers this important subject. Chapter 8 addresses an interesting topic: schedule compression and time-cost trade-offs. In chapter 9, I explain some commonsense ideas about reports and presentations, in the context of scheduling. In chapter 10, I address scheduling as part of the project management effort. This chapter sheds some light on the interrelationships among scheduling, estimating, and other components of construction project management.

Chapter 11 covers a few other scheduling methods, such as the program evaluation and review technique (PERT) and the linear scheduling method (LSM). Chapter 12 provides brief coverage of delay claims, their avoidance, and their resolution. The chapter was written to provide an idea on the subject, and not as an in-depth reference.

Appendix A contains a computer project with multiple assignments that correspond to all subjects discussed in the book. Appendix B contains a few sample reports that the author created using Primavera P3e and SureTrak Project Manager software.

Throughout the book, not only there are illustrated examples for almost every concept, but also end-of-chapter exercises. Such exercises include both numerical type exercises (covering the spectrum of difficulty) and conceptual questions. The latter

type contains mostly short, essay-type questions. Multiple-choice questions are not included because students need to know what the terms and definitions of construction scheduling are, rather than what they are not. Also, several exercise projects are provided so that students can use them for a computer project.

My intent was to introduce a scheduling book suitable for the 21st century. I hope that I have succeeded; however, I am sure that readers—construction professionals, educators, and students—will have suggestions and criticisms of this text. I encourage readers to send their corrections and suggestions to the publisher so that I can include any necessary changes in future editions.

In preparing this book, I relied on the help of many friends and associates. To them, I owe my gratitude. I give specific thanks to the reviewers of this text for their helpful comments: Michael J. Cook, University of Florida; Rocky Gerber, University of Washington; Charles R. Glagola, University of Florida; James L. Jenkins, Purdue University; David Leo Lickteig, Georgia Southern University; and James Stein, Eastern Michigan University. Likewise, thanks to Attorney Barry Bramble, who provided me with his invaluable contribution to chapter 12, Construction Delay Claims.

Construction Project Scheduling and Control

Chapter 1

Introduction



Interstate 4 and 17/92 intersection in Sanford, Florida

PLANNING AND SCHEDULING

Planning and *scheduling* are two terms that are often thought of as synonymous. However, they are not. Scheduling is just one part of the planning effort. The term *planning* is used in many ways and different contexts. We commonly hear about *financial* planning, such as retirement planning and college education planning. Although this type of planning may include other aspects (such as what to do after retirement or which college to choose for your child), the main focus is on finance. Governments, as well as large corporations, have planning units or teams in almost every department. At the individual level, a young person may have plans for marriage, a career, and so forth. However, in the context of this book, the term *planning* is restricted to meaning project planning, with an emphasis on construction projects.

What Is a Project? Before we define project planning, we need to define a project. The Project Management Institute (PMI 2008) defines a **project** as “a temporary endeavor undertaken to create a unique product, service, or result” (p. 434). The key words in this definition are *temporary* and *unique*: any project must have a starting point and an ending point, and it must have a deliverable product or service that is unique. As a generic example, a secretary of education’s saying “We need to improve our students’ SAT scores” does not constitute a project. However, saying “We need to improve our students’ SAT scores by an average of 15 points in 5 years” may qualify as a project.

Some government agencies have specific but ongoing work that they call a project, such as maintenance of a certain facility or park compliance with the Americans with Disabilities Act. Technically, these are not projects because they have no well-defined deliverable product or service and starting and ending points. Each could be called a *program*, instead, with several projects inside each program. Basically, we need to distinguish among:

- *Program*: A “program” may mean different things to different people depending on the context. In project management, a program—usually—is a group of related projects and/or services intended to meet a common objective and usually managed by one entity. A program could also indicate a large and complex project that is divided into several projects for more effective management. The PMI defines a program as “A group of related projects managed in coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements of related work outside of the scope of the discrete projects in the program.” (PMBOK 2008)

Programs may be:

- Temporary/one-time programs: For example, the City of London (UK) may have all the construction projects for the 2012 Summer Olympics under one program. Once this program culminates with the completion of its projects; by the opening of 2012 Summer Olympic Games, it will be completed and closed. The maintenance of these facilities, later on, is a different matter.

- Ongoing (usually periodic/annual) programs: These include projects such as road maintenance and storm water programs for a public works department in many municipalities. Many private and public institutions have maintenance programs for their existing facilities. Such a program usually has annual budget and covers numerous small projects—as many as the budget allows. The program usually lives as long the facility does.

One important note: In the UK, as well as in some other countries that use British terminology, the schedule (timeline) of the project is called program (spelled programme). This is *not* the program that we are discussing.

- *Portfolio:* This is a group of projects, not necessarily related or dependent, usually under one project manager or department. The PMI defines it as “A collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives. The projects or programs of the portfolio may not necessarily be interdependent or directly related.” (PMBOK 2008)
- *Project:* Defined above.
- *Subprojects:* These are segments of the original project that are divided according to specialty, responsibility, phase, area, or other criteria. To the person in charge of a subproject, the subproject is a project, except that he/she has to consider not only the internal relationships among its activities but the external relationships as well (with activities in other subprojects in the same project). For example, in a residential or commercial development project, building the infrastructure may be regarded as a subproject. In fact, building the sewer system in the development can be a subproject (to the entire development project) or even a sub-subproject (to the infrastructure subproject).

Are Projects Unique? Some people may think of two construction projects as identical just because they have the same design. In project management, we may have similar projects, but every project is unique. Differences may come from a difference in location (soil type, weather conditions, labor market, building codes, unforeseen conditions, etc.), in management type and experience, or in circumstances (and how much Murphy’s Law is involved).

Project planning has been defined as “the process of choosing the one method and order of work to be adopted for a project from all the various ways and sequences in which it could be done” (Antill and Woodhead 1990, p. 8; Callahan, Quackenbush, and Rowings 1992, p. 2). The PMI defined the planning process in the PMBOK (4th edition, 2008) as “Those processes performed to establish the total scope of the effort, define and refine the objectives, and develop the course of action required to attain those objectives”. Project planning serves as a foundation for several related functions, such as cost estimating, scheduling, project control, quality control, safety management, and others.

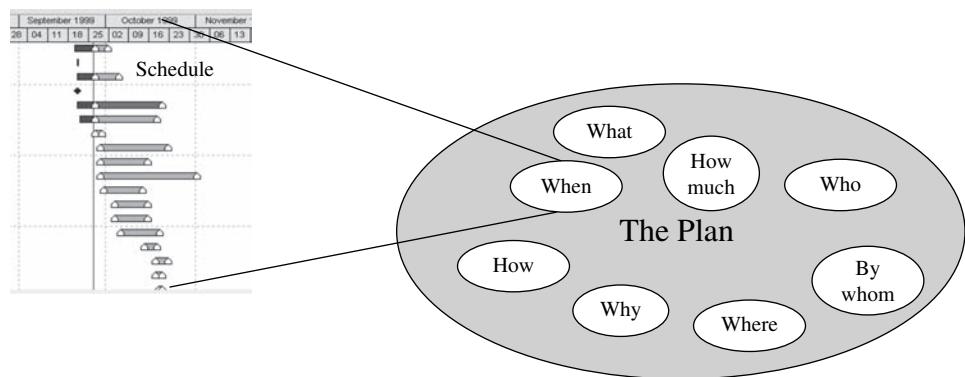


Figure 1.1 Planning and scheduling

Scheduling is the determination of the *timing* and *sequence* of operations in the project and their assembly to give the overall completion time. As mentioned previously, scheduling focuses on one part of the planning effort.

Project planning answers the questions *What* is going to be done? *How*? *Where*? *By whom*? and *When* (in general terms, the project's start and end)? Scheduling deals with *when* on a detailed level.

In fact, scholars have generally separated planning from scheduling “CPM separates planning and scheduling, and once project information is collected and expressed as a network plan and activity time estimates assigned, CPM calculations can be made. Planning ceases and scheduling starts when the first computation is performed that shows a project duration. The project duration is then compared with the desired schedule and scheduling begins.” (O’Brien and Plotnick, 2009, p. 417)

To get an idea about the relationship between project planning and scheduling, assume that you are planning a family vacation “project” for next summer. Your *plan* may include considerations such as these:

- Who will go on the trip?
- Which places do you want to visit? (You would like to visit many places, but your time and monetary resources are limited.)
- What is the time frame for the vacation (just the starting and ending dates)?
- What is the total budget for the “project” (including the contingency you did not tell other family members about)?
- What types of activities do you want to participate in during the trip (sharp differences among the family members)?
- What means of transportation do you plan to use (your car, a rental car, air, train, bus, RV, bicycles, etc.)?
- What other issues, such as accommodations, food, and clothing, need to be addressed?

The project *schedule* is simply the itinerary, such as this:

- Leave home in Tampa, Florida, on June 8, 2010.
- Arrive in Panama City, Florida, on June 8, 2010.
- Leave Panama City on June 15, 2010.
- Arrive in Atlanta, Georgia, on June 15, 2010.
- Leave Atlanta on June 22, 2010.
- Arrive in Gatlinburg, Tennessee, on June 22, 2010.
- Return home to Tampa on July 7, 2010.

Note that not only the plan and the schedule are related, but also many of the elements of the plan are interrelated. For example, most of the choices in the plan (length of stay, type of accommodations, means of transportation, type of activities, food, etc.) affect the budget. Since different means of transportation have longer time durations than others, they may affect not only the cost but the schedule as well. Clearly, a lack of clarity of scope before the project starts may lead to heated arguments and dissatisfaction. In real projects, it may lead to huge budget overruns, schedule delays, and different parties' dissatisfaction. Therefore, it is important to have a clear understanding of the project's scope (objectives), and decide who the "project manager" is. Many issues are at stake in this example, but demonstrating the concepts of planning and scheduling is our objective.

In the context of construction projects, a typical plan for an office building project may include the following:

- A *scope definition*, such as a five-story building for commercial use (offices) with a total area of about 30,000 square feet. The location is also part of the planning, although, in some cases, the exact location may be selected later or a few sites are mentioned as candidates.
- A *schematic or conceptual design*. This is not a must but helps one to visualize the project. The final design may later differ significantly.
- A *budget number* (e.g., \$6 million). The planner must be aware of all project-related expenses, such as the cost of land, permits, design fees, construction, and so forth.
- A *time frame* (i.e., when the project is expected to start and end).
- *Other pertinent information* that may be used to justify the project or clarify some of its aspects. If an investor is doing the planning, a **pro forma** helps predict the rate of return and helps in making the decision whether or not to build the project.

PMI defines **project management plan** as a "formal, approved document that defines how the project is executed, monitored and controlled. It may be summary or

detailed and may be composed of one or more subsidiary management plans and other planning documents. The objective of a project management plan is to define the approach to be used by the project team to deliver the intended project management scope of the project.” (PMBOK 2008)

The project manager creates the project management plan following input from the project team and key stakeholders. The plan should be agreed on and approved by at least the project team and its key stakeholders. It is a good practice, used by professional project management and consulting firms, to have a formal project management plan approved in the early stages of the project and applied throughout the project. Many owners (clients) require the contractor to submit a project management plan and have it approved as part of the contract documents.

PROJECT CONTROL

Once a project starts, certain aspects can easily deviate or go astray. This deviation can be overspending, a schedule slippage, a departure from the objective/scope, or something else. It is of utmost importance to know—at all times—where you stand in relation to where you planned to be (the baseline). If you find yourself behind schedule or over budget, you must know why and then take corrective action to get back on track or, at least, minimize the deviation. If the deviation is positive (i.e., the project is ahead of schedule or under budget), actual performance was probably better than that expected in the baseline plan. This process exemplifies **project control**. Although the concept of project control covers all aspects of the plan (budget, schedule, quality, etc.), our main focus in this book is on schedule and budget control, which are related. (Extensive coverage of project control is provided in chapter 7.)

WHY SCHEDULE PROJECTS?

There are several parties involved in any project (stakeholders). They all need and benefit from project scheduling but from different perspectives. Following is a group of reasons for why project scheduling is needed, from two different perspectives: contractors and owners.

Contractors need project scheduling to:

1. *Calculate the project completion date:* In most construction projects, the general contractor (GC), including subcontractors and other team members, is obligated to finish the project by a certain date specified in the contract. The contractor has to make sure that his or her schedule meets this date. Some contracts contain clauses for penalties for finishing the project later than contractually required and/or incentives (financial or other) for finishing earlier. Also, the schedule may show the stage of **substantial completion**,

when the owner may start occupying and using the facility while the contractor is still doing some final touches.

2. *Calculate the start or end of a specific activity:* Specific activities may require special attention, such as ordering and delivering materials or equipment. For instance, the project manager may want special and expensive equipment to be delivered just in time for installation. Long-lead items may have to be ordered several months in advance. Delivery of very large items may need coordination or a special permit from the city so that such delivery does not disrupt traffic during rush hour. The schedule must show such important dates.
3. *Coordinate among trades and subcontractors, and expose and adjust conflicts:* In today's construction, the GC's role is mostly to coordinate among different subcontractors. The responsibility of the GC may be to allocate the time of use of a tower crane among subcontractors or just to ensure that adequate work space is available for all subcontractors. These tasks are in addition to coordinating logical relationships such as when a subcontractor's activity depends on the completion of another subcontractor's activity. For example, the drywall contractor cannot start until the framing has been done; once the drywall is installed, the painter can start painting; and so on.
4. *Predict and calculate the cash flow:* The timing of an activity has an impact on the cash flow, which may be an important factor for the contractor (or the owner) to consider. The contractor (or the owner) must know his or her total spending in any month or time period. He or she may delay the start of certain activities, within the available *float* (this term is explained subsequently) to make sure that the cash flow does not exceed a certain cap.
5. *Improve work efficiency:* By properly distributing workers and equipment and having efficient materials management (which is explained in chapter 6), the GC can save time and money.
6. *Serve as an effective project control tool:* Project control must have a solid and sound base with which current performance can be compared. Project control is achieved by comparing the actual schedule and budget with the baseline (as-planned) schedule and budget (this subject is explained in chapter 7).
7. *Evaluate the effect of changes:* **Change orders** are almost inevitable, but well-planned projects may have few or minor change orders. Change orders may come in the form of directive, that is, an order to the contractor to make the change, or request for evaluation before authorization. This change may be an addition, a deletion, or a substitution. Change orders may have an impact on the budget, schedule, or both. Cost estimators estimate the cost of change orders (including the impact on the overhead cost as a result of the schedule change), but schedulers calculate the impact of the change on the project schedule. It is the contractor's responsibility to inform the owner on such impact and obtain his/her approval on the change to the budget and/or schedule.

8. *Prove delay claims:* Construction **delay claims** are common. Contractors must be able to accurately prove their claims against owners (or other parties) using project schedules. In most cases, only a **critical path method (CPM)** schedule can prove or disprove a delay claim, which can be a multimillion dollar one.

Project owners and developers need project scheduling to:

1. *Get an idea on project's expected finish date:* Before an owner demands that the general contractor (GC) complete the project by a certain date, he/she needs to make sure that this is a feasible and reasonable date. This date is calculated by a CPM schedule prepared either by the owner or by the designer or other consultant hired by the owner. This date is also important to the owner, even before selecting a contractor, to conduct feasibility studies and financial planning.
2. *Ensure contractor's proper planning for timely finish:* Owners may demand a project schedule from the prospective or bidding contractor, however, it is very important for the owner to review such schedule and make sure that it is reasonably accurate and realistic. Owner's approval of contractor's prepared schedule may imply a liability on the owner's side.
3. *Predict and calculate the cash flow:* The owner is obligated to make timely progress payments to the contractor and other parties along the life of the project. Failure to do so not only may delay the project and/or incur additional cost but it also may—at certain point—be deemed a breach of contract.
4. *Serve as an effective project monitoring tool:* Both owner and contractor must monitor progress of work and compare actual progress (schedule and cost) with the baseline (as-planned) schedule and budget. The contractor uses this process to detect and correct any deviation and also to prepare progress payments. The owner uses this process to verify actual work progress and contractor's payment requests.
5. *Evaluate the effect of changes:* Owners may desire or require change orders. In many instances, owners don't expect or fully appreciate the impact these change orders may have on the schedule and/or budget. It is a wise idea for an owner to find out this impact before making a decision regarding such change order. It is also recommended that owners analyze the contractor's assessment of the change order to make sure that it is fair and reasonable.
6. *Verify delay claims:* Owners use CPM schedules to analyze, verify, and/or dispute contractors' delay claims. Although most delay claims are initiated by contractors against owners, it is possible to reverse roles and have an owner's claim against the contractor, and/or have other parties involved. In either case, a CPM schedule is vital for the owner to prove his/her case.

Other parties involved in the project may also need a CPM schedule, such as the designer, project management consultant, and financial lending institution.

The need for a CPM schedule varies with several factors. In general, it increases with the increase in size and complexity of the project. For example, a home builder who has built tens or hundreds of almost identical homes may not have much need for a CPM schedule. Project control is still needed but may be conducted through simpler methods.

THE SCHEDULER

The Scheduler: A civil engineer, an architect, a computer whiz, a mathematician, a project manager, an artist, or a communicator? An increasing trend—in all industries—is to use computer software and other high-tech tools. These software packages cover the entire spectrum of all industries, including some generic types of software, such as word processors and spreadsheets that everyone uses. However, specialized software requires knowledge of both the software and the discipline. Scheduling is no exception to this rule.

Let us distinguish among three types of knowledge that a scheduler must have:

1. Knowledge of computer software (and perhaps hardware as well)
2. Knowledge of the principles of scheduling and project control (as part of project management)
3. Knowledge of the specific technical field, such as commercial building, industrial, transportation, and so forth

To efficiently operate a scheduling and control program, such as Primavera Project Manager (P6) (Primavera Systems, Inc., Bala Cynwyd, Pennsylvania, now part of Oracle), the scheduler must have the first two types of knowledge. The third type is a plus. Just because an individual knows computers and can surf the Internet does not mean that he or she can operate a scheduling and project control program. Even if the individual can operate it, he or she may not understand its language and may have problems relating to and interpreting the technical information.

Currently, many high-tech innovations such as PCs, PDAs, digital cameras and scanners, and the Internet are available. They have become useful tools and an essential part of our daily life. Nevertheless, the human factor should never be underestimated. The combination of good tools and an educated, experienced operator is the only path to success in project planning.

Certification

Several organizations now have a process and exam that lead to certification in project scheduling. The most prominent ones are:

- The AACE International's Planning & Scheduling Professional (PSP)
- The PMI's Scheduling Professional (PMI-SP)

Usually, an applicant to a certification exam has to fulfill certain conditions:

1. Minimum education requirements
2. Minimum experience requirements
3. Pass the certification examination
4. Submit application and fees

Such certification is important in giving the confidence in the qualifications of the scheduler, particularly to a potential employer. A certification from a reputable organization, however, cannot alone guarantee good results. It is just one component in the scheduling system.

Unfortunately, the author has seen people who carried the title scheduler but lacked the fundamentals for the position. In one incident, the author met the “scheduler” with a construction company who never had education or experience relevant to his job. He was chosen for that position because of his computer skills!

The Tripod of Good Scheduling System

1. *The Human Factor*: A proficient scheduler or scheduling team that understands the concepts, definitions, and applications of project scheduling
2. *The Technology*: A good scheduling computer system (software and hardware) along with capable IT support
3. *The Management*: A dynamic, responsive, and supportive management that believes in the use of scheduling as part of the management effort

If anyone of the above three “legs” is missing, the system will fail.

SCHEDULING AND PROJECT MANAGEMENT

Planning, scheduling, and project control are extremely important components of project management. However, project management includes other components, such as cost estimating and management, procurement, project/contract administration, quality management, and safety management. These components are all interrelated in different ways. The group of people representing all these disciplines is called the **project management team**. It is usually headed by the **project manager (PM)**. In chapter 10, we discuss the relationships between scheduling and other project management components.

CHAPTER 1 EXERCISES

1. Define *project planning* and *scheduling*. Differentiate between the two terms.
2. Define a *project*. What makes planning and scheduling construction projects different from general planning? (*Hint*: Think of the key words in the definition of *project*.)

3. Define a *portfolio* and a *program* in the context of project management. Give examples of each.
4. What is *project management plan*? Give an example.
5. What is *project control*? Why is it important?
6. Think of a construction project you participated in or observed. Write down the steps involved in its planning and the steps involved in its scheduling (without much specificity).
7. List the benefits of CPM scheduling in construction projects from the contractor's perspective.
8. List the benefits of CPM scheduling in construction projects from the owner's perspective.
9. Do all construction projects have the same need for CPM scheduling? Why or why not?
10. What characteristics must a scheduler of a building project have? Can the same person be a scheduler for an industrial project? Why or why not?
11. Meet with a project manager for a construction project. Ask whether he or she uses CPM scheduling. If so, discuss the benefits obtained from such scheduling. If not, politely ask why CPM scheduling is not being used.
12. Search for an article on a CPM scheduling topic (*ENR*, *Civil Engineering*, *PM Network*, *Cost Engineering* are magazines that are good sources; avoid scholarly journals). Summarize and discuss the article.

Chapter 2

Bar (Gantt) Charts



Wadi Dayqah Main and Saddle Dams, Oman

DEFINITION AND INTRODUCTION

A **bar chart** is “a graphic representation of project activities, shown in a time-scaled bar line with no links shown between activities” (Popescu and Charoenngam 1995, p. 96). The bar chart was originally developed by Henry L. Gantt in 1917 and is alternatively called a **Gantt chart**.¹ It quickly became popular—especially in the construction industry—because of its ability to graphically represent a project’s activities on a time scale.

Before a bar chart can be constructed for a project, the project must be broken into smaller, usually homogeneous components, each of which is called an **activity**, or a **task**. No absolutely correct or incorrect way to break down a project exists; however, the scheduler should take a balanced approach and break it down into a reasonable number of activities that are easily measured and controlled without being overly detailed. (Project breakdown is discussed further in chapter 4.)

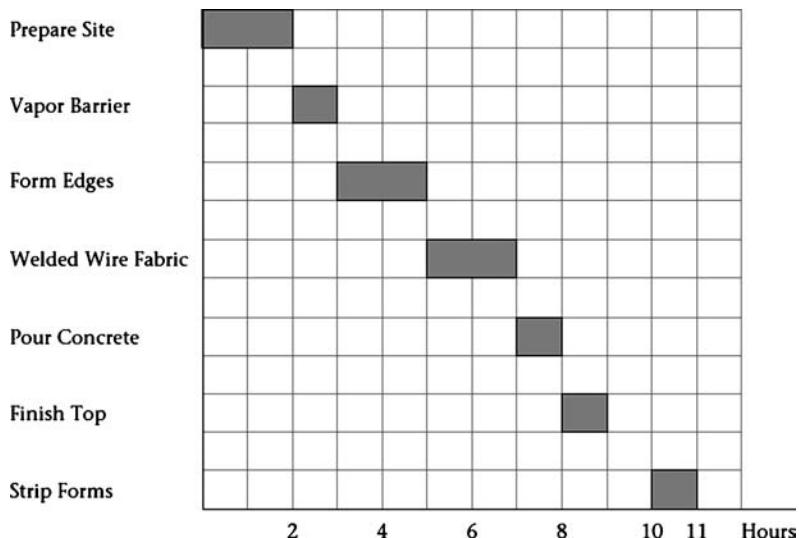
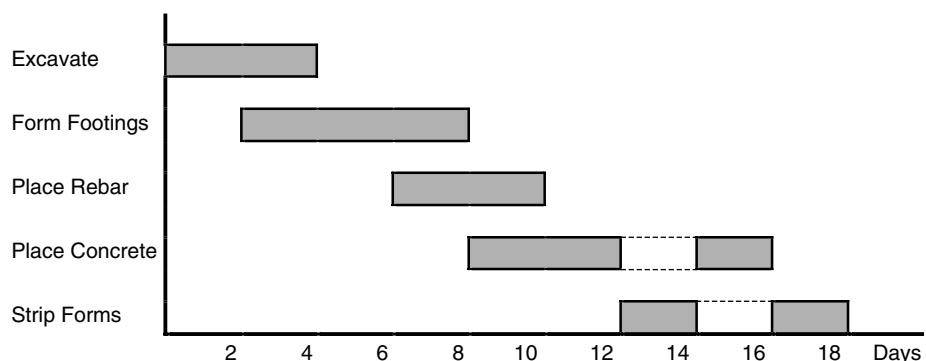
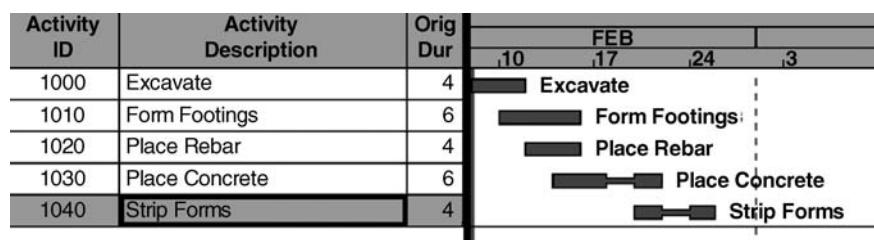
An activity, or a task, may be as large as laying the foundation of a building, as small as erecting the formwork of one footing, or anywhere in between. The duration of each activity must be estimated. Bars are then drawn to show, for each activity, the duration and the starting and ending points. As mentioned previously, links between activities are not usually shown.

On a bar chart, the bar may not indicate continuous work from the start of the activity until its end. For example, the activity Getting a Building Permit may be represented by a 2-month-long bar. However, most of this time is a waiting period. Likewise, a Concrete Foundation summary activity may include several days of waiting for concrete to cure. Noncontinuous (dashed) bars are sometimes used to distinguish between real work (solid line) and inactive periods (gaps between solid lines) (Callahan, Quackenbush, and Rowings 1992).

Bar charts have become a vehicle for representing many pieces of a project’s information. Many variations of bar charts have evolved; some simply show the start and end of each activity (Figures 2.1 and 2.2), some are loaded with resource or budget numbers (Figures 2.3 and 2.4), and others compare the **as-planned schedule** with the **as-built schedule** (Figure 2.5). Using Primavera Project Manager (P6) software (Recently acquired by Oracle), we can show activities with interruptions as continuous bars or as “necked” bars (Figure 2.3).

Since bar charts basically use the *x*-axis only (to depict time), the *y*-axis is used (in addition to showing individual activities) to represent a variable across time, such as man-hours (Figure 2.4), budget (Figure 2.5), percent complete (Figure 2.6), and so forth. This variable is usually shown as a curve superimposed on the bar chart. In Figure 2.5, S curves (also called *lazy-S curves*) represent the percent on extrapolation from the as-built curve.

¹ The notion that bar charts and Gantt charts are two different types of charts is baseless. There is a variety of bar chart types and any or all of them can be called Gantt chart.

**Figure 2.1 Bar chart for placing a simple slab on a grade****Figure 2.2 Alternative bar chart for placing a simple slab on a grade placed in two parts****Figure 2.3 Bar chart for placing a simple slab on a grade, with activities “necked” during nonwork periods**

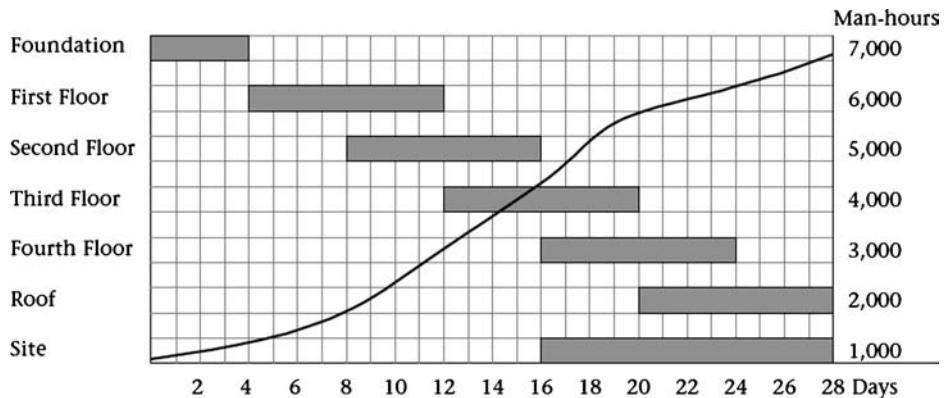


Figure 2.4 Bar chart—loaded with man-hours—for construction of a two-story building

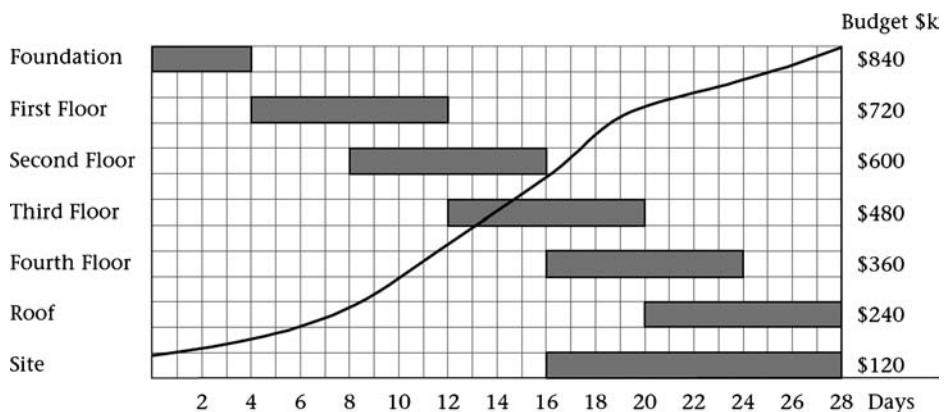


Figure 2.5 Bar chart—loaded with the budget—for construction of a two-story building

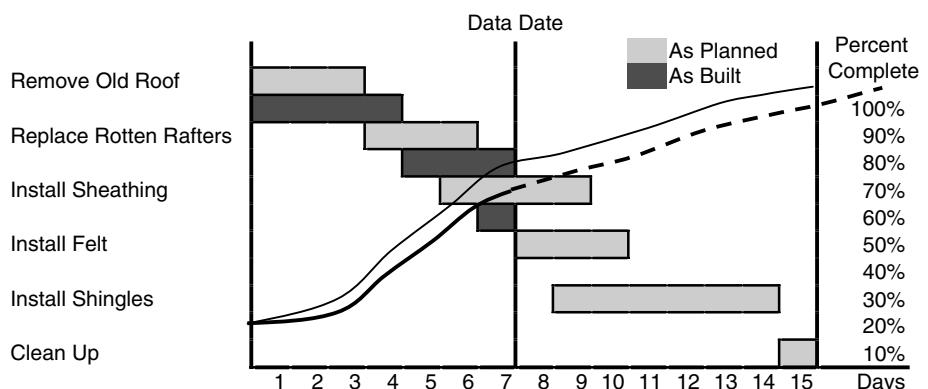


Figure 2.6 Bar chart for replacement of an old roof, showing a comparison between the percent complete of the planned (as-planned) activities (thin line) and that of the actual (as-built) activities (thick line). The dashed line is an extrapolation of the actual curve.

ADVANTAGES OF BAR CHARTS

Bar charts have gained wide acceptance and popularity mainly because of their simplicity and ease of preparation and understanding. No “theory” or complicated calculations are involved. Anyone can understand them. They can be prepared anywhere with just a pencil and paper. So, although bar charts can carry—or be loaded with—other information, the user must be careful not to overload them and, thus, eliminate their main advantage: simplicity.

Unlike networks, bar charts are time-scaled; that is, the length of a bar representing certain activity is proportional to the duration of that activity. Just by looking at the chart one can get an idea on the duration of each activity.

Another advantage is that bar charts particularly appeal to persons who do not have a technical background. For example, some clients and upper-level managers may better understand the plan for carrying out a construction project by looking at a bar chart than by looking at a schematic of a logic network.

A final advantage of bar charts is that, with the advent of the critical path method (CPM) and the evolution of powerful computers, bar charts did not perish or lose importance. Instead, they evolved to a different supporting role that made them more valuable and popular. This role is explained in chapters 3 and 4.

DISADVANTAGES OF BAR CHARTS

The main disadvantage of bar charts is lack of logical representation (relationships): Why did this activity start on that date? Bar charts do not reveal the answer. It could be a logical relationship, a resource constraint, or a subjective decision by the project manager. Although some software programmers tried to depict logical relationships on bar charts, the result was not always clear. The logic lines would get tangled, and unlike networks, bar charts do not allow the length of the bars to be subjectively changed or the bars to be moved around to make the chart look or read better.

Another limitation, rather than a disadvantage, of bar charts is the size and complexity of projects. Bar charts may not be practical for projects with large numbers of activities—*unless* you use them in two ways:

1. You show a subset of the work activities to maintain the simplicity of the chart.
For example, the general contractor can produce bar charts for activities during only a certain period, for **critical activities** (activities that cannot be delayed or the entire project would be delayed; a full definition and discussion follows in chapter 4) only, for activities in a certain section of the project, or for activities under a certain subcontractor.
2. You show summary bars (each bar represents a group of activities combined on the basis of a certain criterion such as department, major component, or responsibility). This can be done during the early planning phase, when details are not available (see, for example, Figure 2.7), and when you are reporting the information to high-level management.

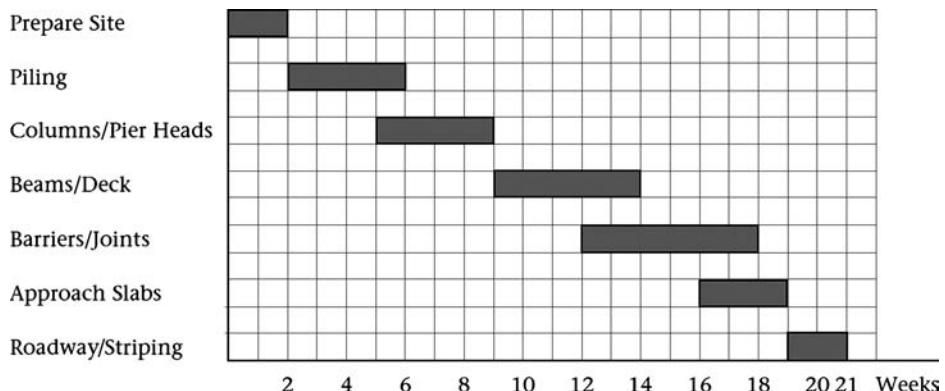


Figure 2.7 Bar chart representing the summary activities for constructing a bridge

New technology (computers, software, printers, plotters, etc.) has ameliorated some of the disadvantages of bar charts by enabling the user to organize, filter, roll up, summarize, or do almost anything to customize the bar chart. Bar chart reporting and presentation is discussed in chapter 10.

CHAPTER 2 EXERCISES

1. What is a *bar chart*? What other term is synonymous? How did the other term originate?
2. What are the main advantages of bar charts that made them so popular? What are their main disadvantages?

In the following exercises, draw a bar chart showing the time scale on the *x*-axis. Use engineering paper, or draw light vertical lines every certain interval (e.g., every 5 days) to help you read the starting and ending dates of any activity. Make simplifying assumptions whenever necessary. Be sure to mention these assumptions.

3. You are running out of space in your house, so you have decided to transform your two-car garage into a family room. In addition, you will build a simple carport in your driveway. Make a bar chart for this project, breaking your project into 10 to 15 work activities.
4. Think of obtaining a bachelor degree from a college as a project. You are advising a friend, a senior in high school who plans to attend college next year. Prepare a bar chart for him, depicting all the courses he must take from the start of college until graduation. Obtain the program course list. Make sure you do not overlook any prerequisite requirements. Make the following simplifying assumptions:
 - a. Your friend is smart. He will not fail any course.

- b. All courses are available every fall and spring semester.
- c. No summer semesters are included. Your friend will work during the summer.
- d. The total load every semester should be no less than 15 credit hours and no more than 18. You can let him take as many as 20 credit hours in one semester only, and only during the last year.
- e. Your friend must graduate in eight semesters.

After finishing the bar chart, show it to your adviser and get his or her approval on your sequence of courses. Note that several correct solutions to this problem may be possible (which is often the case with construction projects).

- 5. Draw a bar chart for building a detached shed in your backyard. Break your project into 10 to 15 work activities.
- 6. You are given the task of changing the worn-out carpet in your office. Draw a bar chart showing all activities involved (including removing and reinstalling baseboards; removing and disposing of old carpet and the pad; selecting, purchasing, and delivering new carpet and a new pad; cleaning up before and after installing the new carpet; and any other relevant activity).
- 7. Prepare a bar chart for building an inground swimming pool. If you do not know the steps involved, ask a friend or a local contractor.
- 8. Contact a contractor and ask him or her whether he or she uses bar charts (they may be called *Gantt charts*). Ask about the main types of bar chart reports. Which groups of activities are included? Ask if the bar charts are prepared as bar charts or as an output for a CPM schedule.
- 9. To demonstrate the concept of summary bars, draw bar charts for building a new home. Use a few summary activities, such as laying the foundation, putting a slab on a grade, framing, doing electrical work, putting in the plumbing, installing an HVAC (heating, ventilation, and air-conditioning) system, putting on the roof, installing doors and windows, and doing the finishing. You may need to show some of these activities (e.g., the electrical work, the plumbing) as discontinuous bars because you start the activity (do a rough-in), stop, and then return and finish it. Take the chart to a specialized contractor and expand one of these bars. Expanding a summary bar means breaking it down into the detailed activities that make up this summary activity. For example, you can expand Framing to Installing First-Floor Bottom Plates, Installing First-Floor Studs, Installing First-Floor Blocking, Installing First-Floor Top Plates, Installing Second-Floor Joists, and so forth. Note that the total duration of the summary activity must equal the total duration (not necessarily the algebraic summation) of the detailed activities underneath the summary activity.

Chapter 3

Basic Networks



Sunny Isles Condominiums, Sunny Isles, Florida

DEFINITION AND INTRODUCTION

A **network** is a logical and chronological graphic representation of the activities (and events) composing a project. Network diagrams are basically of two types: arrow networks and node networks. Arrow networks were more popular in the 1960s and 1970s, then precedence diagrams (an advanced form of node diagrams) became the choice for network scheduling.

Network scheduling has revolutionized the management of construction projects. It has provided management with a more objective and scientific methodology than simply relying completely on the project manager's personal skills.

ARROW NETWORKS

Arrow networks are also called the **arrow diagramming method (ADM)**, **activity on arrow (AOA) networks**, or the **I-J method** (because activities are defined by the *from node*, I, and the *to node*, J). In this book, we use the term *arrow networks*. Following are seven examples of arrow networks.

Example 3.1

Draw the arrow network for the project given next.

Activity	IPA ^a
A	—
B	A
C	A
D	B
E	C, D

^aImmediately preceding activity.

Solution

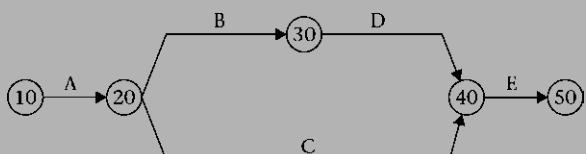


Figure 3.1 Solution for example 3.1: a simple arrow network

Brief Explanation

In the preceding example, the project has only five activities, each represented by an arrow. Each arrow connects two nodes (depicted by circles with numbers in them): the *from node* and the *to node*. These nodes represent events: an **event** is a point in time when an activity starts or ends. In computer software, events with significance can be created as **milestones**,¹ and they are either *start milestones*, such as Notice to Proceed, or *finish milestones*, such as Substantial Completion.

The Logic

In example 3.1, activity A starts the project. Activities B and C follow, but independently. In reality, depending on the availability of resources and other factors, activities B and C may occur concurrently, overlap, or occur consecutively. However, both B and C cannot start till A is complete. Activity D must wait till activity B is complete. Once both C and D are done, activity E can start. The end of activity E means the end of the project. Activity A is considered a **predecessor activity** to activities B and C. Similarly, activity B is a predecessor to activity D. Conversely, we can say that activities B and C are **successor activities** to activity A, activity D is a successor to activity B, and so on. Activity A has successors but no predecessors. Activity E has predecessors but no successors. All other activities have both successors and predecessors.

As mentioned previously, a node in an arrow network represents an event or a point in time. This event is the starting or ending point of an activity (or activities). Node 10 represents the start of activity A (and hence the start of the project). Node 20 represents the end of activity A and the start of activities B and C. Node 30 represents the end of activity B and the start of activity D. Node 40 represents the end of activities C and D, and the start of activity E. Node 50 represents the end of activity E and the project.

Notation

The arrow diagram is also called the *I-J method* because each activity is identified by the two nodes that define its start and end. For example, activity A is also known as 10–20, B as 20–30, C as 20–40, and so on.

Dummy Activities

Let us consider a simple project.

¹ Primavera Project Planner, or P3, has two types of events: milestones and flags. New generation of Primavera Project Management software has just one type: milestone, which has –as will be explained later- two classes: start and finish milestones.

Example 3.2

Draw the arrow network for the project given next.

Activity	IPA
A	-
B	A
C	A
D	B, C

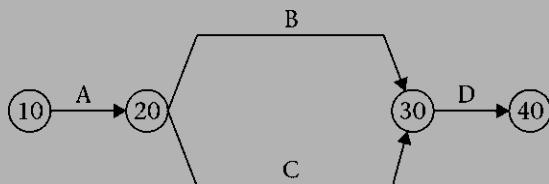
Solution A

Figure 3.2a Improper solution for example 3.2

The main problem in this case is that both activities B and C start from node 20 and finish at node 30. Hence, both are identified as 20–30.

This situation will create an identity problem. To solve this problem, we introduce a fictitious activity and an additional node. This fictitious activity is called a **dummy activity**, d. It is treated in the critical path method (CPM) calculations (discussed in chapter 4) and in computer programs as a real activity even though it is not.

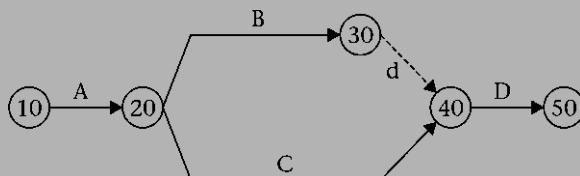
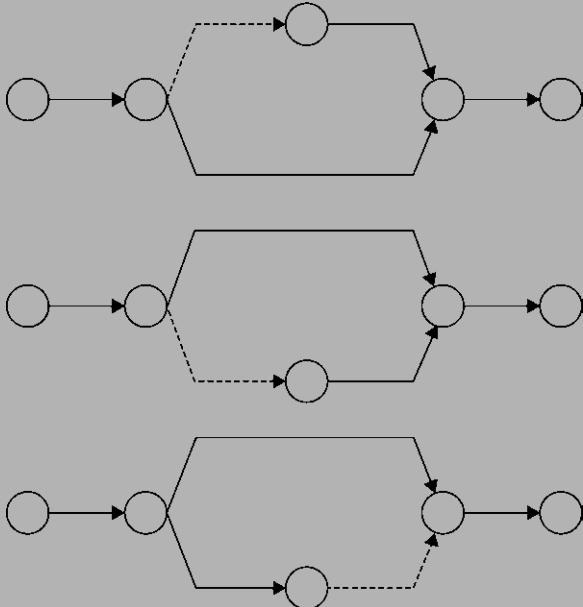
Solution B

Figure 3.2b Proper solution for example 3.2

In this case, activity B is identified as 20–30, whereas activity C is 20–40. Note that the dummy could be inserted in different positions, as shown next. They all serve the same purpose.

Other Solutions**Figure 3.2c Other proper solutions for example 3.2**

Let us now consider another example.

Example 3.3

Draw the arrow network for the project given next.

Activity	IPA
A	-
B	A
C	A
D	B
E	B, C

The problem in this example is how to draw the preceding logic correctly. We need to show that activity E depends on both activities B and C, whereas activity D depends only on activity B. The solution can only be achieved by using a dummy activity, as shown next. Figures 3.3a and 3.3b are examples of improper logic. Figure 3.3c shows the proper logic.

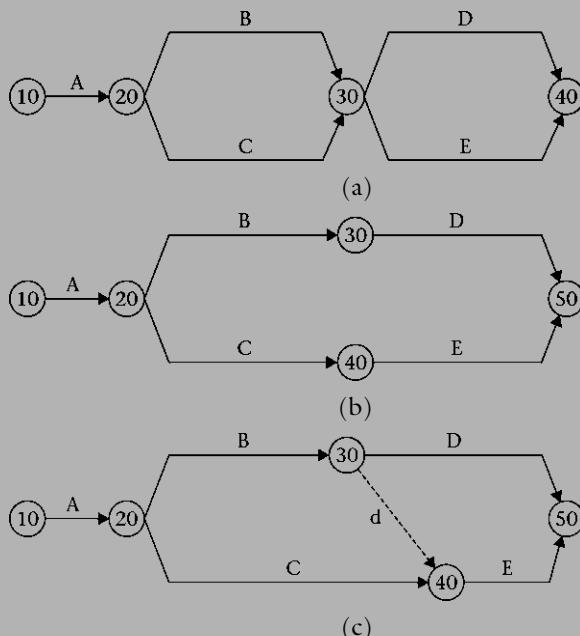
Solutions

Figure 3.3 (a) Improper solution, (b) another improper solution, and (c) proper solution for example 3.3

We can complicate example 3.3 just a little with one change.

Example 3.4

Draw the arrow network for the project given next.

Activity	IPA
A	-
B	A
C	A
D	B
E	B, C
F	C

Solution

The solution requires two dummy activities (or simply *dummies*).

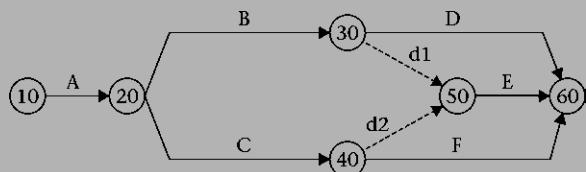


Figure 3.4 Solution for example 3.4

From the previous examples, we can define a dummy activity as a fictitious activity inserted in an arrow network to maintain proper logic or distinguish activities' identities. Two more examples demonstrate the need for dummy activities to straighten up the logic.

Example 3.5

Draw the arrow network for the project given next.

Activity	IPA
A	-
B	-
C	-
D	A, B
E	B, C

Solution

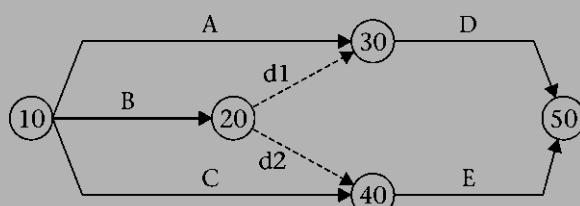


Figure 3.5 Solution for example 3.5

Example 3.6

Draw the arrow network for the project given next.

Activity	IPA
A	-
B	-
C	-
D	A
E	A, B
F	A, B, C

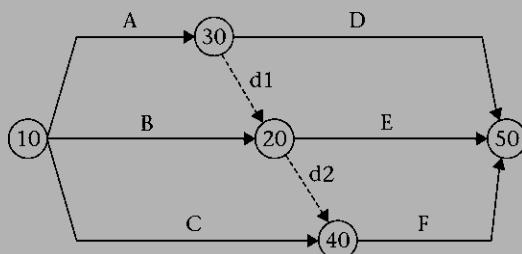
Solution

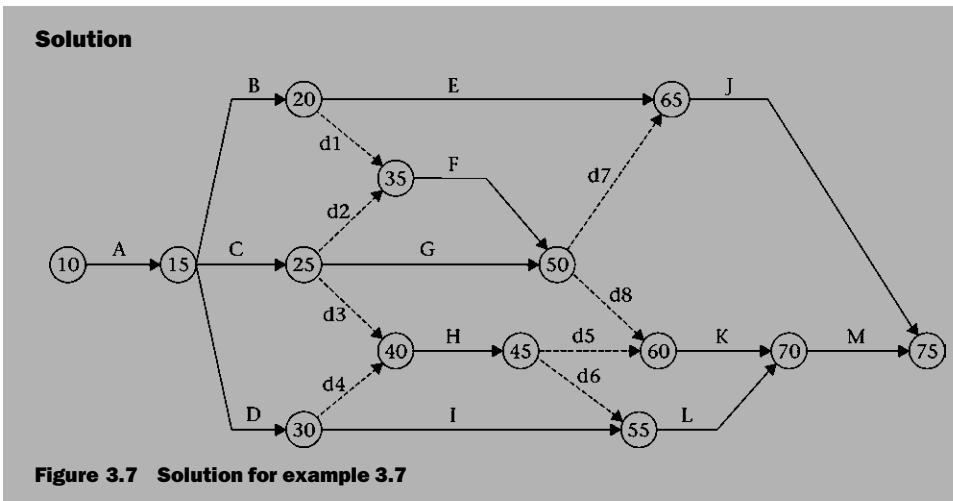
Figure 3.6 Solution for example 3.6

In larger projects, dummy activities may not only increase the number of activities but also complicate the schedule. This fact is one of the main disadvantages of arrow networks. The following example demonstrates this disadvantage.

Example 3.7

Draw the arrow network for the project given next.

Activity	IPA	Activity	IPA
A	-	H	C, D
B	A	I	D
C	A	J	E, F, G
D	A	K	F, G, H
E	B	L	H, I
F	B, C	M	K, L
G	C		



Redundancies

It is interesting to note that when you are building an arrow network, you can have not only a logically improper network but also a proper one with redundant dummy activities. This fact is especially true for complicated networks. Redundant dummy activities are not logically improper: they are just redundant (see Figure 3.8). (Note: Students may lose points on exams for having redundant dummies.)

NODE NETWORKS

Node networks are also called **activity on node (AON) networks**. In node networks, we use a different notation for representation: a node represents an activity. Nodes (activities) are connected with arrows (or lines) that represent the logical relationships. For example, let us redraw Figures 3.1 and 3.2 as node diagrams (see Figures 3.9 and 3.10). There is no need in the node diagram for dummy activities. A scheduling novice can draw a node diagram much more easily than an arrow diagram.

For aesthetic reasons only, we like to start any network with one node (whether this node represents an event or an activity) and end it with one node. Doing so may require one or two fictitious activities in node diagrams that start or end with more than one activity. We call these activities *PS* (*project start*) and *PF* (*project finish*), displayed as diamond-shaped nodes. For example, let us redo Figures 3.3 through 3.6 as node diagrams.

Figures 3.11 through 3.14 show the results. As shown in Figure 3.15, by using a node diagram, we can solve example 3.7 without using the annoying eight dummy activities.

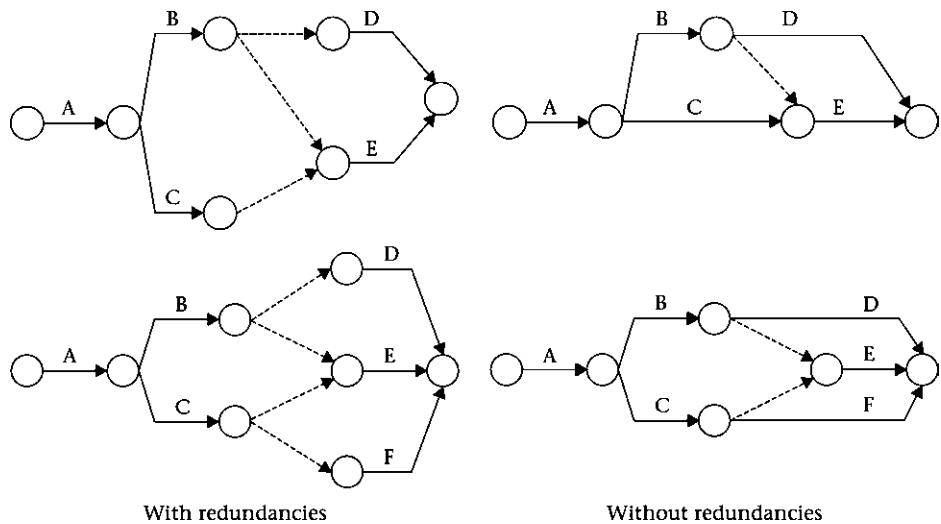


Figure 3.8 Redundant versus nonredundant dummy activities

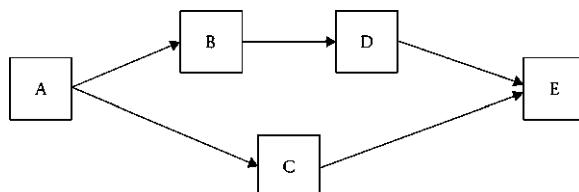


Figure 3.9 Solution for example 3.1 as a node network

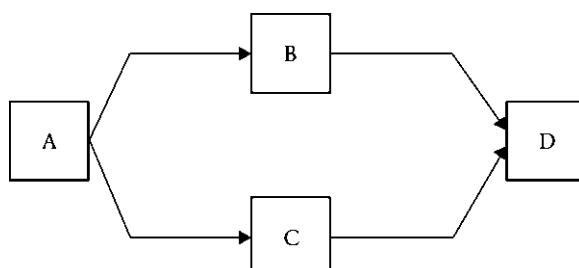


Figure 3.10 Solution for example 3.2 as a node network

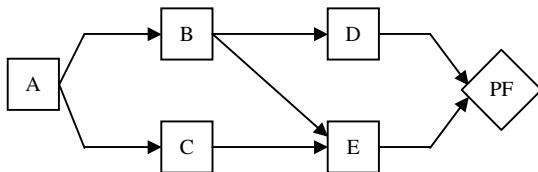


Figure 3.11 Solution for example 3.3 as a node network

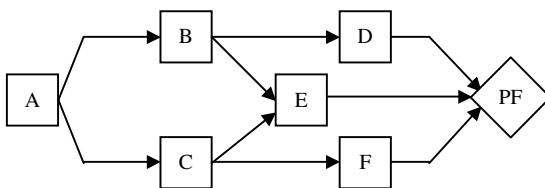


Figure 3.12 Solution for example 3.4 as a node network

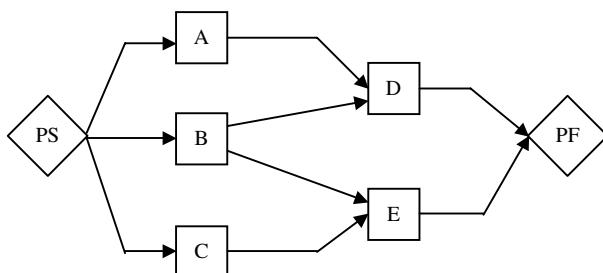


Figure 3.13 Solution for example 3.5 as a node network

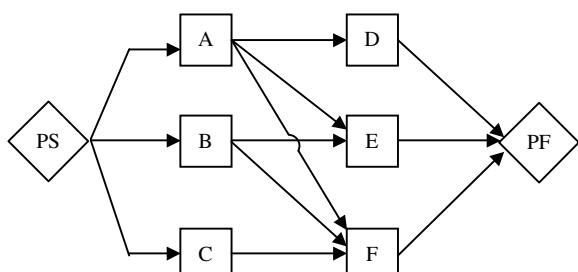


Figure 3.14 Solution for example 3.6 as a node network

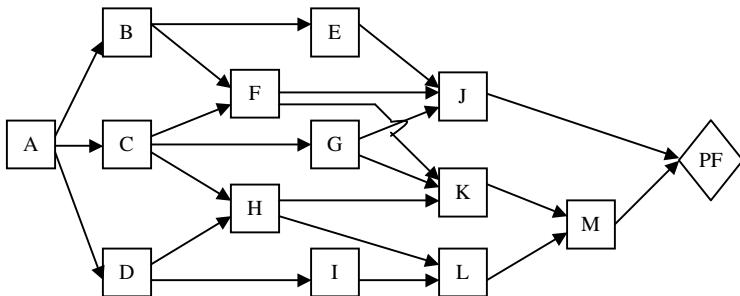


Figure 3.15 Solution for example 3.7 as a node network

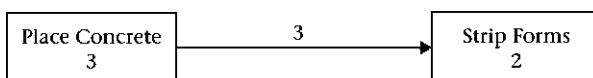
Lags and Leads

In some situations, an activity cannot start until a certain time after the end of its predecessor. A typical example is concrete operations. Let us imagine this sequence:

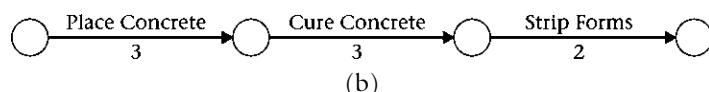
1. Form the concrete column.
2. Install steel reinforcement (commonly known as *rebar*).
3. Place the concrete.
4. Wait for the concrete to set (attain sufficient strength).
5. Strip the forms.

Note that the fourth step is not a “real” activity to which we must allocate resources and a budget. It is merely a waiting period, commonly known as a **lag**. A node network can accommodate such a lag if we simply put the lag on the relationship line between Place Concrete and Strip Forms, as shown in Figure 3.16a. This 3-day lag means a minimum waiting period of 3 days. Waiting less than 3 days violates the preceding logic, whereas waiting more than 3 days does not violate the logic. In some networks, the lag number is put inside a little box for better visibility.

Thus, a **lag** is defined as a minimum waiting period between the finish (or start) of an activity and the start (or finish) of its successor. Arrow networks cannot accommodate lags. The only solution in such networks is to treat it as a real activity with a real duration, no resources, and a \$0 budget (Figure 3.16b).



(a)



(b)

Figure 3.16 (a) A lag in a node network; (b) a lag in an arrow network

With arrow networks, an activity was defined as “a unique unit of the project which can be described within prescribed limits of time” (R. B. Harris 1978, p. 18) or “a time-consuming task” (Callahan, Quackenbush, and Rowings 1992, p. 29). Note that these definitions include “waiting activities” that have no real work or resources. With the current popularity of node (precedence) networks, the author of this book suggests changing the definition to “a resource-consuming task,” since waiting periods are treated as lags rather than real activities.

The term **lead** simply means a negative lag. It is seldom used in construction. In simple language: A positive time gap (lag) means “after” and a negative time gap (lead) means “before.”

Lags and leads are covered in chapter 4, when we discuss CPM calculations.

Recommendations for Proper Node Diagram Drawing

1. Since nodes in arrow diagrams (events) are always drawn as circles, we like to draw nodes in node diagrams (activities) as squares (rectangles). Doing so not only eliminates confusion between an arrow network and a node network, but, more importantly, defines the “start side” of an activity and the “end side.” This distinction is important in precedence networks, which are discussed in chapter 5. Milestones are usually drawn as diamonds to emphasize the fact that they have no duration; thus, nodes have no “sides.”
2. Do not connect nodes (in node diagrams) from the top or bottom (see Figure 3.17). Connect sides only. The left side represents the start side, and the right side represents the end (finish) side. This is very important in precedence diagrams (see chapter 5).
3. Although networks are not time-scaled, in general, they should be designed from left to right in an almost chronological order. Relationship lines (arrows) can be horizontal, inclined, or broken; however, they should go—in general—from left to right. Try to avoid the situation shown in Figure 3.18.
4. Do not combine relationship lines (see Figure 3.19). These relationships are independent from their start to their end. Besides, one of them may carry a lag while the other one does not (or carries a different lag).
5. Try to minimize line crossings (see Figure 3.20). When two lines (relationships) must intersect, make a “jump” on one of them to indicate that they do not intersect or meet.

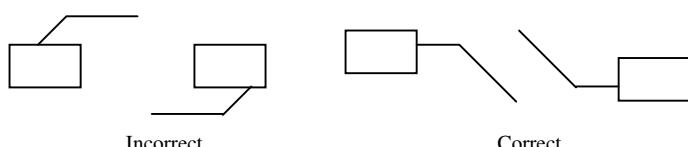


Figure 3.17 Node connection in node networks

6. Start the network with one node and finish it with one node. If the network starts with one activity only (such as those in Figures 3.11 and 3.12), then there is no need for additional node. If not (such as those in Figures 3.13), then insert a PS (Project Start) milestone node at the start and tie it to those activities that start the network. The same concept applies to the end of the network: If it ends with one activity, then there is no need for additional node. If not, (such as those in Figures 3.11 to 3.15), then insert a PF (Project Finish) milestone node at the end and tie those activities that end the network to it.

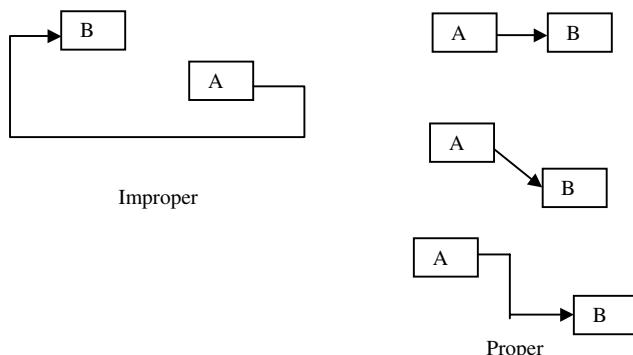


Figure 3.18 Node order in node networks

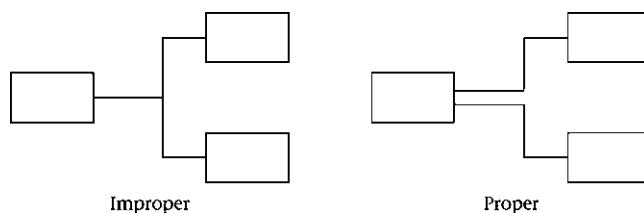


Figure 3.19 Relationship lines in node networks

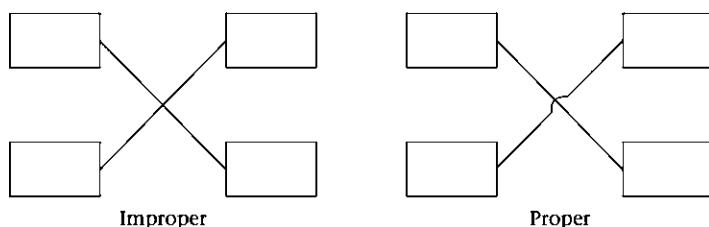
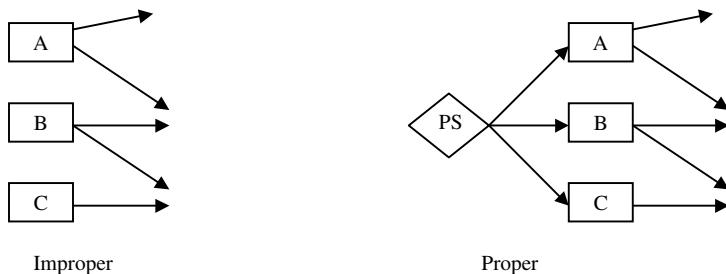
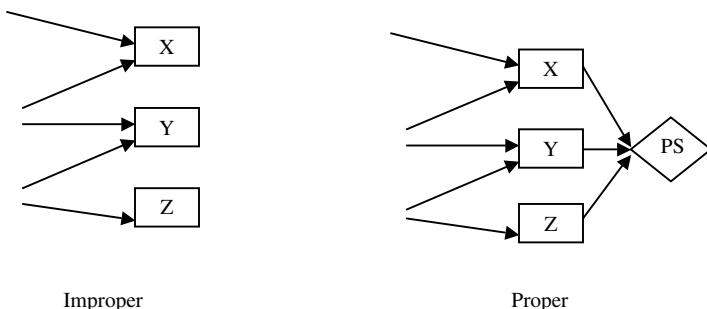


Figure 3.20 Intersecting relationship lines in node networks



(a) Do not start a network with more than one node



(b) Do not end a network with more than one node

Figure 3.21 Converging the start and finish of node networks

7. In many cases of hand drawing, you will need to redraw the network after your first attempt. Although your first attempt may be logically proper, it may look awkward and confusing. Redraw it to minimize line crossing and relocate activities to be as near as possible to their predecessors and successors.

In most of the preceding points, the word *improper* may not mean “incorrect.” However, following the preceding guidelines ensures a better and clearer drawing.

COMPARISON OF ARROW AND NODE NETWORKS

From our discussion of arrow and node diagrams, we find that node networks have the following five advantages over arrow networks:

1. Node networks are easier to draw.
2. Node networks do not require dummy activities to fix the activity identity problem.

3. Node networks do not require dummy activities to straighten up the logic.
4. Node networks can accommodate lags between activities without the addition of more activities.
5. In addition to the preceding advantages, node diagrams can be taken to an advanced stage in which they represent not just the traditional finish-to-start relationship but also three other relationships (start to start, finish to finish, and start to finish). This subject is discussed in detail in chapter 5. However, we mention it here as one more advantage of node networks. Arrow networks can represent only the traditional finish-to-start relationship.

In fairness to arrow networks, they have one important advantage over node networks: They depict activities as well as events. Node networks do not contain provisions for events. This point is circumvented in node diagrams by creating milestone activities (such as in computer programs) with zero duration to represent important events such as substantial completion of a facility. In some cases, milestones in node networks may work better than event nodes in arrow networks. Milestones are tied to the start or end of the specific activity or activities we are considering. An event node in arrow networks may be tied to the end and/or start of two or more activities when we are focusing on just one of these events. To understand the point, consider the event of the completion of activity K in example 3.7. This event is shown in the arrow network of Figure 3.7 as node 70. However, node 70 also represents the completion of activity L and the start of activity M. These three events may not –and usually do not- happen at the same time. Thus, the calculated event time for node 70 may not be accurate. In node networks, we create a milestone activity and tie it directly to the end of activity K. In this case, it will reflect the event of completion of activity K only. In addition, contrary to arrow networks that have a large number of event nodes, user of node networks has the discretion to create only a few milestone activities (events, in actuality), which give them better visibility and more focus.

NETWORKS VERSUS BAR CHARTS

When comparing bar charts with networks, we find that networks have three advantages over bar charts:

1. Networks show logic (i.e., the relationships among activities). Bar charts do not.
2. Networks can better represent large and complicated projects.
3. Networks can estimate, or predict, the completion date of the project, or other dates, on the basis of mathematical calculations of the CPM.

Bar charts predict the completion of the project, or other dates, on the basis of the creator's graphic skills.

In contrast, bar charts have these five advantages:

1. Bar charts are time-scaled (i.e., the length of the activity bar represents the time duration of the activity). Both nodes, in the node networks, and arrows, in the arrow networks, are not time-scaled.
2. Bar charts are simple to prepare.
3. Bar charts are easy to understand.
4. Bar charts are more acceptable for presentations, especially for field people and people who are unfamiliar with the CPM.
5. Bar charts can be loaded with more information, such as cash-flow diagrams and man-hours. This advantage is partially a by-product of being time-scaled.

Effective Use of Bar Charts with the CPM

Bar charts have an effective weapon CPM networks do not have: simplicity and power of presentation. As mentioned in point 4 in the preceding list, bar charts can be used effectively for—mainly—two types of presentations:

1. *Presentation to field people:* The project manager produces customized reports that include only a small group of the project activities (e.g., bar chart reports for subcontractors for their particular activities, or for activities that are supposed to start in the next 2 weeks). You can also isolate a group of activities that are to be done at a specific area of the project, or only critical activities. With the use of activity codes and the power of computer software, there is no limit for such uses.
2. *Presentation to high-level staff:* CEOs and senior managers are usually not concerned with the progress at the individual activity level. They like to get an overall picture of the project and the main components. Roll-up or summary bar charts have become a popular option in computer software. A group of activities is rolled up or summarized according to a common factor such as area, responsibility, phase, or the company's **work breakdown structure (WBS)**. Instead of looking at hundreds or thousands of activities, the top-level executive would be looking at a few bars that give him or her the overall picture of the progress of the project.

TIME-SCALED LOGIC DIAGRAMS

Some scheduling software vendors tried to take the advantage of networks (logic, or relationships) and impose it on bar charts in what some persons called **time-scaled logic diagrams**. The result was more like spaghetti. Depicting all relationships not only complicated bar charts (which eliminates their main advantage) but also did not

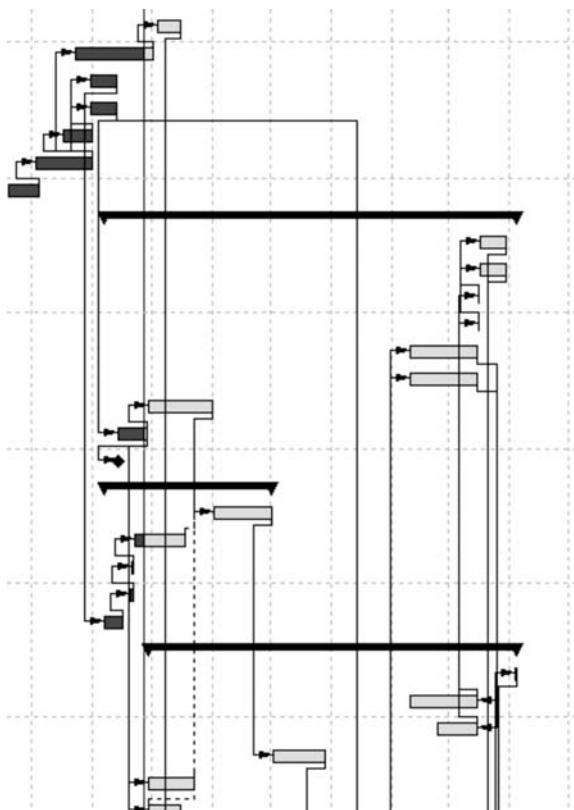


Figure 3.22 Time-scaled logic diagram or bar chart with logic links

make the logic as clear as it is in networks. This experiment was followed—in the software industry—by adding enhancing options such as “show only critical relationships” or “show only driving relationships.” In some simple cases, this approach may work as a good and acceptable solution.

CHAPTER 3 EXERCISES

1. What does a node mean in an arrow diagram?
2. What does an arrow mean in an arrow diagram?
3. What does a node mean in a node diagram?
4. What does a line mean in a node diagram?
5. What are the main differences between bar charts and networks?
6. What are the differences between arrow and node networks?

7. Arrow networks have another name; what is it? What is the reason for this name?
8. What are the main advantages of node networks over arrow networks?
9. What is the main advantage of arrow networks over node networks? How was it overcome?
10. What are *time-scaled logic diagrams*? Discuss their practicality.
11. What are the main advantages of networks over bar charts? How did bar charts manage to stay popular despite the advantages of networks?
12. Draw both the arrow network and the node network for the following project:

Activity	IPA
A	-
B	A
C	A
D	B
E	B, C

13. Draw both the arrow network and the node network for the following project:

Activity	IPA
A	-
B	-
C	A
D	A, B
E	C, D

14. Draw both the arrow network and the node network for the following project:

Activity	IPA
A	-
B	A
C	A
D	A
E	B
F	B, C
G	D, E, F

15. Draw both the arrow network and the node network for the following project:

Activity	IPA	Activity	IPA
A	—	F	D
B	—	G	D, E
C	—	H	C, F, G
D	A, B	I	C, G
E	B	J	H, I

16. Draw both the arrow network and the node network for the following project:

Activity	IPA	Activity	IPA
A	—	H	C, D
B	A	I	D
C	A	J	E, F, G
D	A	K	F, G, H
E	B	L	H, I
F	B, C	M	K, L
G	C		

17. Draw both the arrow network and the node network for the following project:

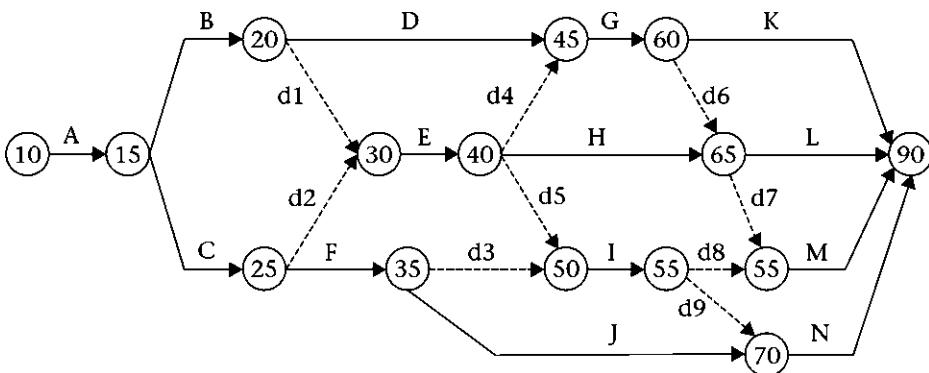
Activity	IPA	Activity	IPA
A	—	H	D, E
B	—	I	D, E, F
C	A	J	F
D	A, B	K	C, H, I
E	A, B	L	I, J
F	B	M	I
G	C	N	G, K

18. Draw both the arrow network and the node network for the following project:

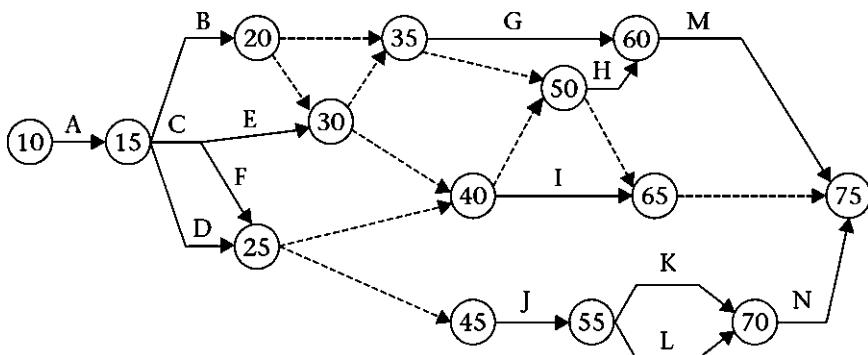
Activity	IPA	Activity	IPA
A	—	L	E, G
B	A	M	F, G, H
C	A	N	F, G, H, I

D	A	O	H, I
E	A	P	M, N, O
F	B	Q	K, L
G	B, C	R	L, M
H	B, C, D	S	J, P
I	C, D	T	Q
J	E	U	Q, R
K	F	V	T, U, S

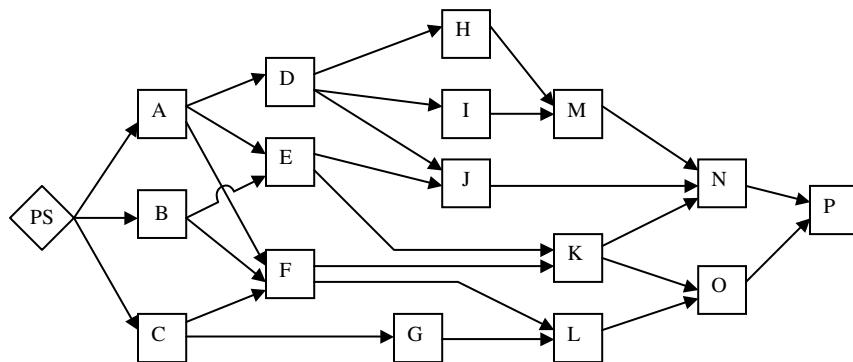
19. Convert the following arrow network into a node network.



20. Find and correct the errors and redundancies in the following arrow network.



21. Convert the following node network into an arrow network.



Chapter 4

The Critical Path Method (CPM)



Expansion Nadd Al Hamar/Beirut Roads Tunnel, Dubai, United Arab Emirates

INTRODUCTION

Suppose that you meet with two friends and decide to go on a hunting trip. One friend will go to get the food, the other will go to get the hunting gear, and you will go to prepare your Jeep. After each person finishes his or her assignment, you will drive together to the hunting location. Also suppose that the first activity (getting the food) requires 2 hours; the second activity (getting the hunting gear), 3 hours; and the third (getting the Jeep ready), 4 hours. If all three activities started at 8:00 A.M. (when each of you would leave to perform his or her task), the following activity (driving to the hunting location) cannot start until all three of you return (i.e., when all three preparation activities are complete). If everything works according to plan, the first person will return with the food at 10:00 A.M.; the second, with the hunting gear, at 11:00 A.M.; and you, with the Jeep ready, at 12:00 P.M. (see Figure 4.1).

Now, ask yourself the following question: Which activity “drives,” or controls, the schedule? The answer is the third activity (preparing the Jeep). Any delay in your return will delay the trip (past 12:00 P.M.). In contrast, your first friend will have 2 extra hours to “waste,” and your second friend, 1 extra hour. They can choose to use the extra time however they like. For instance, they could do the following:

- Get an early start, finish early, then take a break
- Get a late start (10:00 A.M. for the first person and 9:00 A.M. for the second) and finish at 12:00 P.M.
- Take breaks between work periods

We will call this extra time **float**. Your friends will have to watch their time carefully so that they do not waste more time than the float that they have: 2 hours for the first person and 1 hour for the second. Any delay past these float times will result in a delay in the entire schedule. You, however, have no float. You are running on a tight

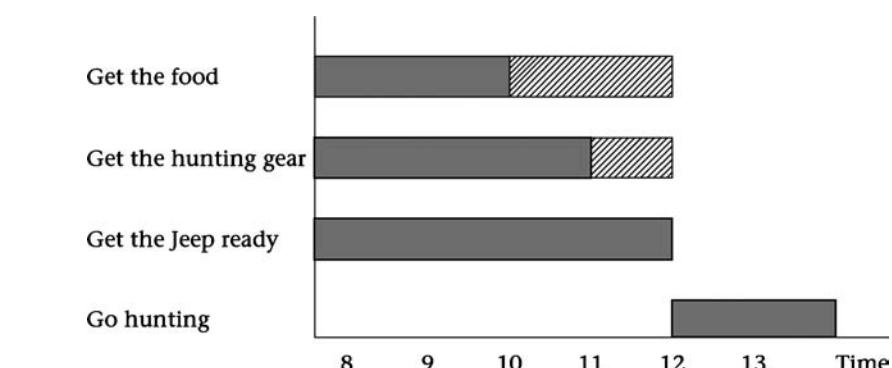


Figure 4.1 Bar chart for introductory hunting trip example

schedule. Your activity is *critical*. This scenario provides a simplified example of the *Critical Path Method (CPM)*.

STEPS REQUIRED TO SCHEDULE A PROJECT

For the planning, execution, and completion of a project, many steps are required that may not be part of scheduling. In this chapter, we discuss the role of the scheduler given that the project has been defined (and designed in most cases). Some schedules (especially those for **fast-track projects**, in which construction starts before design finishes) may include design and design review activities as part of the schedule. In general, the preparation of a CPM schedule includes the following four steps:

1. *Determine the work activities*: Any project, no matter how large or small, must be divided into smaller entities, called *activities*, or *tasks*.¹ An activity is a unique, definable element of work. In this step, there is no absolutely correct or incorrect breakdown. You may give the same project to 10 schedulers, and they may devise 10 different breakdowns, with some breakdowns being significantly different. In this regard, there are two schools of thought:
 - a. *Restrict the number of activities for the simplicity of the project schedule*: In this case, activities become “major” components. However, there is a practical—and sometimes contractual—limit on how large an activity may be. For instance, it is impractical to have Concrete Operations as one activity with 300 days’ duration. In addition, in many contracts, a maximum limit is set on the duration of any activity, usually about 14 to 30 days.
 - b. *Break the project down into small activities*: This approach will result in a large number of activities. The main advantage of this approach is better control of the schedule during execution. You can easily tell the status (percent complete) of a small activity, such as Place Concrete for Spread Footings No. 23, better and more objectively than you can do so for a large activity, such as Building Foundation. The main disadvantage of having many activities is the additional work and hassle. However, this disadvantage may not be as important with the use of computers. Furthermore, you can roll up a group of activities into a major activity, as discussed in chapter 3.

Factors considered in breaking down the project into individual activities for better control:

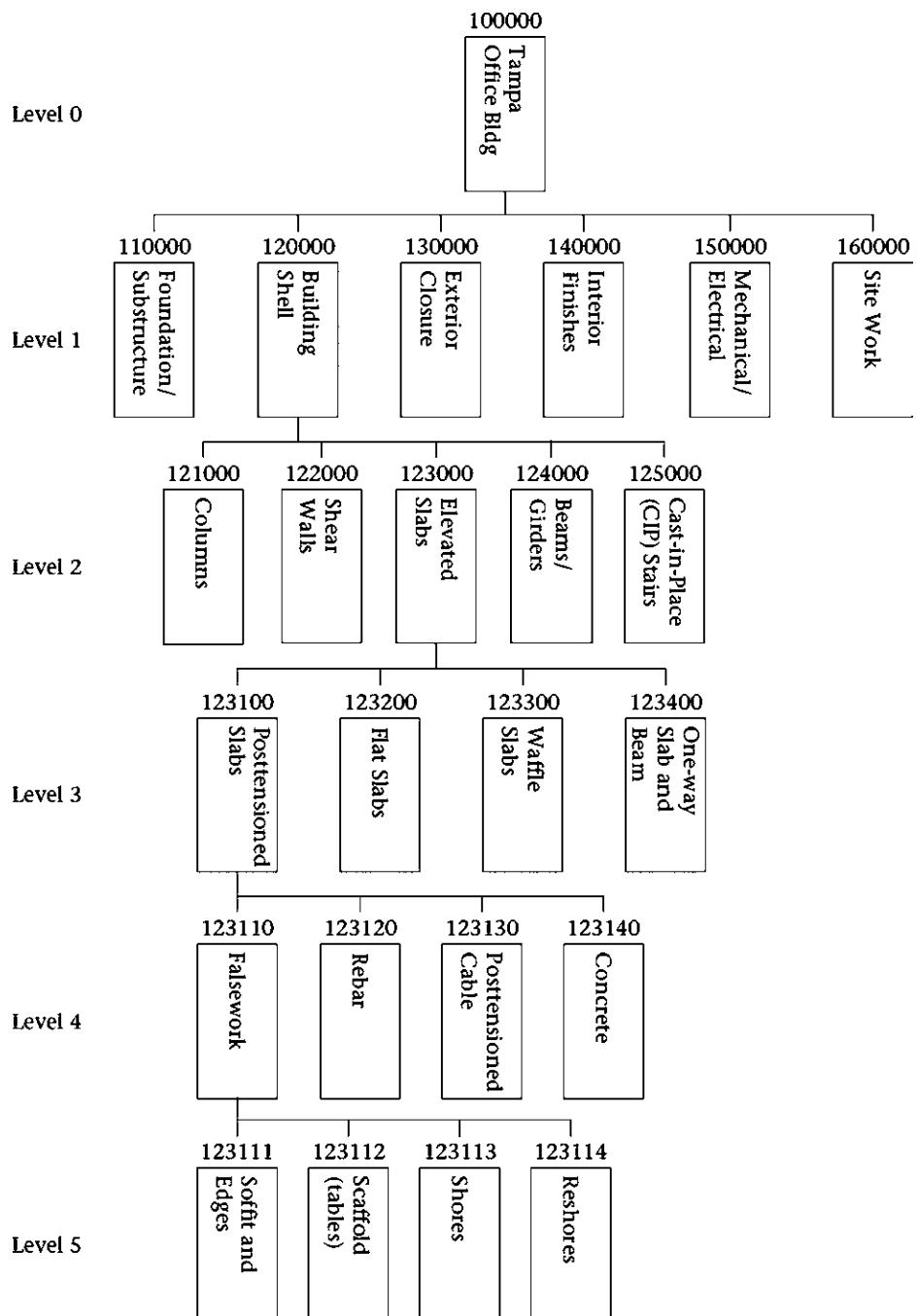
¹ In reality, the two terms are synonymous. Some software packages use the term “task,” while others use “activity” and sometimes with the term “task” indicating subactivity.

- *Nature of the work/Homogeneity*: It is impractical to put apples and oranges in the same basket. If the work involves two different materials and/or measured by different units, it must be divided into two different activities. For example, wall construction involves framing, drywall, and painting as basic different activities.
- *Location/floor*: Activities falling in different locations must be separated.
- *Size/duration*: For large activities or those with large quantity, it is better to divide the activities into small portions. For example, large excavation activities can be divided into smaller activities by grid or depth. For linear excavation, this can be divided by stations or 100-foot segments. This helps in measurement of work progress while execution. As mentioned earlier, this can be a contractual requirement.
- *Timing/chronology*: Sometimes a portion of the work maybe delayed purposely by the contractor. For example, a portion of the slab on grade (SOG) for a building maybe delayed till the end of the project because the area is being used as storage. Such portion must be considered as an activity by itself.
- *Responsibility*: Schedulers must break down pieces of work that are done by different parties (subcontractors). In case of schedule variance, it is important to indicate who is responsible for the variance.
- *Phase*: This can be a division made by the designer based on certain criteria such as timing, location, or other aspects.

The preceding six factors underscore the difference between the cost estimator's and scheduler's mentality in breaking down the project into activities. For example, to the estimator; a slab on grade—in the project—is a slab on grade, no matter where or at what time it was placed. To the scheduler, it does matter.

Each activity must be given a unique identity (ID). In this book, we deal mostly with examples of small projects. We use the alphabet (A, B, C, etc.) as IDs for activities. Real-life projects may comprise hundreds—perhaps thousands—of activities. The ID must be chosen to follow a certain pattern consistently using alphanumeric characters. In many cases, the breakdown must be coded according to the company's policy, where the code reflects the name of the project, location, type of activities, and so forth.

One way to break down a project is by using the **work breakdown structure (WBS)**. The WBS is defined as a task-oriented, detailed breakdown of activities that organizes, defines, and graphically displays the total work to be accomplished to achieve the final objectives of a project. The WBS breaks the project down into progressively more detailed levels. Each descending level represents an increasingly detailed definition of a project component. An example of the WBS can be seen in Figure 4.2. In construction scheduling, the components at the lowest WBS level are used as activities to build the project schedule. As mentioned previously, activities may be rolled up for summarization purposes.

**Figure 4.2 Sample work breakdown structure (WBS)**

Schedulers and estimators can use the standard breakdown of the CSI (Construction Specifications Institute) MasterFormat 1995 (divided into 16 divisions) or MasterFormat 2004 (divided into 50 divisions²).

2. *Determine activities' durations:* Techniques for estimating **activity duration** vary from one situation to another, depending on the type of work, the estimator, and other factors. Most activity durations can be estimated as follows:

$$\text{Duration} = \frac{\text{Total quantity}}{\text{Crew productivity}}$$

For example, for 10,000 CY (cubic yards) of excavation and a crew that averages 800 CY per day, the following is true:

$$\text{Duration} = \frac{10,000 \text{ CY}}{800 \text{ CY per day}} = 12.5 \text{ days} \approx 13 \text{ days}$$

This information could come from the project team (project manager, project superintendent), who receives feedback from field crew leaders; from the estimating department; or from other sources (e.g., subcontractors). It is given to the scheduler with the project manager's approval. Durations are, by no means, carved in stone. They are based on previous experiences, with adjustments for current job conditions (such as weather conditions, design complexity, soil type, etc.). They are also subject to the crew size and the number of crews, if more than one. The durations of some activities are totally subjective and left to the project manager and the technical team, such as the mechanical or electrical repair team, to "guesstimate." Depending on the nature of work and work environment, it is a good idea for the scheduler to be moderately conservative in estimating durations. Remember that such estimates of durations, even when they have a "scientific basis," are future predictions and Murphy's Law is always there!

In most construction projects, durations are calculated in **workdays**, which usually, but not always, follow a 5-day workweek. In some cases, the project, or only certain crews, follow a 6- or 7-day workweek. In some other countries, a 6-day workweek may be the norm. In others, such as those in the Middle East, a workweek starts on Saturday or Sunday, not Monday. The scheduler must be aware of such **calendars**.

The scheduler must also account for **nonworkdays**, such as holidays, rain (weather) days, shutdowns, and the like. The contract usually specifies official holidays and the allowed number of **rain days**. Rain days represent the number of days (per month) that work on the project is expected to be suspended because of weather delays. This prediction is usually calculated on the basis of past meteorological data for the location. It does not include unusual weather and disasters. (Delays due to unusual weather or disasters are discussed in chapter 13). The distribution of this time allowance is discussed in chapter 10.

² Sixteen of the fifty divisions in the CSI MasterFormat 2004 are currently blank and labeled as "Reserved for future use." Some construction professionals refer to the count of the CSI MasterFormat 2004 as 49 divisions, as they forgot to count division 00, Procurement and Contracting Requirements.

Although the workday is the most often used **calendar unit** in construction projects, other units of time, such as the hour, the week, or the month, are not unthinkable. Industrial projects may have to be scheduled by the hour, especially with multiple-shift schedules. The scheduler, along with the management team leaders, must decide on the unit of time before preparing the schedule because changing the unit of time after the project starts is extremely difficult and confusing and can lead to unnoticeable errors. When choosing a time unit for duration, you can roll up the timeline in reporting, but you cannot “roll down.” For example, if the time unit is “week,” you can report in weeks, months, quarters, or years, but you cannot report in days.

3. *Determine logical relationships:* Again, this step is a technical matter. The scheduler should obtain this information from project managers and technical team leaders. Logical relationships should not be confused with **constraints**:
 - a. A **logical relationship** exists between two activities when the start of one activity (or finish, as is explained in chapter 5) depends *physically* on the finish (or start) of another activity. For example, you cannot place the concrete until the formwork and reinforcement are erected. You cannot hang the drywall until framing is done.
 - b. A **resource constraint** (or restriction) is when you can theoretically do two tasks at the same time, but you schedule one as a predecessor of the other because of resource (labor, equipment) limitation.
Some practitioners refer to the preceding two types of relationships as *hard logic* and *soft logic*, respectively. This terminology is scientifically suitable because hard logic cannot be relaxed under any circumstances, while soft logic can be relaxed if more resources are acquired.
 - c. Another constraint is when an activity is subject to a (mostly subjective) constraint such as approval of an owner or a government agency, funding availability, or even workspace availability. Be careful not to confuse this type of constraint with a logical relationship. Typically, a good project schedule should only have a few constraints at most.
4. *Draw the logic network, and perform the CPM calculations.* If you are using a computer program, it will perform these functions for you, provided that you have input the correct data. In this step, you will obtain the calculated finish date of the project, the critical path, and the available float for all noncritical activities. It is important to check the input and the output and not to rely totally on the computer.

In most construction projects, subcontractors are involved, and their input into the schedule is important. The **schedule** is typically one topic discussed in preconstruction meetings of the owner, the general contractor (GC), and major subcontractors. Often, the GC provides an opportunity for the major subcontractors to supply him or her with schedules for work so that he or she can incorporate them into

the master schedule. Alternatively, the GC may create the overall schedule based on feedback from subcontractors and other involved parties (the GC has then to communicate the schedule with all participants and has to get their approval or acceptance of their roles. This topic is discussed further in chapter 10).

SUPPLEMENTAL STEPS

The preceding four steps make up the “backbone” of the CPM. Following are four additional steps that are essential for an effective, accurate, and successful schedule:

5. *Review and analyze the schedule:* First, review the logic and make sure that every activity has the correct predecessors and no redundant relationships. Common errors are as follows:
 - a. *Wrong relationship:* A wrong relationship occurs when the relationship is connected to the wrong activity or to the appropriate activity but at the wrong end (e.g., you connect the end of an activity when the relationship is start to start).
 - b. *Missing relationship:* A missing relationship occurs when a predecessor of an activity is simply not shown. The possibility of this type of error is why we like to start a project with one activity and finish it with one activity. Computer programs such as Primavera Project Manager, P6, list all activities with either no predecessors or no successors. We typically like to see only one of each. Project managers and schedulers look at excessive float (explained later) as a red flag. Such large float usually—but not always—indicates an activity not tied to any other activity, so the computer program gives it float till the end of the project. Even with such practice, there is still a possibility of missing relationships, particularly external ones, that is, those that tie activities under one party to other activities under other parties.
 - c. *Redundant relationship:* When, for example, C requires B and B requires A, if you draw A and B as predecessors of C, A is a redundant predecessor for C (Figure 4.3a). Redundant relationships are not errors. They are just a nuisance and complication to the network.
 - d. *Logic loop:* A *logic loop* occurs when you leave a point on the network, then return to it later (e.g., A requires B, but B requires A) (Figure 4.3b). This error terminates the calculations in any CPM computer program. The author of this book strongly recommends that when drawing (or inputting) the relationships, you do so from one side only. This means looking at either predecessors or successors, not both at the same time. The author personally prefers dealing with predecessors. When reviewing the logic, you may look at both ends of an activity for accuracy of the logic.

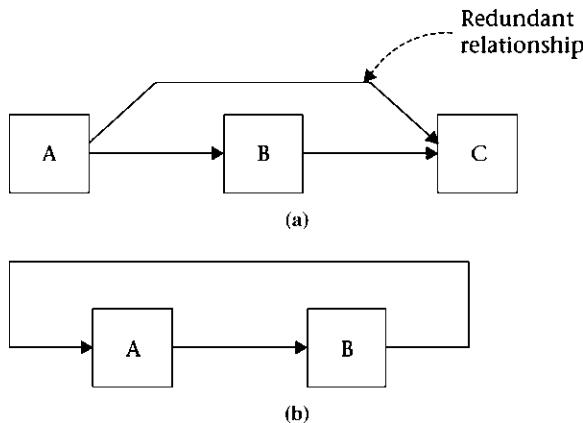


Figure 4.3 Common scheduling errors: (a) redundant relationship; (b) logic loop

6. *Implement the schedule:* Implementing the schedule means taking the scheduling from paper to execution. This step is important for fulfillment of the schedule. Most importantly, the scheduler (under directions from the project manager) must choose start and finish dates within the range of the calculated dates (early and late). When an activity has a range of dates (e.g., can start as early as 13 June 2011 and as late as 11 July 2011), it is *not* a good idea to give the choice of date selection to the field crew or even subcontractor.

Every participating party must receive correct information at the appropriate time. Too little or too much information may be counterproductive. Three important points should be noted: First, the schedule must be realistic and fairly accurate. Second, the upper managers must take it seriously. Third, such implementation and commitment must continue throughout the project.

7. *Monitor and control the schedule:* As defined in chapter 1, *project control* means comparing the **baseline** (what was planned or what was supposed to have been done) with what has actually been done, analyzing any deviation (variance) from the baseline, and taking corrective action whenever and wherever needed. The main difference between the two terms (*monitor* and *control*) is the corrective action. *Monitoring* includes observing and reporting, and perhaps analyzing. *Control* adds corrective action to this definition. The two terms are mentioned because the schedule may be monitored by the owner or the project management consultant, PMC. These two parties have no power to take direct corrective action during execution of the project. Only the party who is executing the work (usually the GC and subcontractors) can perform control. As in the last step, keeping open communication channels among all involved parties and disseminating appropriate information are extremely important.

An important part of the control effort is **forecasting**. Forecasting is done mostly by extrapolating actual performance for the remaining portion of the project. When actual performance is below the baseline, forecasting is used more as a warning. For example, the project manager may say, “We are 20% complete for the project and we are \$10,000 over budget. If we don’t make an adjustment, we’ll finish the project \$50,000 in the red.” The scheduler can also experiment with different future scenarios and even use simulation for possibilities and impact of outcomes.

8. *Revise the database and record feedback:* This process is continuous and iterative. All cost and time estimates for activities are based on past experience. This past experience must be documented in a well-organized, easy-to-retrieve fashion. Every new cycle should be a little more accurate than the previous one. Suppose that you are estimating your new job on the basis of the past three jobs. After finishing this job and inputting the new results, your database now has four jobs, and the next job will be based on the four previous jobs, and so on.

In addition to documenting and organizing, you must record any unusual events and explain any adjustment because your record may be used for future estimates. For example, your productivity for a certain activity may be significantly below normal because of extreme weather, sticky soil, hard rock, equipment failure, low morale as a result of an accident, or some other reason. Your productivity may be above average because of an unusually favorable (or lucky³) work environment. Unusual recordings must be adjusted or normalized. If the job being estimated is expected to be completed under unusual circumstances, the estimate must be adjusted accordingly.

RESOURCE ALLOCATION AND LEVELING

In addition to the eight steps just discussed, other optional steps may be implemented for a comprehensive approach to scheduling as part of project management:

9. *Cost/resource allocation (or loading):* **Resources** in this context include labor, equipment, and materials. Cost loading is assigning the appropriate cost (or budget) to each activity. When the cost of all activities is added up, it should equal to the project’s budget. **Resource allocation** simply means assigning the right amount of resources to each activity at the right time. The objective of this step is to load each activity with the amount of resources it requires and, hence, calculate its budget. This can help link scheduling with estimating and accounting. At any point in the project, you should be able to tell the original (baseline) budget, actual cost, **estimate to complete (ETC)**, **estimate at**

³ We teach that good results and smooth, flawless work are no accident or coincidence. However, the term *lucky* is used in this instance to emphasize the reality of estimation.

completion (EAC), and other financial data for each activity and for the entire project. You may also link to cost accounting for procurement, invoicing, and other functions.

Resource loading—along with the “Resource Dictionary”⁴—will result in cost loading to each activity but in a smarter way than just assigning cost figures. Let’s compare the cost of an “Excavation” activity with 12 days duration, assigned in two different ways:

- a. A cost number of \$14,976, or
- b. One Equipment Operator, one Laborer, and one Hydraulic Excavator

From the resource dictionary, we find the unit cost for these resources:

Equipment Operator @ \$30/hour

Laborer @ \$21/hour

Hydraulic Excavator @ \$840/day

So, the total cost for Excavation = 12 days * [8 hours/day * (30 + 21) + 840] = \$14,976

Assigning a budget by assigning resources to activities (method “b” above) has many advantages, such as:

- Ease of changing/updating the cost of an activity and the project when the unit price of a resource changes, especially when multiple activities use that resource
- Ability to integrate with accounting and procurement
- Ability to estimate and store (in database) productivities and man-hours and to do cost analysis
- Ability to do resource leveling and to set upper limits on resource consumption
- Ability to use “resource-driven” activities (i.e., allow the program to assign the maximum available resource amount to an activity, thus, controlling its duration and timing within its float)

10. *Resource leveling*: This topic is discussed in detail in chapter 6. **Resource leveling** is simply trying to maintain uniform daily use of a resource (or resources) for the entire life cycle of the project or for the longest continuous segment of it. The objective of this step is to improve the efficiency of resource utilization (particularly labor and equipment) during the life cycle of the project.

⁴ Resource Dictionary in Primavera P3 or P6 is small database, at the level of the project, containing information on all resources such as cost and availability. It can—and usually is—exported from one (existing) project to another (new) one.

BEGINNING-OF-DAY OR END-OF-DAY CONVENTION

In this book, for mathematical computations, and for the sake of simplicity, we follow the **end-of-day convention**: any date mentioned for an activity means the end of that day. In this convention, projects usually start at the beginning of day 1, which becomes the end of day 0. Almost all authors use this convention. Computer software programs, however, are more sophisticated: the start date follows the **beginning-of-day convention**, and the finish date follows the end-of-day convention. These conventions are explained further in the following examples.

THE CPM EXPLAINED THROUGH EXAMPLES

Example 4.1: Logic Networks and the CPM

Example 4.1

Draw the logic network and perform the CPM calculations for the schedule shown next.

Activity	IPA ^a	Duration ^b
A	—	5
B	A	8
C	A	6
D	B	9
E	B, C	6
F	C	3
G	D, E, F	1

^aImmediately preceding activity. ^bIn days.

Solution: The Forward Pass

The project starts with activity A, which starts at the beginning of day 1 (end of day 0). It takes 5 days to finish activity A; it finishes on day 5 (end of the day). At this point, activities B and C can start. Activity B takes 8 days; it can start on day 5 (directly after activity A finishes), so it can finish as early as day 13. Similarly, activity C can finish on day 11 (5 + 6). Activity D follows activity B. It can start on day 13 (end of B) and end on day 22. Activity E must wait till *both* activities B and C are finished. Activity C finishes on day 11, but activity B does not finish till day 13. Thus, activity E cannot start till day 13. With 6 days' duration, activity E can then finish on day 19. Activity F depends on activity C only. Thus, it can start on day 11 and finish on day 14. The last activity, G, cannot start till activities D, E, and F are finished. Through simple

observation, we can see that activity G cannot start till day 22 (when the last activity of D, E, and F finishes). Activity G takes 1 day, so it can finish on day 23. Figure 4.4 shows the completed logic network.

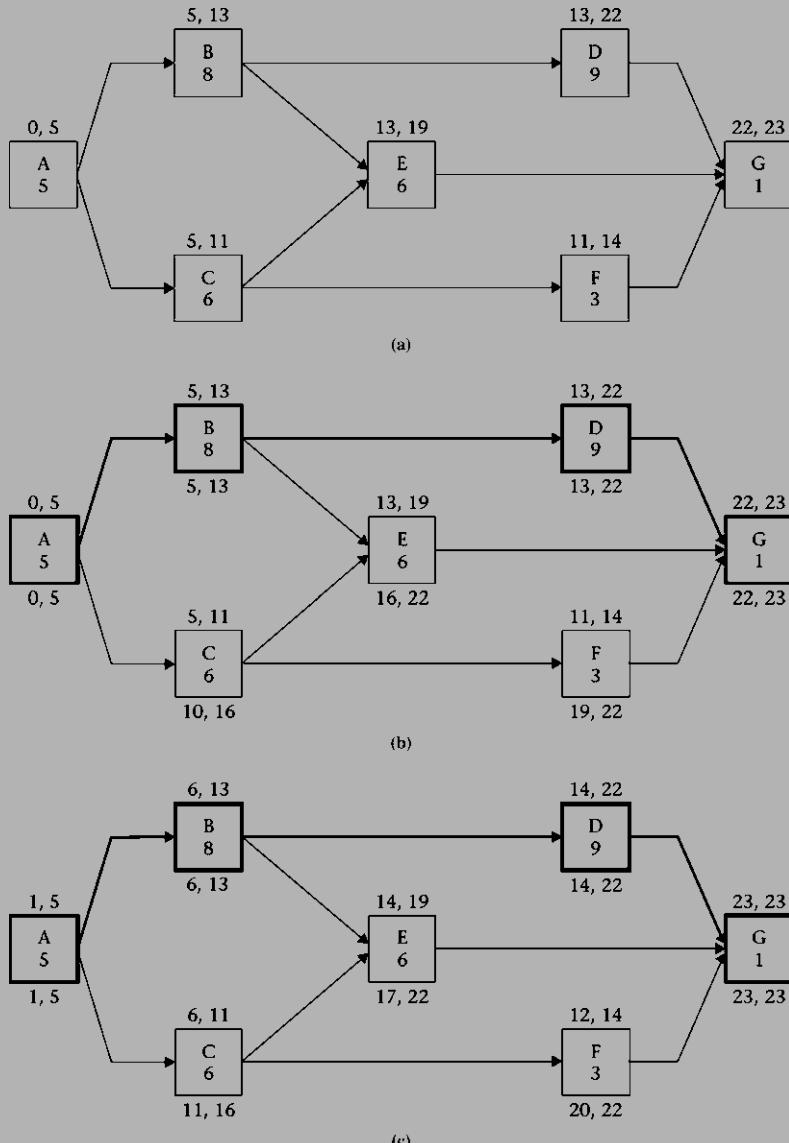


Figure 4.4 Completed logic network: (a) forward pass; (b) forward and backward passes; (c) computer generated

For this example, we have calculated two types of dates:

1. The expected completion date of the project: day 23
2. The earliest date when each activity can start and finish

These dates are called the **early start (ES)** and the **early finish (EF)** dates for each activity. As you will soon learn, an activity cannot start earlier than its ES date and cannot finish earlier than its EF date, but it *may* start or finish *later* than these dates.

In mathematical terms, the ES time for activity j (ES_j) is as follows:

$$ES_j = \max(EF_i) \quad (4.1)$$

where (EF_i) represents the EF times for all immediately preceding activities.

Likewise, the EF time for activity j (EF_j) is as follows:

$$EF_j = ES_j + Dur_j \quad (4.2)$$

where Dur_j is the duration of activity j .

The **forward pass** is defined as the process of navigating through a network from start to finish and calculating the **early dates** for each activity and the completion date of the project. See Figure 4.4 (a).

Solution: The Backward Pass

Now let us start from the end of the project and work our way back to the start. We already know the end-of-project date⁵: day 23. Activity G must finish by day 23. Its duration is only 1 day, so it must start no later than day 22 ($23 - 1$) so that it does not delay the project. Similarly, activities D, E, and F must finish no later than day 22 so that they will not delay activity G. Through simple computations, we can find their late start dates: activity F: $22 - 3 = 19$; activity E: $22 - 6 = 16$; and activity D: $22 - 9 = 13$. Activity C must finish before activities E and F can start. Their late start dates are 16 and 19, respectively. Clearly, activity C must finish by the earlier of the two dates, day 16, so that it will not delay the start of activity E. Thus, its late start date is day 10 ($16 - 6$). Similarly, activity B must finish by the earlier of its successors' late start dates: day 13 for D and day 16 for E. Therefore, the late finish date for activity B is day 13 and its late start date is day 5 ($13 - 8$). The last activity (from the start) is A: It must finish by the earlier of the late start dates for activities B and C, which are day 5 for B and day 10 for C. Consequently, the late finish date for activity A is day 5, and its late start date is day 0 ($5 - 5$).

⁵ For now, we'll start the *Backward Pass* with the project's completion date calculated in the *Forward Pass*. Later on (in this chapter), we will discuss other cases when an *Imposed Finish Date* is implemented.

In mathematical terms, the **late finish (LF)** time for activity j (LF_j) is as follows:

$$LF_j = \min(LS_k) \quad (4.3)$$

where (LS_k) represents the late start times for all succeeding activities.

Likewise, the **late start (LS)** time for activity j (LS_j) is as follows:

$$LS_j = LF_j - Dur_j \quad (4.4)$$

The **backward pass** is defined as the process of navigating through a network from finish to start and calculating the **late dates** for all activities. This pass, along with the forward-pass calculations, helps identify the critical path and the float for all activities.

If you refer to Figure 4.4b, you can see that for some activities (light lines), the late dates (shown under the boxes) are larger (i.e., later) than their early dates (shown above the boxes). For other activities (thick lines), late and early dates are the same. For the second group, we can tell that these activities have strict start and finish dates. Any delay in them will result in a delay in the entire project. We call these activities critical activities. We call the continuous chain of critical activities from the start to the end of the project the **critical path**.

Other activities have some leeway. For example, activity C can start on day 5, 6, 7, 8, 9, or 10 without delaying the entire project. As mentioned previously, we call this leeway float.

There are several types of float. The simplest and most important type of float is **total float (TF)**:

$$TF = LS - ES \text{ or } TF = LF - EF \text{ or } TF = LF - Dur - ES \quad (4.5)$$

We tabulate the results in the following table (boldface activities are critical):

Activity	Duration	ES	EF	LS	LF	TF
A	5	0	5	0	5	0
B	8	5	13	5	13	0
C	6	5	11	10	16	5
D	9	13	22	13	22	0
E	6	13	19	16	22	3
F	3	11	14	19	22	8
G	1	22	23	22	23	0

With the completion of the backward pass, we have calculated the late dates for all activities. With both passes completed, the critical path is now defined and the amount of float for each activity is calculated.

The CPM with Computer Software Programs

If we plot the previous CPM network by using one of the commercially available computer software programs, such as Primavera Project Manager or Microsoft (MS) Project, Figure 4.4c will be the result. The only difference between the network shown in Figure 4.4b and that shown in Figure 4.4c is the start dates because, as mentioned previously, these computer programs use the start of the day when calculating start dates and the end of the day when calculating finish dates. This approach affects the forward-pass and backward-pass calculations. Equations 4.1 through 4.4 are, thus, rewritten as follows:

$$ES_j = \max(EF_i) + 1 \quad (4.1)'$$

$$EF_j = ES_j + Dur_j - 1 \quad (4.2)'$$

$$LF_j = \min(LS_k) - 1 \quad (4.3)'$$

and

$$LS_j = LF_j - Dur_j + 1 \quad (4.4)'$$

The Critical Path

If we think about the situation in the project we just scheduled, we will notice that activities A, B, D, and G are “driving” the schedule. These activities are critical because any delay in their start or finish will delay the entire project. For example, if activity B takes 9 days instead of 8 days, it will finish on day 14. Activity D can then start and will finish on day 23. Finally, activity G can start on day 23 and will finish on day 24, which is 1 day past the originally scheduled date. This delay in the project completion date may not occur with a delay (within certain limits) in other activities, such as C, E, or F. Project managers usually focus on the critical path because of its criticality and direct impact on the project finish date. Knowing not only which activities are critical and which are not but also the impact of the delay of one activity on other activities and on the entire project is the crux of understanding scheduling.

Following are five observations about the critical path:

1. In every network, there must exist at least one critical path.
2. More than one critical path may exist. Multiple paths may share some activities.
3. Any critical path must be continuous from the start of the project till its end. There is one exception: When a constraint is imposed (which is discussed later), a path may become critical—as a result of the constraint—from start till

the constrained activity or from the constrained activity till the end. In general, the entire path must be either critical or noncritical.

4. If all paths in a network must go through one particular activity, this activity must be critical (e.g., activities A and G in example 4.1).
5. Some people like to define the critical path as the path with zero float. This definition is correct only if no **imposed finish date** is used in the backward-pass calculations (again, this point is discussed later). However, our definition—the longest path in a network, from start to finish—is more appropriate because it is always true. We can also say that the critical path is the path with least float.⁶

Driving and Nondriving Relationships: Activity E in example 4.1 has two predecessors: B and C. We observe that the relationship coming from activity B is the one that controls the start of activity E. The relationship coming from activity C has no bearing on the starting of activity E. In this case, we call the relationship from activity B to activity E a driving relationship. Conversely, we call the relationship from activity C to activity E a nondriving relationship. Similarly with activity G, the relationship from activity D is driving, while the relationships from activities E and F are nondriving.

Definitions Pertaining to Example 4.1

Activity, or task: A basic unit of work as part of the total project that is easily measured and controlled. It is time- and resource-consuming.

Backward pass: The process of navigating through a network from end to start and calculating the late dates for each activity. The late dates (along with the early dates) determine the critical activities, the critical path, and the amount of float each activity has.

Critical activity: An activity on the critical path. Any delay in the start or finish of a critical activity will result in a delay in the entire project.

Critical path: The longest path in a network, from start to finish, including lags and constraints.

Driving Relationship: A relationship from a predecessor activity that controls the start or finish of a successor activity. For any activity with predecessors, there must be at least one driving relationship.

Early dates: The early start date and early finish date of an activity.

Early finish (EF): The earliest date on which an activity can finish within project constraints.

Early start (ES): The earliest date on which an activity can start within project constraints.

⁶ Think algebraically; $TF = -8$ is less than $TF = 0$.

Event: A point in time marking a start or an end of an activity. In contrast to an activity, an event does not consume time or resources. In computer software, events with significance can be created as milestones, and they are either start milestones, such as Notice to Proceed, or finish milestones, such as Substantial Completion.

Forward pass: The process of navigating through a network from start to end and calculating the completion date for the project and the early dates for each activity.

Late dates: The late start date and late finish date of an activity.

Late finish (LF): The latest date on which an activity can finish without extending the project duration.

Late start (LS): The latest date on which an activity can start without extending the project duration.

Total float (TF): The maximum amount of time an activity can be delayed from its early start without delaying the entire project.

Examples 4.2 and 4.3: Node Diagrams and the CPM

Example 4.2

Draw the node diagram and perform the CPM computations for the schedule shown next.

ACTIVITY	IPA	DURATION
A	—	2
B	A	6
C	A	10
D	A	4
E	B	7
F	B, C	5
G	C, D	3
H	E, F	5
I	G, H	2

Solutions

Performing forward and backward passes yields the solution shown in Figure 4.5. The critical path is A, C, F, H, I. Activities B, D, E, and G have total floats equal to 2, 13, 2, and 7, respectively.

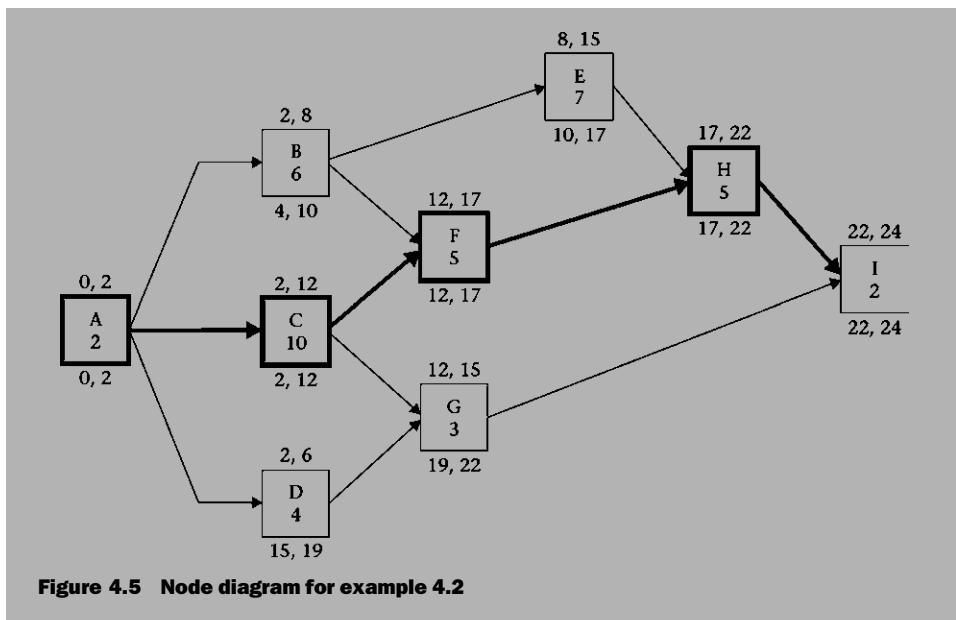


Figure 4.5 Node diagram for example 4.2

Free Float

Let us examine the impact that one activity may have on other activities when it consumes its total float or part of it. In example 4.2, if activity B is delayed by 1 day only and starts on day 3 (which is well within its available float), it will finish on day 9. (*Remember:* We always mean the end of the day.) Activity E, then, cannot start on its early start date (i.e., day 8). The earliest date E can start is day 9. If we delay activity B by 2 days, activity E cannot start till day 10 and, thus, becomes critical. This 1- or 2-day delay in the start of activity B will not affect the project completion date. However, if we delay activity B by more than 2 days, it will finish past day 10, which will affect the start of the critical activity H and, thus, delay the entire project. This discussion illustrates the concept of *total float*, which was defined previously as the maximum amount of time an activity can be delayed without delaying the entire project. Note, though, that this delay—within the total float—may (and did in this case) or may not delay the early start of the subsequent activities.

Now let us apply the same discussion to activity G. It has 7 days of total float. Delaying it by as many as 7 days will not affect the succeeding activity, I. The same argument applies to activity E, only with 2 days of total float.

Next, we discuss yet another case of total float. Consider activity D, which has 13 days of total float. When we delay it by 1 or 2 days, for example, we notice that this delay does not affect the early start of the following activity, G, since G is waiting for the completion of activity D as well. However, when the delay of activity D exceeds 6 days, the situation changes. If we consider delaying activity D by 7 days, it finishes on day 13. Activity G, then, cannot start until day 13. It should finish on day 16, which

will not delay activity I and the entire project. This 7-day delay in activity D delayed the early start of its successor (activity G), yet did not delay the entire project. We can increase this delay to 13 days (which is the total float for activity D) without affecting the completion date of the entire project but affecting the succeeding activity, G.

We can divide activity D's 13-day total float into two portions: The first 6 days will not delay its successor. This is called **free float (FF)**. The other 7 days will cause a delay to its successor even though they will not delay the entire project. This is called **interfering float (Int. F)**. We can look at the situation this way: Activities D and G share the 7-day interfering float. If the first activity in line uses it, it will be taken away from the next activity. Similarly, we can determine that activity B has no free float (total float is all interfering float). The free float of activity G equals its total float (no interfering float). To calculate free float for an activity, we need to compare its early finish date with its successor's early start date. When there is only one successor activity (Figure 4.6a), the calculation is simple:

Activity G's free float, $FF = 22 - 15 = 7$ days When the activity has more than one successor (Figure 4.6b), you must pick the earliest early start date among the successors: Activity B's free float, $FF = \min(12, 8) - 8 = 0$ days In general, *free float* is calculated by using the following equation: $FF_i = \min(ES_{i+1}) - EF_i$, where $\min(ES_{i+1})$ means the least (i.e., earliest) of the early start dates of succeeding activities.

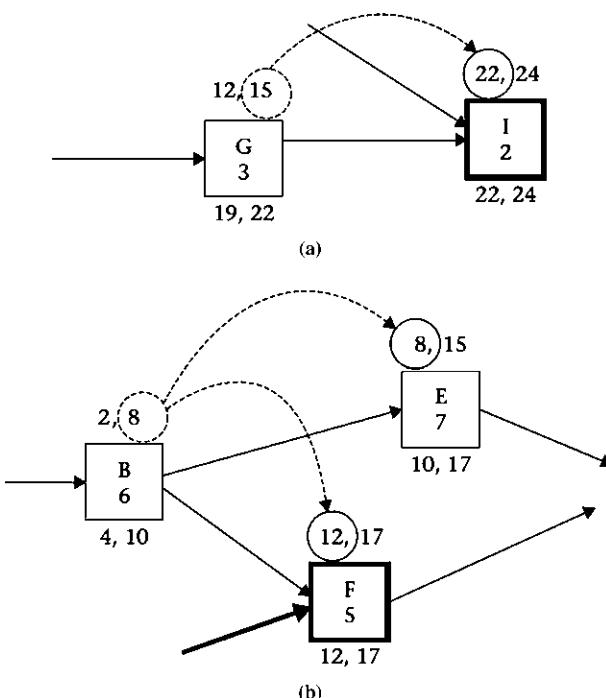


Figure 4.6 Free float with (a) one successor activity and (b) more than one successor activity

Example 4.3

Draw the node diagram and perform the CPM computations for the schedule shown next.

Activity	IPA	Duration	Activity	IPA	Duration
A	—	2	H	D	9
B	A	7	I	F, G	12
C	A	10	J	F	5
D	A	4	K	E, J	5
E	B	6	L	G, H	6
F	B, C	5	M	F, H	4
G	C, D	8	N	I, K, L, M	3

Solution

Performing forward and backward passes yields the solution shown in Figure 4.7.

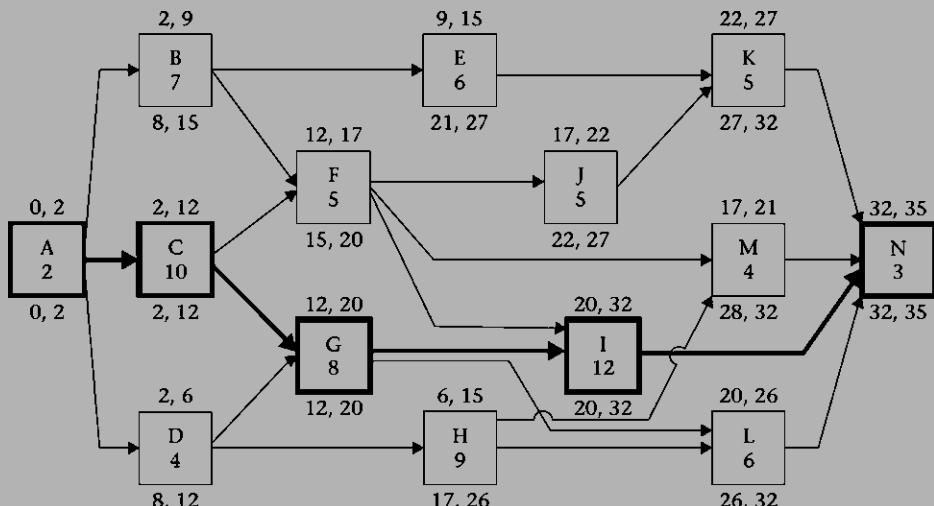


Figure 4.7 Node diagram for example 4.3

Performing the CPM calculations, we find the early dates, late dates, total float (TF), and free float (FF) for all activities, as shown in the following table.

Activity	Duration	ES	EF	LS	LF	TF	FF
A	2	0	2	0	2	0	0
B	7	2	9	8	15	6	0
C	10	2	12	2	12	0	0
D	4	2	6	8	12	6	0
E	6	9	15	21	27	12	7
F	5	12	17	15	20	3	0
G	8	12	20	12	20	0	0
H	9	6	15	17	26	11	2
I	12	20	32	20	32	0	0
J	5	17	22	22	27	5	0
K	5	22	27	27	32	5	5
L	6	20	26	26	32	6	6
M	4	17	21	28	32	11	11
N	3	32	35	32	35	0	0

Definitions Pertaining to Examples 4.2 and 4.3

Free float may be defined as the maximum amount of time an activity can be delayed without delaying the early start of the succeeding activities. Some authors add “and without delaying the entire project.” This statement is not incorrect, but it is redundant. The first condition “without delaying the early start of the succeeding activities” is more stringent than “without delaying the entire project.”

We must always realize that $FF \leq TF$. In fact, free float is the part of total float that will not affect the early start of the following activities.⁷ The other part, interfering float, may be defined as the maximum amount of time an activity can be delayed without delaying the entire project but causing delay to the succeeding activities. It represents the part of the total float that remains after free float is deducted:

$$TF = FF + \text{Int. F} \quad \text{or} \quad \text{Int. F} = TF - FF$$

In some scheduling software programs, we may assign a start or finish constraint to a certain activity. Total float may then be calculated as the maximum amount of time we can delay the activity from its early start without delaying the entire project or the constraint (whichever is more stringent). In example 4.3, let us assign a finish constraint on activity E: Finish No Later Than (also called *Finish on or Before*) Day 18. In this case, $TF = 18 - 15 = 3$ days. The computer program may still calculate the

⁷ The author calls *Free Float* the “unselfish” portion of the total float.

free float on the basis of the early start of the succeeding activities, $FF = 7$ days, without regard to the constraint. In such a situation, you may wonder how could free float be greater than total float. It is not! The software program is calculating the two variables (TF and FF), in this case, using different criteria. Nevertheless, our earlier rule, $FF \leq TF$, still stands always.

If we look further into free float, we find that it is calculated so as to not affect the succeeding activities, but it may be affected by the preceding activities. For example, in example 4.3, if activity B is delayed (within its total float), this amount will be taken away from the total float and the free float of activity E. Let B start on day 8 and finish on day 15 (using its entire total float). Activity E will then start on day 15 and finish on day 21. This leaves activity E with only 6 days of total float, one of which is free float.

If we look at the **independent float (Ind. F)** of an activity, which is not shared or affected by any other activity, we may define it as the maximum amount of time an activity can be delayed without delaying the early start of the succeeding activities and without being affected by the allowable delay of the preceding activities. Independent float is calculated as follows:

$$Ind. F_i = \min(ES_{i+1}) - \max(LF_{i-1}) - Dur_i$$

For activity E in the previous example, $Ind. F = 22 - 15 - 6 = 1$ day. This equation may result in negative numbers, which should be interpreted as zero independent float. Independent float is part of free float, so make sure that $Ind. F \leq FF$. Independent float is the only float that can be considered truly an activity float, that is, not shared with any other activity, predecessor or successor.

Interfering float and independent float are not used in construction scheduling or even calculated by commercially available software-scheduling programs. They are sometimes used, although rarely, in delay-claims resolution.

Node Format

Since each activity has several data items, schedulers have been creative in depicting these data items inside the activity node. In the examples in this book, the author follows a simple node format in which the box contains the activity ID and original duration. The early dates are above the box, and the late dates under the box. Whether we are drawing the CPM network manually or by computer, we may follow one of many node formats or we may devise our own format. This is a matter of personal preference; there is no correct or incorrect format. Primavera Project Manager and MS Project provide ways to customize nodes. Two examples of node formats are shown in Figure 4.8.

It is not uncommon to include information such as activity codes (responsibility, area, phase, etc.) or cost in the activity box. The challenge becomes balancing the amount of information inside the box, the legibility and clarity of the information, and the size of the chart.

ES	Activity ID	EF	ES	Act ID	EF
Activity Name			Activity Name		
LS	Duration	LF	LS	TF	LF
TF		FF	OD	RD	PC

(a)

(b)

Figure 4.8 Node formats: (a) activity ID and name, duration, early start (ES), early finish (EF), late start (LS), late finish (LF), total float (TF), and free float (FF). (b) Activity ID and name, ES, EF, LS, LF, TF, original duration (OD), remaining duration (RD), and percent complete (PC). If early dates are followed by the letter A, they are actual dates, and late dates are not used.

Examples 4.4 and 4.5: Introduction of Lags and Leads into CPM Networks

As defined in chapter 3, a *lag* is a minimum mandatory waiting period between the completion (or start) of an activity and the start (or completion) of its successor. *Lead* is a negative lag. Although lags are not “real” activities, they consume time and must be incorporated into the CPM calculations. They are shown as numbers above the lines of arrows: These numbers may be boxed (as in Figure 4.11) or not boxed (as in Figure 4.9).

Example 4.4

Redo example 4.2 with some lags added as shown next.

Activity	IPA	Duration	Lag
A	—	2	
B	A	6	
C	A	10	
D	A	4	4
E	B	7	
F	B	5	3
	C		
G	C, D	3	
H	E, F	5	
I	G	2	
	H		1

Solution

Performing forward and backward passes yields the solution shown in Figure 4.9. The 4-day lag between activities A and D means that activity D cannot start

until at least 4 days after the completion of activity A. The same principle applies to the lags between activities B and F and between activities H and I.

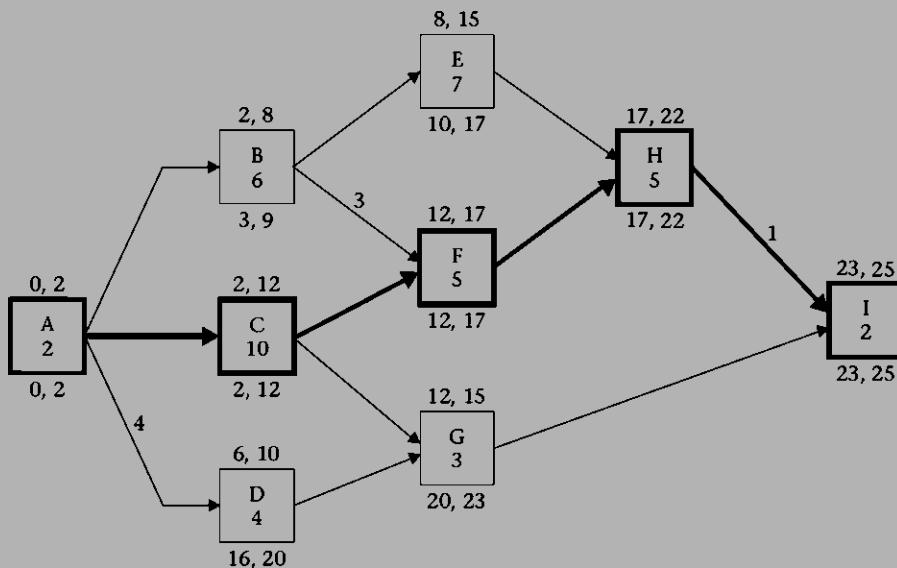


Figure 4.9 Lags in a CPM network

In this example, the critical path does not change, but it may in other cases. The 1-day lag between activities H and I adds 1 day to the project. In fact, if we look at the definition of *critical path* (the longest path in the project network from start to finish), we need to include the lags as part of the path. In this example, the critical path is A, C, F, H, I. Its length (i.e., the duration of the entire project) is $2 + 10 + 5 + 5 + (1) + 2 = 25$ days (the lag is in parentheses).

Other lags in this example contribute to changes in the forward-pass and backward-pass calculations, causing total float and free float to change in some cases. Notice that in the CPM calculations, the lags must be added in the forward pass and subtracted in the backward pass.

Example 4.5

Draw the node diagram and perform the CPM computations for the schedule shown next.

Activity	IPA	Lag	Duration	Activity	IPA	Lag	Duration
A	—		2	G	C		5
B	A	2	5	H	D, E		10
C	A		6		F	2	
D	B		6	I	E, F, G		8
E	B	3	7	J	D		7
F	B, C		4	K	H, J		1
				I		1	

Solution

Performing forward and backward passes yields the solution shown in Figure 4.10. The critical path in this example is A, B, E, H, K. Its length is $2 + (2) + 5 + (3) + 7 + 10 + 1 = 30$ days. The solution to example 4.5 is summarized in the following table.

```

graph LR
    A[0,2/A/2] -- 2 --> B[4,9/B/5]
    A -- 2 --> C[2,8/C/6]
    B -- 3 --> D[9,15/D/6]
    B -- 3 --> E[12,19/E/7]
    C -- 2 --> D
    C -- 2 --> F[9,13/F/4]
    D -- 13,19 --> E
    D -- 13,19 --> H[19,29/H/10]
    E -- 12,19 --> F
    E -- 12,19 --> H
    F -- 9,13 --> G[8,13/G/5]
    F -- 9,13 --> H
    G -- 15,20 --> H
    G -- 15,20 --> I[19,27/I/8]
    H -- 19,29 --> I
    H -- 19,29 --> J[22,29/J/7]
    H -- 19,29 --> K[29,30/K/1]
    I -- 20,28 --> J
    I -- 20,28 --> K
    J -- 22,29 --> K
  
```

Figure 4.10 Lags in scheduling software

Activity	Duration	ES	EF	LS	LF	TF	FF
A	2	0	2	0	2	0	0
B	5	4	9	4	9	0	0
C	6	2	8	7	13	5	0
D	6	9	15	13	19	4	0

E	7	12	19	12	19	0	0
F	4	9	13	13	17	4	4
G	5	8	13	15	20	7	6
H	10	19	29	19	29	0	0
I	8	19	27	20	28	1	1
J	7	15	22	22	29	7	7
K	1	29	30	29	30	0	0

Lags and Leads in Computer Software

In software scheduling programs, you may assign different calendars to different activities. For example, activity A follows a 5-day calendar, but activity B follows a 7-day calendar. Which calendar does the lag follow? Theoretically, it could follow A's, B's, or its own. Some software packages do not give the user the choice and some do. You need to know which calendar the lag follows and whether you have any choices.

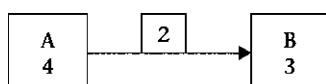


Figure 4.11 Two-day lag

One interesting scenario (Figure 4.11) may lead to a pitfall: There is a 2-day lag, but the scheduler timed activity A to finish on a Friday without inserting a lag. The next activity, B, would start on the next business day (i.e., Monday). This leaves a “natural lag” of 2 days: Saturday and Sunday. A good example of this is concrete placement. Let us assume activity A to be Formwork, Rebar, and Concrete and activity B to be Strip Forms. The schedule works well unless a delay forces activity A to finish 1 or 2 days later. Activity B would then start the next day without any lag. Ideally, a 2-day lag must be entered. If there is a choice for the lag calendar, we should choose the 7-day calendar. If not, we may create a 2-day activity (Wait for Concrete to Set), in lieu of the lag, and assign the 7-day calendar to it. Such activity will have no resources or cost assignment.

Further Discussion of Float

From realistic observation, we can deduce the following five points about float:

1. In construction project scheduling, total float, TF, is the most frequently used type of float. Free float, FF, comes in a distant second. Interfering float and independent float are almost unheard of, except in some delay-claim resolution cases. In fact, most commercially available computer software programs do not calculate these two types of float or even mention them.

2. The project manager should be responsible for distributing the total float and should understand that total float, in most cases, is shared among several activities. If the first activity in line consumes it, the remaining activities will be affected and may be left without float (or with less float) and become critical.
3. Total float may be used for resource leveling, which is explained in chapter 6. The project manager may choose a certain day on which to start an activity (between the early start and the late start) to satisfy certain resource or other needs. For example, an activity that includes the installation of expensive equipment may have 60 days of float. The owner may elect to delay the installation as late as possible to defer the cost.
4. The question of float ownership is a broad and complicated subject. It is not only a technical subject but a legal one as well. Some contracts spell out whether the contractor has granted the owner float ownership. If not, the float could be distributed in different ways. Some regulations give the right of “first come, first served.” Others suggest distributing it in proportion to the duration, budget, a “priority code,” or other criteria of the activities that share it. There are many publications on this subject, such as those by Pasiphol and Popescu (1994) and Ponce de Leon (1986).
5. The project manager may choose to hide or reduce the total float. Scheduling software provides several tricks for doing so, such as imposing a constraint on the activity to finish by a certain date. In computer programs such as Primavera Project Manager, P6, you can do the following:
 - Reduce or eliminate the total float by imposing a finish constraint. For example, activity H in example 4.3 has an early finish date of day 15 and a late finish date of day 26, which gives it 11 days of float. If we impose the constraint Finish No Later Than Day 19, day 19 will replace the late finish date in the calculation of total float. Thus, $TF = 19 - 15 = 4$ days. Of course, if we impose the constraint Finish No Later Than Day 15, the total float will be zero and activity H will be critical. Different software packages provide different types of constraints: Some can override the logic and some cannot. For example, if we impose the constraint Finish No Later Than Day 13 (which is earlier than its early start date), will it then be forced to start on day 4 (before activity D is finished) and finish on day 13? You must check the definitions of constraints in the software.
 - Restrict the activity to its early dates and totally eliminate its total float. In MS Project, the constraint is called *ASAP (As Soon As Possible)*, and in Primavera Project Planner, it is called *ZTF (Zero Total Float)*. Note that the difference between this constraint and the one discussed previously is that this constraint is dynamic and the previous one is static. For example, if a delay in activity D causes it to finish on day 8, the ASAP or ZTF constraint

will force activity H to finish on its *new* early finish date (i.e., day 17). The Finish No Later Than constraint will not adjust because of the change in the calculated dates.

- Delay the activity to its latest dates. Doing so may—and usually does—affect the float of the succeeding activities.
- Delay the activity as much as possible without affecting the succeeding activities. Both Primavera Project Manager and MS Project have such a constraint. In some programs, it is called *Zero Free Float*, and in others, *As Late As Possible*. For example, if we add a Zero Free Float constraint to activity E in example 4.3, it will be delayed by 7 days to start on day 16 and finish on day 22. It will still have 5 days of total float left (compared with 12 without the constraint). This type of constraint is particularly useful in procurement activities. When you have an equipment procurement activity with large float, you may not want the equipment to be delivered too early or the contractor and the owner may have problems (the possibility of theft or vandalism, lack of storage space, tying up the cash, etc.)

Effect of Choice of Dates on Cash Flow

The effect of different dates on cash flow is shown in Figure 4.12. Early dates and late dates provide a time frame within which the project manager can choose his or her planned dates. Conservative thinking leans more toward early dates (especially for the contractor). The owner's financial considerations may lean towards late dates. The contractor may have other considerations for choosing planned dates, such as resource availability and cost, resource leveling (explained in chapter 6), other ongoing or potential projects, and so forth.

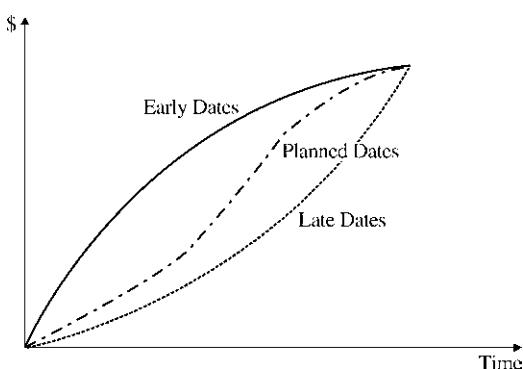


Figure 4.12 Effect of choice of dates on cash flow

Example 4.6: Event Times in Arrow Networks

Event times in arrow networks are calculated in the following manner:

- The early event time, T_E , is the largest (latest) date obtained to reach an event (going from start to finish).
- The late event time, T_L , is the smallest (earliest) date obtained to reach an event (going from finish to start).

The preceding logic is similar to that of the forward and backward passes: When you are going forward, pick the largest number. When you are going backward, pick the smallest number.

Example 4.6

Perform the CPM calculations, including the event times, for the arrow network shown in Figure 4.13a.

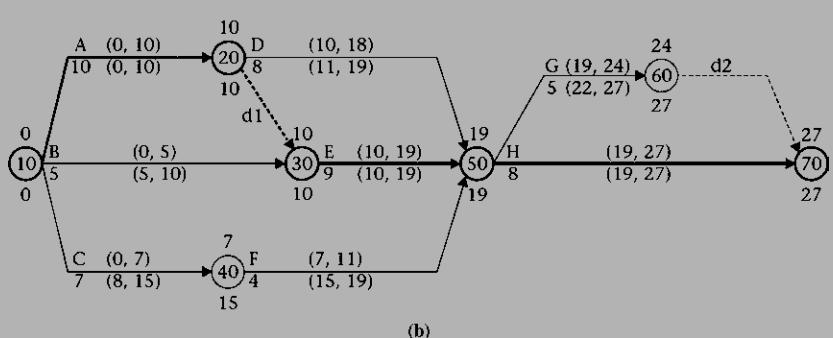
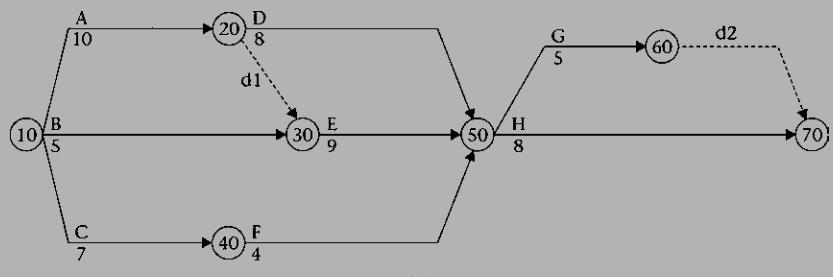


Figure 4.13 (a) Arrow network for example 4.6; (b) event times in arrow network

Solution

Early Times, T_E . We start the project at node 10 with an early event time of $T_E = 0$ (Figure 4.13b). Event (node) 20 is reached when activity A is complete, which

is on day 10. However, event 30 requires both A and B to be completed. In this case, we take the larger of $(0 + 10 = 10)$ and $(0 + 5 = 5)$, which is 10, for the early time. The early time for event 40 is $0 + 7 = 7$. Event 50 needs activities D, E, and F to be finished. We take the largest date of 18, 19, and 11 for the early time. The answer is 19. Similarly, early events 60 and 70 have early times of 24 and 27, respectively. Late times, T_L . Starting at event 70, the late time, T_L , is 27. Since all dummies have zero duration, event 60 has $T_L = 27$. For event 50, we must pick the earlier of the following: T_L of event 60 – Duration of G ($27 - 5 = 22$) and T_L of event 70 – Duration of H ($27 - 8 = 19$). So, T_L for event 50 = 19. For event 40, $T_L = 19 - 4 = 15$. For event 30, $T_L = 19 - 9 = 10$. For event 20, pick the earlier of $(19 - 8 = 11)$ and $(10 - 0 = 10)$. Hence, $T_L = 10 - 0 = 10$. For event 10, pick the earliest of $(10 - 10 = 0)$, $(10 - 5 = 5)$, and $(15 - 7 = 8)$. Clearly, $T_L = 0$. Event float. We easily find that events 40 and 60 have floats of 8 and 3 days, respectively. All other events are critical.

Example 4.7: Effect of the Imposed Finish Date on the Schedule

So far, all calculations have been based on the duration estimate for each activity, along with the logic between these activities. The result is a **calculated finish date**. In many cases, the calculated finish date is different from that set by the owner. As a result, the contractor must adjust the schedule to meet the owner's imposed finish date. Doing so may require *accelerating* the schedule, a subject covered in chapter 8. In this section, we just study the effect that such an imposed date may have on the schedule.

The concept is simple: Do the CPM forward pass as usual; find the project's calculated finish date, based on the assumptions of durations and logic. Then, on the backward pass, start with the imposed finish date and use this date for your backward-pass calculations. The imposed finish date may be earlier or later than the calculated finish date:

- If the imposed finish date is earlier than the calculated finish date, the activities on the critical path will have negative float equal to the difference between the imposed finish date and the calculated finish date. Other activities may also develop negative float but greater (or less, in absolute value) than the total float of the critical path. The contractor must accelerate the project (i.e., reduce its duration) by an amount of time equal to the negative float of the critical path. This acceleration, say 8 days, may be taken from several activities (e.g., 1 day from one activity, 2 days from another, and so on), with a total duration reduction equal to 8 days.
- If the imposed finish date is later than the calculated finish date, the contractor is in good shape (at this point!). The difference between the two dates may be regarded as a **time contingency**, and the contractor may keep the calculated finish date as a target date. In such a situation, inserting the imposed finish date

into the computer program will result in the “disappearance” of the critical path. This occurs because we gave each activity a “bonus float” equal to the difference between the imposed finish date and the calculated finish date. Since, by default, most computer programs define critical activities as those with zero or less float, no critical activities will be found. For this reason, the scheduler should not enter the imposed finish date until the calculated finish date is determined.

Example 4.7

The owner of the project discussed in example 4.3 needs to have the project finished in 30 days. Use the imposed finish date to determine the effect on the entire schedule and on individual activities. See Figure 4.14.

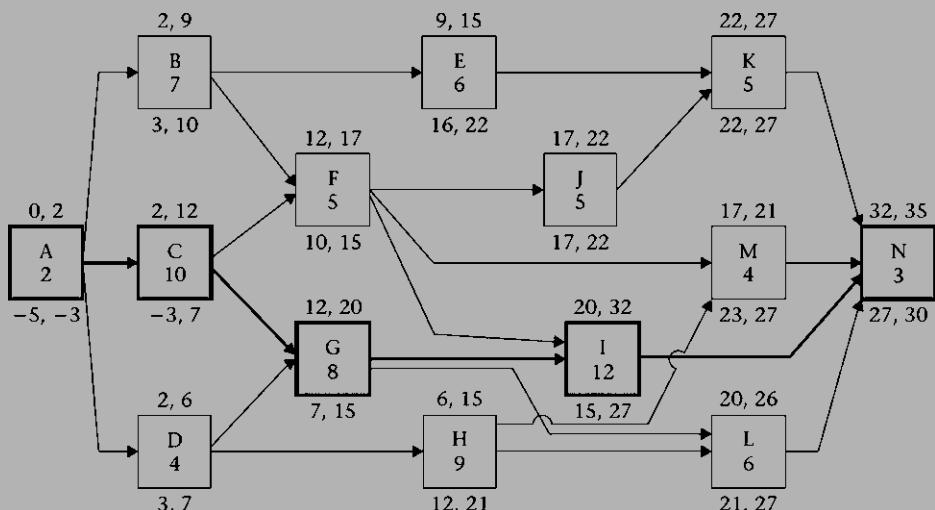


Figure 4.14 Effect of imposed finish date on the schedule

Solution

The results of example 4.7 can be tabulated as follows.

Activity	Duration	ES	EF	LS	LF	TF
A	2	0	2	-5	-3	-5
B	7	2	9	3	10	1
C	10	2	12	-3	7	-5
D	4	2	6	3	7	1
E	6	9	15	16	22	7

F	5	12	17	10	15	-2
G	8	12	20	7	15	-5
H	9	6	15	12	21	6
I	12	20	32	15	27	-5
J	5	17	22	17	22	0
K	5	22	27	22	27	0
L	6	20	26	21	27	1
M	4	17	21	23	27	6
N	3	32	35	27	30	-5

Discussion of Example 4.7

We leave the details of project compression to chapter 8, but we note that in cases such as example 4.7, when the project needs acceleration, not all activities need to be shortened. This often overlooked point may result in a lot of wasted money in construction projects. Shortening activities B, D, E, and so forth does not help. At the same time, we observe that activity F, which is not on the critical path, needs to be accelerated by 2 days. However, this may not be exactly true. If we accelerate any activity on the critical path, other than G, by at least 2 days, activity F will not need to be accelerated. Following is a numerical illustration of this point:

1. The critical path (A, C, G, I, N) is 35 days long.
2. The path (A, C, F, I, N) is 32 days long.
3. We need to shorten any path that exceeds 30 days.
4. Shortening a path is achieved by shortening the duration of an activity or a combination of activities by the desired amount of days—5 in this case.
5. Since the two paths share all activities except F and G, any reduction in the duration of any shared activity (A, C, I, or N) will result in a reduction in both paths.

This subject is discussed further in chapter 8.

LOGIC AND CONSTRAINTS

A trend among many schedulers and project managers is to “fix” the dates of activities rather than allowing the software to calculate them using the CPM concepts. For example, the project manager might ask the scheduler to make Door Installation start on 26 APR 2010. The scheduler would assign a constraint to this activity so that it would start on that particular date. This practice strips the schedule of its most important advantage: logic. The difference is simple: Logic is dynamic. Constraints are not. The author—when put in the shoes of this scheduler—would ask the project

manager, “Why do you want to start that activity on 26 APR 2010?” The project manager would give an answer such as “That’s when drywall will be finished” or “That’s when doors will be delivered.” The scheduler can then tie Door Installation to Finish Drywall and/or Doors Delivery. To appreciate the advantage of logic over constraints, assume that the predecessor, Finish Drywall, is delayed. With the absence of logic, we need to go to Door Installation and manually move it. With logic, all we have to do is recalculate the schedule.

It is also possible to combine logic and constraints. Assume that an activity may be completed as early as 07 June 2011, but the project manager wants to delay it till 14 July 2011 for a reason that may have nothing to do with logic, such as cash-flow requirements. The scheduler may add a constraint (without taking out the logic) that will not allow it to start before 14 July 2011, assuming this date is \leq LF.

The author believes that the overwhelming reason for using constraints in lieu of logical relationships is a lack of understanding of the mechanics of the CPM. Some contractors, especially those who work on small projects, used to make bar chart “schedules” by using a spreadsheet program or even by drawing a bar chart manually without any CPM calculations. In such schedules, the contractor would choose the start and finish dates for every activity rather than calculating them. Such a bar chart is subjective and not based on CPM. Furthermore, it may not have much value in the court of the law. Consequently, using such schedules is strongly discouraged.

Nevertheless, constraints may be extremely important. The owner may have, in addition to the project completion date, other deadlines, such as Substantial Completion. Substantial Completion usually indicates the stage when the facility is completed to the point that the owner may use it while the contractor completes the final items (or **punch list**). Even though the deadline for Substantial Completion may be in the contract, the contractor must show it as a milestone on the schedule. The owner bears the responsibility of noting the absence of such milestones in the schedule before accepting it.

CHAPTER 4 EXERCISES

- For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	3	—						
B	7	A						
C	4	A						
D	5	B						
E	8	B, C						

2. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	LS	EF	LF	TF	FF
A	7	–						
B	10	–						
C	15	A						
D	8	A, B						
E	4	C, D						

3. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	2	–						
B	4	A						
C	6	A						
D	9	A						
E	5	B						
F	7	B, C						
G	3	D, E, F						

4. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	6	–						
B	2	–						
C	8	A						
D	5	A, B						
E	3	B						
F	6	D, E						
G	5	C, D						
H	2	F, G						

5. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	6	—						
B	2	—						
C	9	—						
D	4	A, B						
E	7	B						
F	5	D						
G	10	D, E						
H	8	C, F, G						
I	3	C, G						
J	2	H, I						

6. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	2	—						
B	7	A						
C	10	A						
D	5	A						
E	4	B						
F	4	B, C						
G	3	C						
H	6	C, D						
I	3	D						
J	6	E, F, G						
K	8	F, G, H						
L	5	H, I						
M	3	K, L						

7. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	3	—						
B	5	—						
C	6	A						
D	9	A, B						
E	4	A, B						
F	6	B						
G	5	C, D						

H	12	D, E
I	7	D, E, F
J	9	E
K	10	G, H, I
L	6	I, J
M	4	G, I
N	2	K

8. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	3	—						
B	10	A						
C	7	A						
D	6	B						
E	5	B, C						
F	4	C						
G	2	D						
H	4	D, E						
I	10	E						
J	6	E, F						
K	4	G, H, I						
L	2	H, I						
M	1	J, L						

9. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	ES	EF	LS	LF	TF	FF
A	5	—						
B	7	A						
C	10	A						
D	5	A						
E	9	A						
F	6	B						
G	4	B, C						
H	8	B, C, D						
I	2	C, D						
J	5	E						
K	8	F						
L	9	E, G						
M	7	F, G, H						
N	3	F, G, H, I						

O	6	H, I
P	4	M, N, O
Q	3	K, L
R	5	L, M
S	4	J, P
T	6	Q
U	4	Q, R
V	1	T, U, S

10. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	Lag	ES	EF	LS	LF	TF	FF
A	5	—							
B	6	A							
C	4	A	3						
D	5	A							
E	3	B							
F	2	C, B							

11. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	Lag	ES	EF	LS	LF	TF	FF
A	4	—							
B	9	—							
C	6	A							
D	4	A							
			B	2					
E	4	B							
F	2	B, C							
G	6	D							
			E	3					
H	3	F, G							

12. For the following schedule, draw the node network, perform the CPM calculations, mark the critical path, and complete the table.

Activity	Duration	IPA	Lag	ES	EF	LS	LF	TF	FF
A	5	—							
B	6	A							
C	4	A	3						
D	5	A							
E	9	B							
F	7	B	2						
		C							
G	6	C							
H	8	C							
		D	4						
I	3	D							
J	7	E, G							
		F	2						
K	4	F, G, H							
L	1	H	3						
		I							
M	2	K, L							

13. What is the main reason for the overuse of date constraints? How do you minimize such overuse?
14. Create a WBS for building a house. Use four levels of details and provide activity codes for each breakdown element.

Chapter 5

Precedence Networks



Interstate 4 and 17/92 intersection in Sanford, Florida

DEFINITION AND INTRODUCTION

Precedence networks are node networks that allow for the use of four types of relationships: finish to start (FS), start to start (SS), finish to finish (FF), and start to finish (SF). To understand the idea of precedence networks, consider the simple project of laying 1,000 LF (linear feet) of a utility pipe. The logic is simple: dig a trench, provide a 6-inch-thick gravel subbase (bedding), lay the pipe, backfill, and compact—five consecutive activities. However, are they actually “consecutive”? Do you need to finish excavating the entire 1,000 LF before you can start the subbase? Do you need to finish the subbase completely before you start laying the pipe? If the answer is yes, your bar chart may look like the one shown in Figure 5.1.

Most likely, though, the answer to the preceding questions is no. Practically, once you have dug a reasonable amount, say 100 LF, your second crew can start providing the subbase, while the first crew continues digging. Once digging reaches about 200 LF (say 20%), the subbase is about 10% complete, and your third crew can start laying the pipe. As a result, the bar chart for the project looks like the one shown in Figure 5.2. Clearly, relationships exist among these activities, but not the traditional FS relationship. The activities are said to be *overlapping*. This project may be represented in one of two common ways. A third method, using the Linear Scheduling Method, will be discussed in chapter 11.

1. *The stair-type relationship:* In this method, each activity is divided into two or more parts (Figure 5.3): After Excavation I is complete, both Excavation II and Subbase I can start. Once Subbase I is finished, Subbase II and Pipe I can start (probably Excavation III as well), and so on. This method is well known and widely acceptable. It is popular for projects such as heavy construction (highway, utilities, etc.) in which activities are few but large and have long durations. It is customary to divide the activities of these projects into phases, steps, or “subactivities.” The main drawbacks of this method are the increase in the number of activities and the confusing similarity of their titles. For instance, in the example shown in Figure 5.3, a 5-activity project became a 15-activity project.
2. *The precedence diagramming method:* The project can alternatively be represented as shown in Figure 5.4. The activities in this network have SS

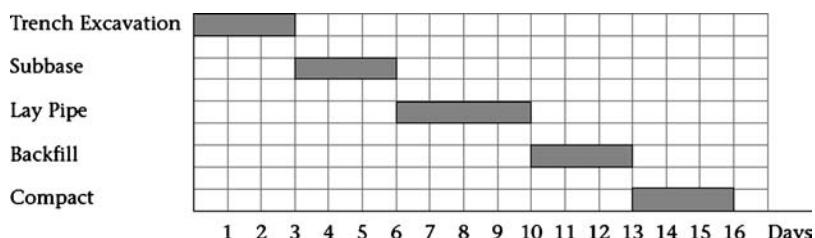


Figure 5.1 Bar chart for five consecutive activities

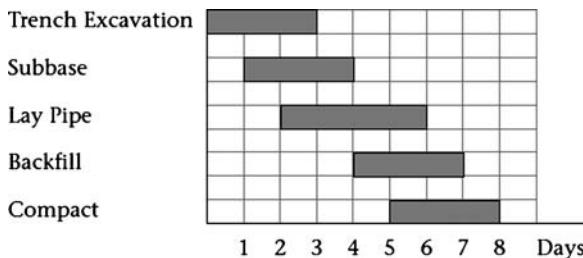


Figure 5.2 Bar chart for five overlapping activities

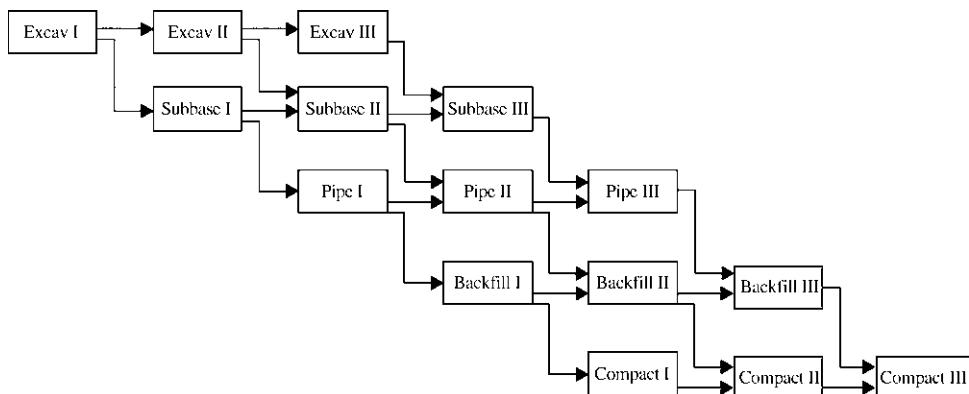


Figure 5.3 Stair-type schedule for utility pipe installation project

relationships. This means Subbase cannot begin till Excavate has started, Lay Pipe cannot begin till Subbase has started, and so on. Theoretically, all five activities can start simultaneously (one immediately after the other), then the project can finish in 7 days (the largest single duration). However, this scenario may be a little too unrealistic. In real life, some amount of excavation must be done (say 20%) before Subbase can start. The same can be said of the other steps.

We can add lags to the network shown in Figure 5.4, as shown in Figure 5.5. In Figure 5.5, if Excavate starts on day 0 (*remember*: the end of day 0 means the beginning of day 1), Subbase can start 1 day later, at the end of day 1. Lay Pipe can start 2 days

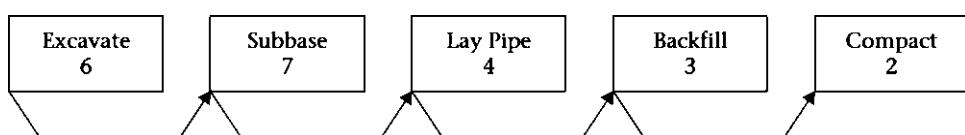


Figure 5.4 Precedence diagram, for utility pipe installation project, using start-to-start relationships with no lags

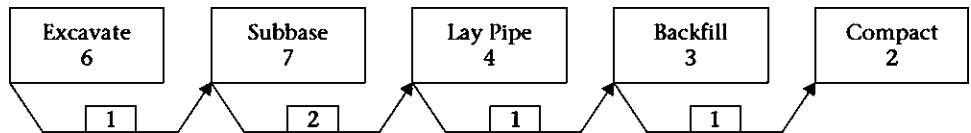


Figure 5.5 Precedence diagram, for utility pipe installation project, using start-to-start relationships with lags

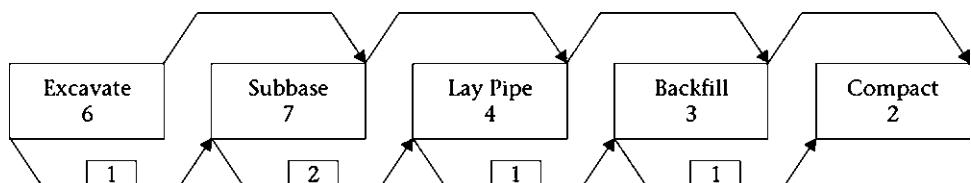


Figure 5.6 Precedence diagram, for utility pipe installation project, using a combination relationships and lags

later (on day 3), Backfill can start on day 4 ($3 + 1$), and Compact can start on day 5 and finish on day 7.

With careful estimates of both durations and lags, this method can work well. However, what may result is an awkward situation in which a successor finishes before the predecessor.¹ For example, we just calculated the finish of the last activity in the project: Compact, on day 7. However, by that date, the second activity, Subbase, has not finished. This situation is unacceptable, so we must either increase the lags or add FF relationships, as shown in Figure 5.6. FF relationships ensure that no successor can finish before its predecessor. Thus, Subbase cannot finish till Excavate is finished, Lay Pipe cannot finish till Subbase is finished, and so on. Since we did not add lags to the FF relationships, theoretically two or more activities could finish at the same time. If this possibility is unacceptable, we can add lags, as shown in Figure 5.7. In the network shown in Figure 5.7, Subbase cannot finish till 1 day after Excavate has finished, and Backfill cannot finish till 1 day after Lay Pipe has finished.

One important note: These relationships are “binding in one way,” which means that you can exceed the lag in one direction but not the other. For example, Subbase cannot start till *at least* 1 day after Excavate has started. It is allowed to start *more than 1 day* after the start of Excavate. The same argument holds for the FF relationship: Subbase cannot finish earlier than 1 day after the finish of Excavate, but it can finish more than 1 day after the finish of Excavate.

The relationships shown in Figures 5.6 and 5.7 are called *combination relationships*. In this type of relationship, two activities are related by two relationships. Some

¹This situation may be acceptable in some, but not all, cases. For example, if the predecessor is Clear & Grub and the successor is Excavate Foundation; you may have to lag the start of excavation a few days after starting Clear & Grub. However, you may finish excavation before finishing clearing and grubbing because the completion of the two activities is independent.

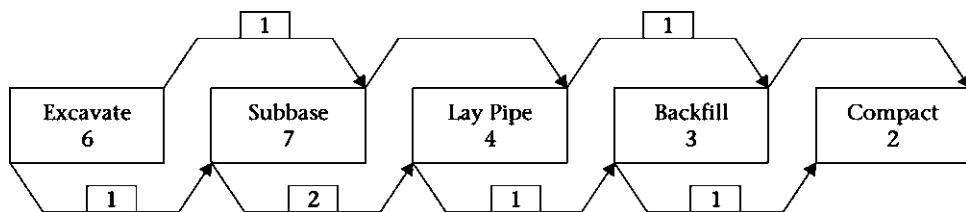


Figure 5.7 Precedence diagram, for utility pipe installation project, using a combination relationships and more lags

computer software, such as Microsoft (MS) Project, does not allow combination relationships.

THE FOUR TYPES OF RELATIONSHIPS

As mentioned previously, four types of relationships are possible in precedence networks:

1. **Finish-to-start (FS) relationship:** The most common type of relationship is the FS relationship. Many project managers still insist on using only this type. Many examples of this type exist, such as the following:
 - The concrete cannot be placed (poured) until the formwork has been built.
 - The doors cannot be hung until door frames have been installed.
2. **Start-to-start (SS) relationship:** The SS relationship is common and extremely useful. Examples of this type are as follows:
 - Excavation for the foundation cannot start until clearing and grubbing begins (usually with a certain lag; i.e., a certain percentage is finished).
 - Laying felt on the roof cannot start until sheathing has started (also usually with a lag).
3. **Finish-to-finish (FF) relationship:** The FF relationship is also common and useful. Examples of this type are as follows:
 - Landscaping cannot finish until the driveway is finished.
 - Backfilling a trench cannot finish until the pipe in the trench has been laid.
4. **Start-to-finish (SF) relationship:** The SF relationship is uncommon and almost nonexistent in construction projects.

Important Comments about the Four Types of Relationships

1. Practically, the only two types of relationships that can be combined are SS and FF, as shown in the previous example.

2. You can always use lags and leads with the four relationships. In fact, you will have more need to use lags with SS and FF relationships than with the traditional FS relationship.
3. With regard to critical path method (CPM) calculations (discussed later in this chapter), when you are using a combination relationship (SS and FF), usually only one of the two relationships becomes binding (driving). This situation may change if some criterion—such as duration, lag, or logic—changes.

THE PERCENT COMPLETE APPROACH

O'Brien and Plotnick (2009, p. 159–160) suggested a slightly different approach. The relationship shown in Figure 5.8a means that activity B can start after A is at least 50% complete. In Figure 5.8b, the final 30% of activity B cannot progress until A is completely finished. Although this approach makes sense, it did not gain popularity. Perhaps the main reason is that in the CPM, early and late dates of an activity are calculated using lags that have a definite number of days (constant) rather than a percentage of completion of another activity (variable), although the conversion of this variable to a constant is simple.

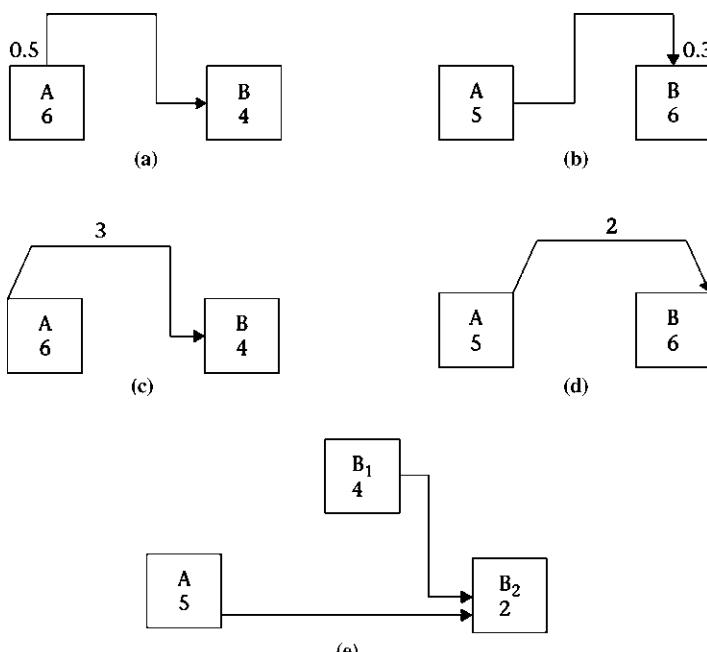


Figure 5.8 Percent complete approach: (a) activity B starts after activity A is at least 50% complete; (b) final 30% of activity B progresses only after A is complete; (c) Figure 5.8a with lags; (d) Figure 5.8b with lags; (e) activity B split

We must note here that MS Project accommodates such relationships. For example, the relationship shown in Figure 5.8a can be entered as follows: B's predecessor is A, relationship: SS + 50%. Primavera P6 does not accept a relationship in this form: it must be in number of days.

In reality, the lags we use in the CPM are nothing but an estimate of the portion (percent complete) of the preceding activity that must be finished before the succeeding activity can start (or finish). For example, Figures 5.8a and 5.8b can be redrawn as shown in Figures 5.8c and 5.8d. Note that the relationship shown in Figure 5.8b is not equivalent to that shown in Figure 5.8d, but close enough. If you try to do CPM calculations for both, assuming activity A starts the project, you will find A's early dates are (0, 5). The last 30% of activity B is about 2 days. Thus, the last 2 days of B must follow A (i.e., occur on days 6 and 7). However, the early start of activity B is not restricted, so it can be zero (start of the project), in which case the early dates of B are (0, 7), which is also true in Figure 5.8d, unless activity B is contiguous. In this case, early dates for B are (1, 7). (Contiguous and interruptible activities are discussed later in this chapter.)

Another way we can redraw the relationship shown in Figure 5.8b is by splitting activity B. This redrawing is shown in Figure 5.8e.

FAST-TRACK PROJECTS

The term *fast-track* in the construction world means starting the construction process while the design is still under development. Under normal circumstances (i.e., the traditional way), the design must be complete before construction can start. In some situations, time may be so tight that the owner or project management team decides to “fast-track” the project. In this case, the project is divided into several phases, and the construction of a phase proceeds after the design of that phase is complete, while the design of latter phases may not yet completed, as shown in Figures 5.9a and 5.9b.

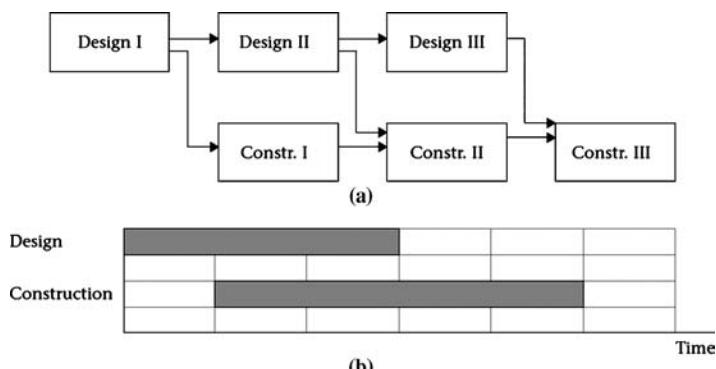


Figure 5.9 (a) Stair-type diagram and (b) bar chart for a fast-track project

In many cases, the design development (DD) stage is identified with a certain percentage, such as DD 30%, DD 60%, and so forth. The number represents an approximation of the completeness of the design. Obviously, the higher the percentage, the more well-defined the design and the fewer assumptions must be made.

Fast-tracking takes advantage of precious time, but with a cost. The concept is to start building something that you have a general, but not an exact, idea of what it is. Doing so minimizes the ability of the contractor, and other participants, to practice value engineering and constructability studies (see the definitions of *value engineering* and *constructability* in chapter 8). Fast-tracking may also lead to more change orders and higher cost. For obvious reasons, contractors cannot take these types of projects on a lump-sum basis, so owners may not know the final cost of the project until it is complete. To counterbalance this unknown, the contractor may give the owner an estimate with a “guaranteed maximum budget.” Refer to the project management books listed in the Bibliography for more discussion on this concept.

A PARALLEL PREDECESSOR?

You learned in chapters 3 and 4 that a predecessor is an activity that must happen before another one can happen. For example, if A is a predecessor of B, then A must happen before B can start, but not necessarily immediately after A (Figure 5.10a).

If A is a predecessor of B with an SS relationship, both may occur in parallel (Figure 5.10b). Would A still be called a *predecessor*? The answer is yes because A must start first (even with zero lag). If B starts several days after A starts, the logic is not violated. However, if B starts first—by any amount of time—the logic *will* be violated. Activity A, thus, controls activity B and is still called a *predecessor*. Note the direction of the arrow in Figure 5.10b: it points from the activity that controls to the activity that is controlled.

Realistically, a portion (maybe a small portion) of A must occur before B can start. Popescu and Charoenngam (1995) defined a *predecessor* as “an activity that has some measurable portion of its duration logically restraining a subsequent activity or activities” (p. 438). In reality, we may show two activities with an SS relationship and zero lag, but a certain—possibly small—portion of the predecessor must occur before the successor starts.

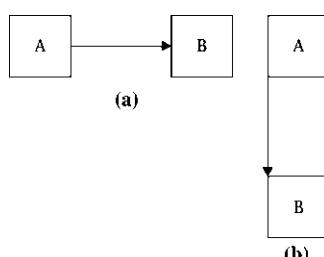


Figure 5.10 (a) Typical predecessor relationship; (b) parallel predecessor relationship

CPM CALCULATIONS FOR PRECEDENCE DIAGRAMS

The CPM calculations for precedence diagrams differ from those for standard arrow or node diagrams. However, before we start the CPM calculations, *we must establish an important distinction: Are the activities contiguous (continuous) or interruptible?* In other words, once an activity starts, can it be paused and then resumed, or must it proceed continuously until it is finished? In real life, both scenarios are possible, but the assumption about whether the activities are contiguous or interruptible makes a substantial difference in the calculation method used and possibly in the calculated finish date of the entire project.

Interruptible Activities

Let us start with the simple three-activity project depicted in Figure 5.11. The three activities are tied with only SS relationships, with no lags. Theoretically, all three activities can start at the same time. The project finishes when the activity with the longest duration, A, finishes. Thus, activity A is critical. Activities B and C have floats equal to the difference between their duration and the duration of A (the float for B is $10 - 5 = 5$ and the float for C is $10 - 3 = 7$). Now, let us add some lags, as shown in Figure 5.12.

In Figure 5.12, we are forcing a delay in the start of activities B and C, maybe because we want to see a certain percentage of activity A finished before B can start, and a certain percentage of activity B finished before C can start. We find that, in this example, activity B is the critical activity, since it takes 11 days to finish (6-day lag + 5 days' duration). The problem is that activity C may finish early, on day 10, which is 1 day *before* activity B is scheduled to finish (in reality, this situation may or may not be a problem). Consequently, let us try to tie the ends of the activities with FF relationships rather than the SS relationships (Figure 5.13).

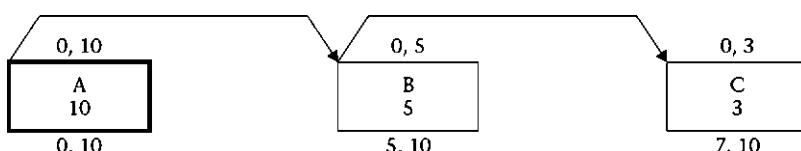


Figure 5.11 Three-activity project using a start-to-start relationship

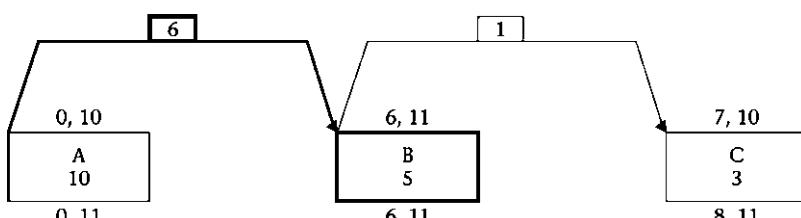
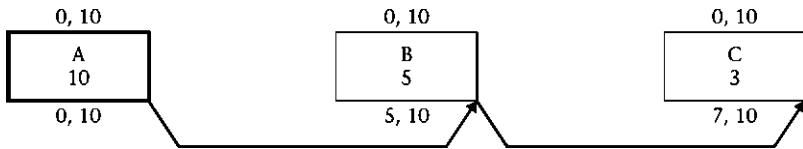
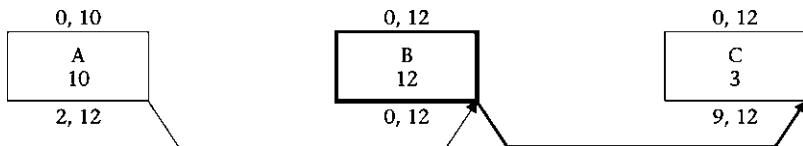


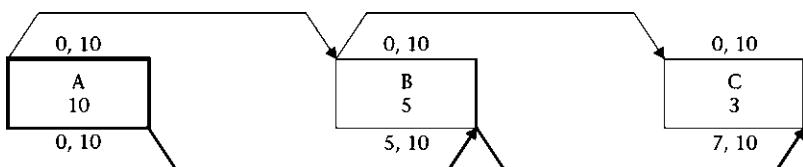
Figure 5.12 Three-activity project using a start-to-start relationship with lags

**Figure 5.13** Three-activity project, with 10-day duration, using a finish-to-finish relationship**Figure 5.14** Three-activity project, with 12-day duration, using a finish-to-finish relationship

In Figure 5.13, the finish of each activity is restricted to the finish of the predecessor. Activity B cannot finish till A is finished. Activity C cannot finish till B is finished. No restriction is put on their start other than the start of the project. Thus, not only is activity A (the activity with the longest duration) critical but also the *ends* of activities B and C are. This criticality can change if, for example, activity B has 12 days' duration, as shown in Figure 5.14.

In Figure 5.14, B has become the driving activity. It has no control over the completion of the predecessor (activity A), but it has control over the finish of activity C. Activity B automatically becomes critical (since it has the longest duration). The end of activity C is still critical, since it is tied to (follows) the end of B. Activity A has 2 days' "unrestricted" float.

If we tie both the start and the end of the activities shown in Figure 5.13; we get Figure 5.15. The relationships shown in Figure 5.15 combine those shown in Figures 5.11 and 5.13. As mentioned previously, in the case of two activities tied with two relationships, in most cases, one of these two relationships governs (i.e., becomes driving). In an unlikely case, both relationships govern (become driving). The main difference between Figures 5.15 and 5.11 is that we did not allow activities B and C, in Figure 5.15, to finish before day 10, the finish date for activity A. There are no differences—as far as dates are concerned—between Figures 5.13 and 5.15. However, a logic difference exists between the two cases, but as a result of the durations of the activities, the FF relationships control. This control can change with a change in duration, as shown in Figures 5.16 and 5.17.

**Figure 5.15** Three-activity project, with a 10-day duration, using a combination relationship

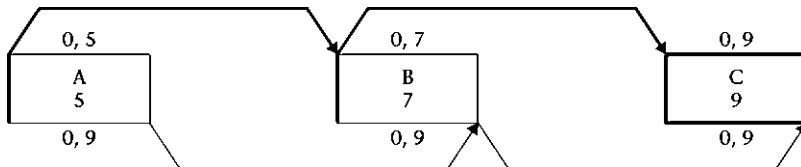


Figure 5.16 Three-activity project, with 9-day duration, using a combination relationship

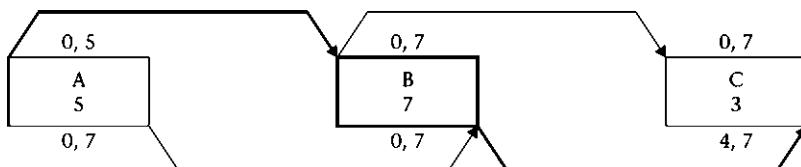


Figure 5.17 Three-activity project, with 7-day duration, using a combination relationship

Note that, in all the preceding cases—Figures 5.11 through 5.17, the duration of any activity may be longer than the difference between its finish and start dates: $EF - ES$ or $LF - LS$. This means it may stretch across a period that is longer than its duration (i.e., started, stopped, and then resumed), which is in accordance with our assumption of interruptible activities.

The Simplistic Approach

CPM calculations for precedence diagrams are similar to, but not the same as, the CPM calculations discussed in chapter 4. The differences can be summarized by the following three points:

1. In chapter 4 (arrow and node diagrams), we had only the FS type of relationship. Activities were always connected in only one way: from the end of an activity's predecessor to its start, and from its end to the start of its successor. In precedence diagrams, we use four types of relationships. Thus, you must be careful about the type of relationship chosen. An activity can be controlled (driven) not only from its start but from its end as well.
2. In precedence diagrams, we may use combination relationships (mainly SS and FF). Doing so creates a condition in which each relationship yields a different set of dates, but one set prevails. Let us go through the calculations for Figure 5.17, for example:
 - a. In the forward pass, activity A starts the project. $ES = 0$; $EF = 0 + 5$ (duration) = 5.
 - b. Activity B is connected to A by a combination relationship. The SS relationship (with no lag) means B can start just after A has started. This

means activity B's $ES = 0$. However, its EF is controlled by the later of the following:

$$EF = ES + Dur = 0 + 7 = 7$$

or

$$EF(B) = EF(A) + Lag \text{ (if any)} = 5 + 0 = 5$$

The first, $EF = 7$, prevails.

- c. The same method applies to activity C. Its start is controlled by the start of activity B, so its $ES = 0$. Its EF is controlled by the later of the following:

$$EF = ES + Dur = 0 + 3 = 3$$

or

$$EF(C) = EF(B) + Lag \text{ (if any)} = 7 + 0 = 7$$

The second, $EF = 7$, prevails.

- d. In the backward pass, we start at the end of activity C with its finish no earlier than day 7: $LF = 7$; $LS = LF - Dur = 7 - 3 = 4$.
- e. Activity B must finish no later than the LF of C; that is, $LF(B) = LF(C) - Lag = 7 - 0 = 7$. Its LS is controlled by the earlier of the following:

$$LS = LF - Dur = 7 - 3 = 4$$

or

$$LS(B) = LS(C) - Lag \text{ (if any)} = 4 - 0 = 4$$

The first, $LS = 4$, prevails.

- f. Activity A must finish no later than the LF of B; that is $LF(A) = LF(B) - Lag = 7 - 0 = 7$. Its LS is controlled by the earlier of the following:

$$LS = LF - Dur = 7 - 0 = 7$$

or

$$LS(A) = LS(B) - Lag \text{ (if any)} = 7 - 0 = 7$$

The latter, $LS = 7$, prevails.

- 3. Note that unlike in chapter 4, the durations may not be equal to $EF - ES$ or $LF - LS$. Furthermore, all or some of the total float may be restricted. This will be elaborated in the detailed approach (discussed subsequently). Total float is always calculated by using this simple equation:

$$TF = LF - Dur - ES$$

Free float (FF) is calculated the same way as in chapter 4 and is always less than or equal to total float.

General Notes on the Simplistic Approach

Two points regarding the simplistic approach should be noted:

1. The position of the relationship arrows (i.e., from top or bottom of the same side) is a matter of aesthetics and is left to the user's choice. It has nothing to do with the choice of early or late dates. For example, the network of Figure 5.17 can be redrawn as shown in Figure 5.18.
2. We may have **dangling activities** in precedence diagrams. Dangling activities are tied from one end only. In other words, dangling activities have either no predecessors or no successors. As mentioned previously, we like to always start the network with one activity (e.g., Notice to Proceed) and end it with one activity (e.g., Final Completion). As an example of dangling activities, you may have a Clear & Grub activity with an SS relationship to the next activity, Excavation, with a 4-day lag (Figure 5.19). Nothing controls the end of the Clear & Grub activity (other than the end of the project). In this case, the LF date of the Clear & Grub activity is the end of the entire project. Another example is when the start of Order & Deliver Equip. is not tied logically to another activity, but its finish controls the Install Equip. activity near the end of the project (let us imagine the activities in Figure 5.20 at the end of a large project network). In this case, the ES of Order & Deliver Equip. is the start of the entire project (day 0).

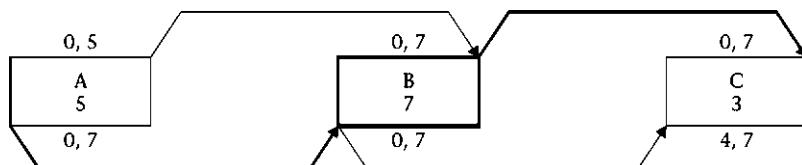


Figure 5.18 Figure 5.17 redrawn

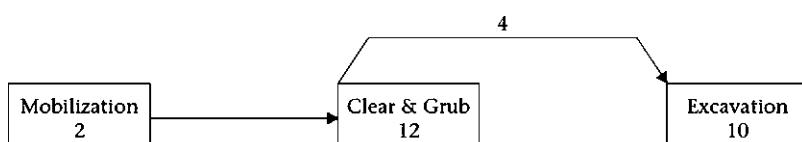
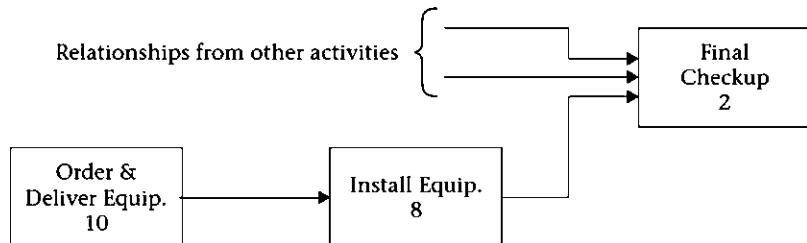


Figure 5.19 Example of a dangling activity

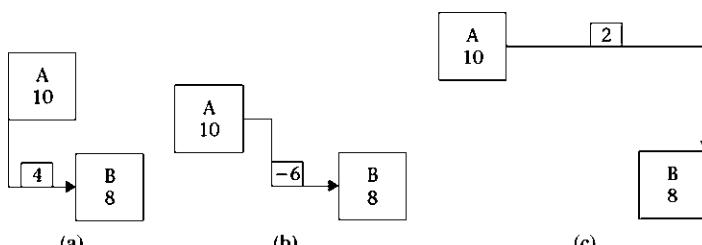
**Figure 5.20 Another example of a dangling activity**

You should not leave any dangling activities. Instead, tie them to the most reasonable predecessor or successor. For example, you can make Order & Deliver Equip. in Figure 5.20 a successor to Submittals or another activity. Scheduling software such as Primavera P6 lists all activities with no predecessors or successors in its scheduling report. Ideally, you should have only one –not several- of each.

Alternative Approaches

Let us consider the activities shown in Figure 5.21. After performing the calculations for the three sets, we get the same results: the dates for A are (0, 10) and the dates for B are (4, 12), for both early and late dates. However, are the three approaches equivalent? The answer is no. In Figure 5.21a, the finish of A may be delayed without delaying B (if A is interruptible). In Figure 5.21c, the start of both activities is independent. In addition, if the duration of A changes, the three scenarios will yield different results. The scheduler must be careful, when choosing the logical ties (relationships), to reflect the actual relationship as much as possible.

In general, a positive lag means “after” and a negative lag (lead) means “before.” The author has introduced a new relationship (DML) that performs more consistently in all these scenarios without the pitfalls. It is explained in Chapter 12.

**Figure 5.21 Three alternative approaches (a) Activity B can start at least 4 days after the start of Activity A (b) Activity B can start no more than (at most) 6 days before the finish of Activity A (c) Activity B can finish at least 4 days after the finish of Activity A**

Example 5.1

Perform the CPM calculations for the network shown in Figure 5.22.

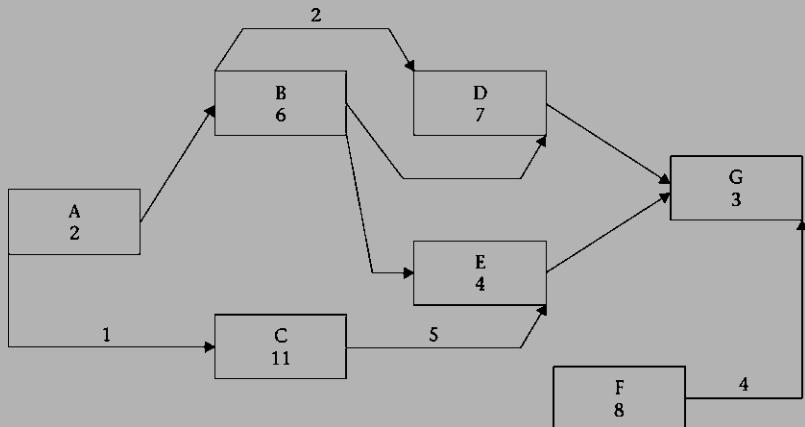


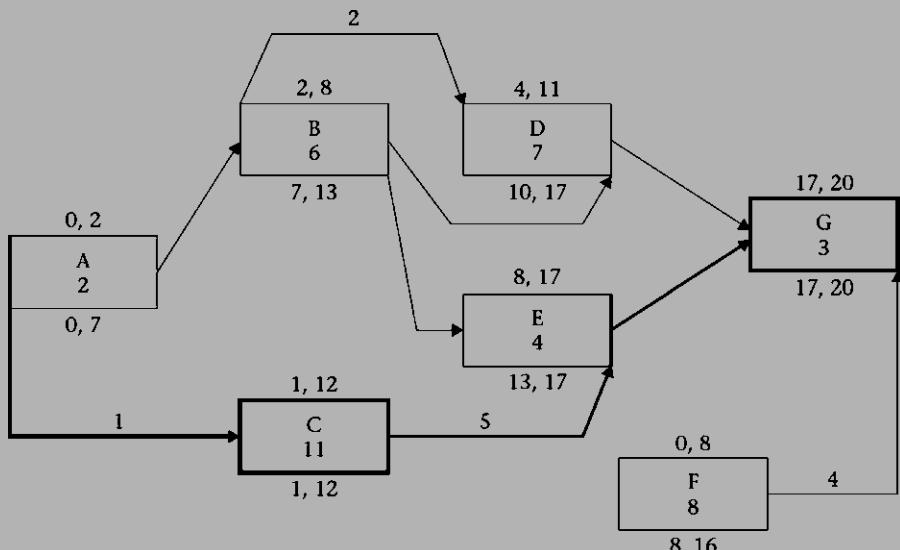
Figure 5.22 Network for example 5.1

Solution**Forward Pass**

1. Start the project at activity A. $ES = 0$. $EF = 0 + 2 = 2$.
2. Activity B can start as soon as activity A is finished. $ES = 2$. $EF = 2 + 6 = 8$.
3. Activity C can start 1 day after A has started. $ES = 1$. $EF = 1 + 11 = 12$.
4. Activity D can start 2 days after activity B has started. $ES = 2 + 2 = 4$. Use the later of $EF = 4 + 7 = 11$ and the EF (for B) = 8. We choose $EF = 11$.
5. Activity E can start as soon as B is finished. $ES = 8$. Use the later of $EF = 8 + 4 = 12$ and EF (for C) + 5-day lag = $12 + 5 = 17$. We choose $EF = 17$.
6. Activity F has no restriction for its start (dangling activity). $ES = 0$. $EF = 0 + 8 = 8$.
7. Activity G can start after both D and E are finished. ES (for G) = 17 (the later of 11 and 17). Use the later of $EF = 17 + 3 = 20$ and EF (for F) + 4-day lag = $8 + 4 = 12$. We choose $EF = 20$.
8. The calculated early finish date for the project is day 20 (project duration is 20 days).

Backward Pass

1. Start at activity G. $LF = 20$. $LS = 20 - 3 = 17$.
2. Activity F must finish 4 days prior to the finish of G (i.e., $LF = 20 - 4 = 16$; $LS = 16 - 8 = 8$).
3. Activity E must finish before G can start. $LF = 17$. $LS = 17 - 4 = 13$.
4. Activity D must finish before G can start. $LF = 17$. $LS = 17 - 7 = 10$.
5. Activity C must finish 5 days before the finish of E. $LF = 17 - 5 = 12$. $LS = 12 - 11 = 1$.
6. Activity B must finish before D has finished, on day 17, and before E has started, on day 13. $LF = 13$ (the earlier). Use the earlier of $LS = LF - Dur = 13 - 6 = 7$ and 2 days before the LS for D (i.e., 8). We choose the earlier: $LS = 7$.
7. Activity A must finish before B can start. $LF = 7$. Use the earlier of $LS = 7 - 2 = 5$ and LS (for C) – 1-day lag = $1 - 1 = 0$. We choose $LS = 0$.
8. The critical path is the start of A, all of C, the end of E, and all of G (Figure 5.23).

**Figure 5.23 Solution for example 5.1**

9. The total float equals 5, 5, 6, 5, and 8 for A, B, D, E, and F, respectively. Some of this float is restricted; some is not. This subject is discussed in the following section.

The Detailed Approach

Unlike the arrow and node diagrams in chapter 4, precedence diagrams may show the start or finish of an activity to be critical while the rest of the activity is not. This is the situation in Figures 5.12 through 5.21. Let us add a twist to this scenario, as shown in Figure 5.24.

In this case, both activities A and C are completely critical. Activity B has a critical start and a critical finish but is not critical between.

Looking at Figures 5.12 through 5.24, we also notice that, contrary to the arrow and node diagrams in chapter 4, the duration of an activity may not always be equal to its $EF - ES$ or $LF - LS$. What does this mean? In Figure 5.17, for example, activity A must start on day 0; otherwise, the start of activity B, which is critical, will be delayed. The only restriction on the finish of activity A is that it should not delay the LF of activity B, which is day 7. This leaves activity A with 7 days, but it has only 5 days' duration. Therefore, activity A has 2 days of *restricted float*, which we explain later in this chapter. The crew for activity A has two options:

1. Start the activity on day 0, work nonstop, and finish early on day 5.
2. Start the activity on day 0, finish a certain portion, take a break of 1 or 2 days, and return and finish the activity by day 7.

A third float option, which activity A *does not have*, is to delay its start. If its start is delayed, the start of B will be delayed, which will delay the whole project. This is why we call it *restricted float*. This particular type of restricted float is called **start-restricted float**. Looking at activity C in Figure 5.17, we also find that C has 4 days of float in its start. However, no matter when it starts, it must finish on day 7; not before, not after. We conclude that activity C has 4 days of restricted float, or **finish-restricted float**. The work crew has the following two options:

1. Start the activity on day 0, finish a certain portion, take a break (or breaks) of 1 to 4 days, and return and finish the activity by day 7.
2. Delay the start of the activity till day 4, work nonstop, and finish on day 7.

A third float option, which activity C *does not have*, is to start early *and* finish early on day 3. It cannot finish before activity B is finished.

Looking at Figures 5.14 through 5.16, we find activities A and B in Figure 5.16 with *start-restricted floats*. Activity C in Figure 5.14 and activities B and C in Figure 5.15 have *finish-restricted floats*.

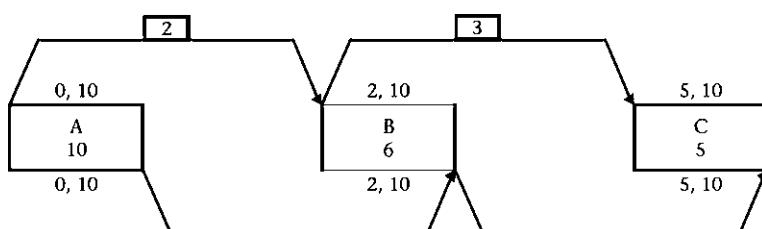


Figure 5.24 Network for the detailed approach

Activity B in Figure 5.24 must start on day 2 and must finish on day 10. We note that it has only 6 days' duration but must fill an 8-day time interval. We call the difference ($8 - 6 = 2$) *start-finish-restricted float*, or, for short, **double-restricted float**.

Activity B in Figure 5.11 has unrestricted float. The work crew can use this float in one of three ways:

1. Start the activity on day 0, work nonstop, and finish early on day 5.
2. Start the activity on day 0, finish a certain portion, take a break (or breaks) of 1 to 5 days, and return and finish the activity by day 10.
3. Delay the start by 1 to 5 days, work nonstop, and finish on or by day 10.

This type of float is similar to the total float discussed in chapter 4. We call it **unrestricted float**. *Total float* is the combination of all types of float, whether restricted or unrestricted.

Definitions

Start-restricted float. The amount of time we can delay the rest of the work in the activity, after it has started on its critical start date, without delaying the entire project.

Finish-restricted float. The amount of time we can delay the start of work on the activity, or the rest of it if it has started, then finish on time without delaying the entire project.

Double-restricted float. The amount of time we have to delay the rest of the work in the activity after it has started, then finish on time without delaying the entire project.

Unrestricted float. The amount of time we can delay all or part of the activity without delaying the entire project.

The Equations

For calculation purposes, let us put both *start-restricted float* and *finish-restricted float* under one category, **single-restricted float** (*SRF*, as compared with *double-restricted float* (*DRF*) or *unrestricted float* (*URF*)). As mentioned previously, in this chapter, *total float* (*TF*) includes all types of float, restricted or unrestricted.

For calculations, follow these steps:

1. Calculate the DRF:

$$DRF = \max [(EF - LS - Dur), 0] \quad (5.1)$$

2. If $DRF = 0$, apply these equations:

$$URF = \min [(LS - ES), (LF - EF)] \quad (5.2)$$

and

$$SRF = \text{abs} |(LS - ES) - (LF - EF)| \quad (5.3)$$

or

$$SRF = TF - URF^2 \quad (5.4)$$

² See equation 5.6 for *TF*.

3. If $DRF > 0$, apply these equations:

$$URF = \min[(LS - ES), (LF - EF)] \quad (5.2)$$

and

$$SRF = \max[(LF - LS), (EF - ES)] - Dur - DRF \quad (5.5)$$

$$4. \quad TF(URF + SRF + DRF) = [LF - ES - Dur] \quad (5.6)$$

The preceding equations combine start-restricted float and finish-restricted float as single-restricted float. You can distinguish between the two types mostly by simple observation, or by the following rule:

If $(LF - EF) > (LS - ES)$, then SRF is start restricted.

However,

If $(LF - EF) < (LS - ES)$, then SRF is finish restricted.

Contiguous (Uninterruptible) Activities

Let us assume that our activities cannot be interrupted (**contiguous activities**). In other words, once they start, they must continue till they are finished.³ All types of restricted float are eliminated. The activity becomes like an indivisible unit: If there is float, the whole activity slips or does not slip. In this case, activities become, simply, either critical or noncritical. Calculations are much simpler, but they may give you a different (later) project finish date than those for interruptible activities.

Let us return to Figure 5.12: With activity A as contiguous, it becomes entirely critical, with both early and late dates as (0, 10). Activities B and C in Figure 5.13 become entirely critical, with both their early and late dates as (5, 10) for B and (7, 10) for C. The same is true of activity C in Figure 5.14. Its early and late dates become (9, 12). In Figures 5.15 and 5.16, all activities also become critical.

In the preceding cases, the finish date of each project does not change, despite the change in assumption from interruptible to contiguous. The only change is that activities with restricted float lose their float and become totally critical. However, this may not always be the case. In Figure 5.24, if activities become contiguous, the dates change per Figure 5.25, and the entire project is pushed back 2 days. CPM calculations for such cases are similar to those described previously for interruptible activities, with one exception: We must satisfy the following equation:

$$Dur = EF - ES = LF - LS$$

This can force the early dates to be pushed forward (to a later date) or late dates to be pushed backward (to an earlier date). In the previous example (Figure 5.24), we find that the early dates for activity B violate the preceding equation:

$$Dur = 6 < (EF - ES)$$

³ Even with this assumption, a real-life interruption can occur. In computer programs such as Primavera P3/P6 or MS Project, there is a special (manual) function to suspend or pause an activity, then resume it. This type of manual suspension and resumption is not factored into the calculation. Programs still treat the activity as one unit. The suspension time may not count as part of the duration of the activity but will certainly affect the succeeding activities and possibly the entire project.

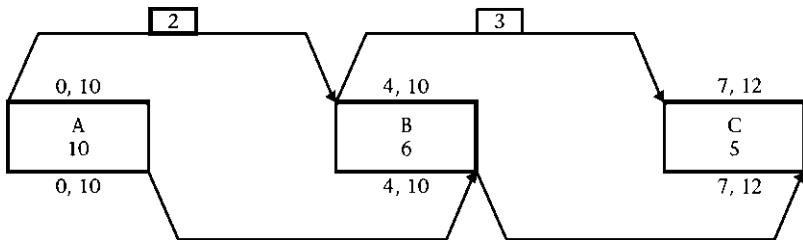


Figure 5.25 Network in Figure 5.24 with contiguous activities

We have to move one of the two dates. Moving the EF date to day 8 will satisfy the equation but will violate the FF relationship between B and A. The only choice we have is to move the ES date to day 4. Then, the early dates for activity B are (4, 10). The same argument applies to late dates. All three activities in this case are critical and have no float of any type.

To formalize the rules, we can say that activities with a combination (SS and FF) relationship, say A and B, for example, will have two sets of early dates and two sets of late dates. One set will prevail:

- a. In the forward pass, the SS relationship (plus lag if any) determines the ES_1 date for activity B, which is ES (for A) + 2 (lag) = 2. The EF_1 for B is calculated as $EF_1 = ES_1 + Dur = 2 + 6 = 8$. The first set of early dates for activity B is (2, 8).
- b. The FF relationship (plus lag, if any) determines the EF_2 date for activity B. The EF date for activity A is day 10, which is the same for B (since the lag on the FF relationship is 0). The ES_2 for activity B is then calculated as $ES_2 = EF_2 - Dur = 10 - 6 = 4$. The second set of early dates for activity B is (4, 10).
- c. Pick whichever date set—(ES_1, EF_1) or (ES_2, EF_2)—is later; that is (4, 10).
- d. In the backward pass, the SS relationship (minus lag if any) determines the LS_1 date for activity B, which is LS (for C) - 3 (lag) = 7 - 3 = 4. The LF_1 for B is calculated as $LS_1 + Dur = 4 + 6 = 10$. The first set of late dates for activity B is (4, 10).
- e. The FF relationship (minus lag if any) determines the LF_2 date for activity B as LF (for C) - Lag (0 in this case) = 12 - 0 = 12. The LS_2 for B is calculated as $LF_2 - Dur = 12 - 6 = 6$. The second set of late dates for activity B is (6, 12).
- f. Pick whichever date set—(LS_1, LF_1) or (LS_2, LF_2)—is earlier; that is (4, 10).

The preceding process looks complicated in theory but is actually intuitive. Total float and free float are calculated the same way as in chapter 4.

If we re-solve example 5.1 using contiguous activities, we will get the same finish date for the project; day 20. The only difference will be that activities A and E will be completely critical. As mentioned previously, this is not always true. Let us look at the following example:

Example 5.2

Perform the forward and backward passes on the precedence network shown in Figure 5.26, on the basis of the following: interruptible activities and contiguous activities.

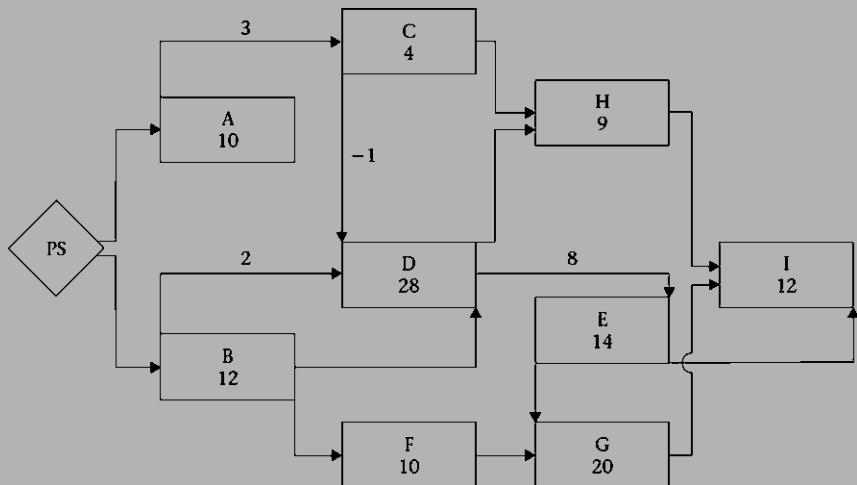


Figure 5.26 Network for example 5.2

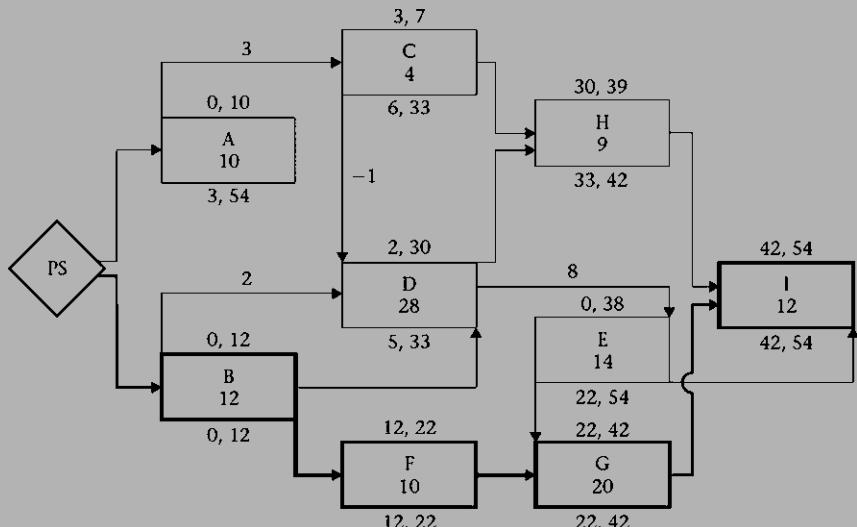
Solution with Interruptible Activities

Figure 5.27 Solution for example 5.2 with interruptible activities

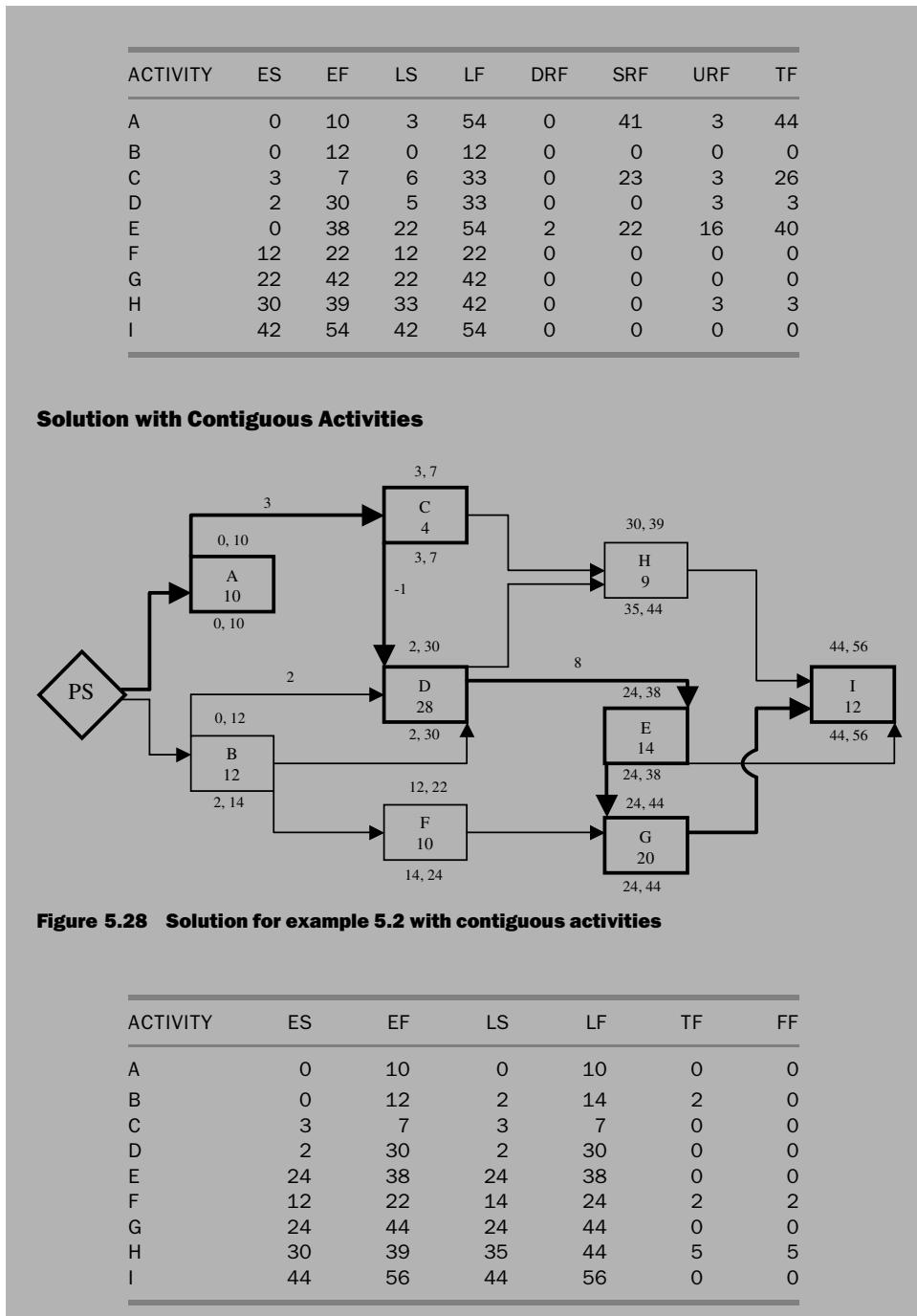


Figure 5.28 Solution for example 5.2 with contiguous activities

The simple difference between the two solutions is that in the case of contiguous activities, we do not allow restricted float. Once an activity starts, it must continue till it is finished. Calculations were going similar until activity E. The early dates (24, 38) were calculated from its FF relationship with activity D. This is not good enough for activity G, whose critical start on the 22nd day depends on the start of activity E. This forces a delay in activity G, which will delay the entire project by 2 days. As a result, the critical path becomes: A, C, D, E, G. This leaves only three noncritical activities: B, H, and F. Activities B and F were critical in the “interruptible activities” solution but now gained a float of 2 days as a result of forcing this 2-day delay on activity G. Activity H had 3 days of total float in the “interruptible activities” solution, and now the float has added 2 days to become 5.

Note also that a relationship between two critical activities is not necessarily critical. For example, the FF relationship between activities E and I is not driving and, thus, is not critical.

Stretchable Activities?

As you saw earlier in the interruptible activities case, an activity may have a critical start but a flexible finish, or vice versa. In other words, it may have a time slot to fill that is larger than its duration (see many examples in Figures 5.12 through 5.18). The difference in this time slot (LF–ES) contains the duration plus the restricted float. If this activity becomes contiguous, the restricted float disappears and the activity is pushed forward or backward (depending whether its finish or start was critical). We proved in Example 5.2 that going from interruptible to contiguous type of activity may cause a later completion date for the schedule. What if we can keep the activity contiguous but reduce the resource allocation, that is, slow down work pace so that the activity duration can fill the entire time slot (original duration + restricted float)? This may solve the problem; that is, we would consider the activity contiguous yet get the project completion date obtained with the interruptible activity solution. If this is not possible, then we should consider splitting the activity into two or more segments. For example, activity B in Figure 5.25 is split into two segments; each has 3-day duration.

With this procedure, we were able to complete the project by day 10, which is same as the completion date with interruptible activities. In reality, the solution of Figure 5.29 represents an interruptible activity B but done as two separate and contiguous activities. The interval between the start of B1 and finish of B2 is 8 days, which is same as in the solution of Figure 5.24. However, this is a workaround in case the computer software does not allow interruptible activities.

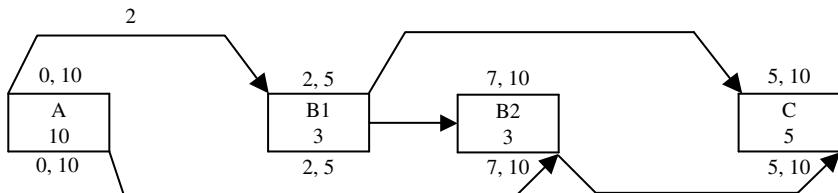


Figure 5.29 Splitting Activity B of Figure 5.25

FINAL DISCUSSION

Four final points should be considered:

1. The subject of precedence diagrams can be somewhat complicated. It is easy for someone in the field to use the “sour grapes” excuse and say, “Who uses these things anyway?” There is nothing wrong with making assumptions that simplify our life. However, if these simplifications mean avoiding a subject that we perceive as complicated or unfamiliar to us, we may be missing something important. Understanding the nature of relationships among activities is extremely important. Making the assumption of interruptible or contiguous activities is also important. It can result in a difference of several days in the project’s completion date. We just proved this when we compared Figures 5.24 and 5.25. Maybe the project manager does not need to discuss the types of float with his or her work crews, but he or she *must* understand—in layperson’s terms—that some activities must start with a certain portion (but not all) of them finished before a succeeding activity can start. Failure to understand this point may result in an inaccurate schedule and a possible conflict between field operations and the office-prepared schedule.
2. In reality, most project managers and schedulers overlook the issue of interruptible or contiguous activities and may also overlook the type of relationship and lags. They try to compensate for the inaccurate logic by “correcting” it through schedule updates. For example, the baseline schedule may show a Clear & Grub activity with 12 days’ duration followed by an Excavation activity (FS relationship). Once the project starts, you may indicate an Actual Start for Excavation only 4 days after Clear & Grub has started, a clear violation of the set logic. The scheduling report may indicate “Activity started; predecessor has not finished.” The calculation of the updated schedule will depend on whether you want to apply **Retained Logic** (i.e., schedule the remainder of Excavation *after* the predecessor, Clear & Grub, has finished) or to apply **Progress Override** by allowing Excavation to continue independently of the Clear & Grub activity (this topic is explained in more detail in chapter 7). This option is available with some computer software

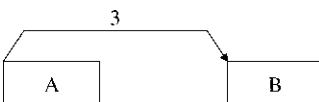
programs, but the author's observation has been that many software users never pay attention to this choice. As a result, the program always uses the more conservative assumption—Retained Logic—which may result in a later calculated finish date for the project.

3. At the same time, the scheduler should use the KISS (keep it simple and smart, not stupid) approach as much as possible. Sometimes, instead of having a combination (SS and FF) relationship with lags, splitting the predecessor activity into two and then using the traditional FS relationship may be simpler and more acceptable. The precedence diagramming method is an effective and powerful tool, but it should be used in a reasonable and effective way.
4. Computer programs, to the best of the author's knowledge, either do not give the user the choice of (interruptible or contiguous activities) or allow it at the entire project level only. In the latter case (such as in Primavera Project Planner, P3), the user must decide whether *all* activities are interruptible or contiguous (although the user can choose the contiguous option, then manually interrupt and resume certain activities). Real-life activities are not exactly one way or the other. This puts the responsibility back into the scheduler's hands (remember the discussion on the scheduler's qualifications at the end of chapter 1). He or she must make intelligent and informed decisions that should align the schedule assumptions with reality as closely as possible within the limitations of computer programs and practicality. Remember, it is the human being behind the computer, not the computer itself, who makes the important decisions.

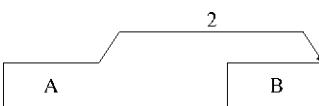
CHAPTER 5 EXERCISES

1. Explain the main differences between the standard node diagram (covered in chapter 4) and precedence diagrams.
2. What is the *stair-type relationship*? What is the advantage of precedence diagrams over it? Draw a network for a roofing job (install trusses, install sheathing, install felt, install shingles), using each method (i.e., draw two diagrams, one for each method).
3. Give a practical example for each of the following:
 - a. Start-to-start (SS) relationship only
 - b. Finish-to-finish (FF) relationship only
 - c. Combination SS and FF relationship
4. What does the following relationship mean?
 - a. Activity B must start exactly 3 days after the start of A.
 - b. Activity B can start at least 3 days after the start of A.

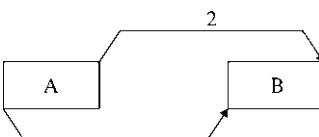
- c. Activity B can start at most 3 days after the start of A.
- d. None of the above.



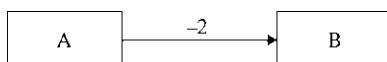
5. What does the following relationship mean?
- a. Activity B must finish exactly 2 days after the finish of A.
 - b. Activity B can finish at least 2 days after the finish of A.
 - c. Activity B can finish at most 2 days after the finish of A.
 - d. None of the above.



6. What does the following relationship mean?
- a. Activities A and B must start simultaneously, but B must finish exactly 2 days after the finish of A.
 - b. Activity B can start after the start of A but must finish at least 2 days before the finish of A.
 - c. Activity B can start before the start of A but must finish at most 3 days after the finish of A.
 - d. Activity B can start after the start of A but must finish at least 2 days after the finish of A.



7. What does the following relationship mean?
- a. Activity A can start 2 days before the start of activity B.
 - b. Activity B can start 2 days after the completion of activity A.
 - c. Activity B can start 2 days before the completion of activity A.
 - d. Activity B has to start at least 2 days before the completion of activity A.



8. Define a *fast-track operation*. Briefly discuss its pros and cons.
9. Mention examples in which using fast-tracking is bad, good, or a “must” option.

10. From the following table, draw the precedence network, perform the CPM calculations, and complete the table entries, assuming interruptible activities.

Activity	Duration	IPA	Type Rel ^a	Lag	ES	EF	LS	LF	TF	FF
A	3	–								
B	5	A	SS	3						
C	2	A								
D	6	B	FF							
		C								

^aIf the relationship type is not mentioned, it is finish to start (FS). If no lag is mentioned, it is zero.

11. From the following table, draw the precedence network, perform the CPM calculations, and complete the table entries, assuming interruptible activities.

Activity	Duration	IPA	Type Rel ^a	Lag	ES	EF	LS	LF	TF	FF
A	4	–								
B	3	–								
C	8	A	SF							
D	7	A, B								
E	6	D	SS	3						
F	3	D								
G	5	F	SS	2						
	2	F	FF							

^aIf the relationship type is not mentioned, it is finish to start (FS). If no lag is mentioned, it is zero.

12. From the following table, draw the precedence network, perform the CPM calculations, and complete the table entries, assuming interruptible activities.

Activity	Duration	IPA	Type Rel ^a	Lag	ES	EF	LS	LF	TF	FF
A	5	–								
B	7	A	SS	2						
C	8	A								
D	10	A	SS FF	3						
E	4	B	FF	2						
F	6	C, D								
G	2	E, F								

^aIf the relationship type is not mentioned, it is finish to start (FS). If no lag is mentioned, it is zero.

13. Repeat exercise 10 using contiguous activities.
 14. Repeat exercise 11 using contiguous activities.

15. Repeat exercise 12 using contiguous activities.
16. Prove that using interruptible activities in the following project allows the project to finish 5 days earlier than if the activities were contiguous.

Activity	Duration	IPA	Type Rel ^a	Lag	ES	EF	LS	LF	TF	FF
A	7	—								
B	6	A	SS	3						
		FF	4							
C	2	B	SS	1						
		FF								
D	6	C	SS							
		FF	4							
E	10	D	SS	3						
		FF	2							

^aIf the relationship type is not mentioned, it is finish to start (FS). If no lag is mentioned, it is zero.

17. Give real-life (not necessarily construction) examples for the following:
 - a. An SS (start-to-start) relationship without lag. No FF (finish-to-finish) relationship is required.
 - b. An SS relationship with lag. No FF relationship is required.
 - c. An SS and FF combination relationship.
 - d. An FF relationship, with or without lag.
18. A subcontractor must do the following:
 - a. Framing (5 days)
 - b. Drywall installation (4 days)
 - c. Drywall finish and paint (3 days)

Assuming he wants to make sure each activity finishes as least 1 day after its predecessor has finished, draw these three activities in a precedence diagram and calculate how much time the subcontractor would need to finish all three activities.
19. Look at your solution to the previous exercise. Is it a unique solution, or can you achieve the same result with different logic?
20. Mention an example for each of the following:
 - a. Start-restricted float
 - b. Finish-restricted float
 - c. Double-restricted float
 - d. Unrestricted float

Chapter 6

Resource Allocation and Resource Leveling



Lauderhill City Hall, Lauderhill, Florida

INTRODUCTION

The term *resource* is used in many fields and contexts. Most companies have *human resources* departments, which match the need for employees with the appropriate supply by hiring and laying off workers. The term *financial resources* is commonly used to indicate available monetary sources. In project management, we use the term *resources* to indicate three main categories: labor (human), materials, and equipment. Ultimately, everything is translated into a monetary quantity that may be—for the accounting department—a part of the financial resources.

THE THREE CATEGORIES OF RESOURCES

All expenses, in any construction project, can be classified under one of the three categories just mentioned.

Labor

Labor can be further classified into the following two subcategories:

1. *Salaried staff*: These individuals include the project manager, superintendent, project engineer, secretary, and any other person who is tied to the project but not tied to one particular activity or work package. Salaried persons usually get paid a fixed salary for the duration of the project or their assignment.
2. *Hourly workers*: These individuals are hired to perform a specific task or activity. Examples include carpenters, masons, ironworkers, electricians, foremen, and so forth. They are usually paid for actual hours worked.

Equipment and Materials

Equipment and materials can also be further classified into two subcategories:

1. *Construction equipment and materials*: This type of equipment and materials is used for the construction process but is not permanently installed in the project. Examples of *construction equipment*¹ are bulldozers, backhoes, cranes, power generators, forklifts, mechanical trowels, heaters, and blowers. Inexpensive personal tools are usually treated differently (either as a lump sum for all tools or as the laborer's personal property). Examples of *construction materials* are formwork materials and scaffolding.
2. *Installed equipment and materials*: This type of equipment and materials stays permanently in the project after completion. Examples of *installed equipment* are heat pumps, emergency generators (in hospitals, industrial projects, and

¹ In the UK, this type of equipment is called *plant*

some other projects), kitchen equipment, and many specialized equipment in industrial projects. Examples of *installed materials* are concrete, rebar, CMUs (concrete masonry units), brick, mortar, insulation, framing wood, shingles, floor tile and carpet, bathroom accessories, plumbing pipes and fittings, and electrical wires. Elevators and escalators may be classified as either installed equipment or installed materials, but in most cases, they are installed by the same vendor and in the estimate are considered a subcontractor cost.

For estimators, the *equipment* category includes mostly construction equipment. Installed equipment belongs in the *materials* category.

WHAT IS RESOURCE ALLOCATION?

Resource allocation is the assignment of the required resources to each activity, in the required amount and timing. Resource allocation is also called *resource loading*.

RESOURCE LEVELING

What Is Resource Leveling?

Resource leveling is minimizing the fluctuations in day-to-day resource use throughout the project. It is usually done by shifting noncritical activities within their available float. It attempts to make the daily use of a certain resource as uniform as possible.

Why Level Resources?

When the contractor adds the daily total demand for a specific resource for all activities, he or she must provide the required amount, or work will be delayed.

This daily demand for a certain resource naturally fluctuates during the lifecycle of the project, depending on the work being performed that day (i.e., activities requiring that resource) and the resource demand for each activity. This fluctuation (say, 10 carpenters for the first two weeks, 6 for the week after, 18 for 4th and 5th week, 12 for week 6, and so on) is not practical or economical.

Leveling may also be necessary for an expensive piece of equipment (which may cost money not only in rental expenses but also in the cost of mobilization, setup, maintenance, and demobilization). Say, for example, two activities require a tower crane at the same time. If you can delay the start of the second activity till the first has finished, you will redirect your resource (the tower crane) to the second activity. By doing this, you will have reduced the maximum demand of tower cranes at any time to only one, which will save expenses.

Do All Resources Have to Be Leveled?

Not all resources need to be leveled. The main idea of resource leveling is to improve work efficiency and minimize cost during the life of the project. This concept applies to

resources that are hired or rented—namely, labor and (major) construction equipment. The need for such resources may vary significantly as some activities start (they pull new resources) and other activities finish (they release their resources). Likewise, the resource requirement of some activities changes during their duration.

In general, materials do not need to be leveled. For instance, it is common practice to place 100 CY (cubic yards) of concrete in one day, place no concrete for one week, then place more concrete the week after, and so on. Project managers mainly have to arrange small deliveries in an economical way. Materials must be managed using a completely different concept, as discussed at the end of this chapter.

Multiproject Resource Leveling

Some resources may be shared among projects. The question is which resources and how much of them. For small projects in a relatively close vicinity, for example, some staff (project manager, safety manager, quality manager, secretary, etc.) and equipment may be shared. Project managers must make decisions when the situation looks like a borderline case: for instance, would it be more efficient to have someone travel between two jobs or to hire another person even though the person will not be occupied 100% of the time? The same argument holds for equipment. In general, convenience and simple economics are mostly the driving criteria. However, other issues may be considered, such as the short- and long-term need; future market expectations; staff morale, fatigue, and satisfaction; relationships with vendors and subcontractors; and so forth.

Example 6.1

Assume a project engineer costs his employer \$50 per hour. Two projects are within x miles of each other. The engineer travels at an average speed of 40 miles per hour and costs the company \$0.50 per mile to travel between the two projects. Assume that the following four statements are true:

1. The engineer is needed a minimum of 3 hours/day in each project.
2. Travel between the two projects occurs only once a day (the engineer starts his or her day on job A, travels to job B, and then comes back home near job A).
3. Overtime, if needed, is compensated at 1.5 times the regular rate.
4. And a second engineer costs the same amount as the first one.

What is the maximum distance between the two projects that makes sharing the same engineer efficient?

Solution

Let's consider two situations.

First—no overtime: No overtime means the engineer may travel between the two jobs (roundtrip) for no more than 2 hours (3 hours at job A + 3 hours at job B + 2 hours' travel = 8 hours per day).

Maximum distance = 2 hours * 40 mph = 80 miles roundtrip or 40 miles one way, Mileage compensation = 80 * \$0.50/mile = \$40 per day, Total cost per day = \$50 * 8 + \$40 = \$440,
and

$$\text{Average cost per hour} = \$440/8 = \$55.$$

It is clearly much more economical to use one engineer than to hire two engineers at a combined cost of \$100 per hour.

Second—with overtime: Let us assume the two jobs are 100 miles apart. The engineer will have 5 hours of driving time (2.5 hours each way), or 11 hours of work per day.

Mileage compensation = 200 * \$0.50/mile = \$100 per day, Overtime compensation = 3 * \$50 * 1.5 = \$225², Regular-time compensation = 8 * \$50 = \$400,
and

$$\text{Total cost per day} = 100 + 225 + 400 = \$725.$$

This cost is still less than \$800 per day (the cost of two engineers, one at each job), but the difference is narrowing.

When the time needed at each job plus the travel time between the two jobs increases, hiring a second engineer may be more economical. Other factors influencing such decisions are length of need and future expected need. If the need is temporary, it may be more cost efficient to pay overtime to one engineer. Alternatively, some companies use temp (temporary) workers to fill their short-term needs.

Staff members who do not have to be present at the job site every day may be spread out, either by dividing the day between two or more jobs or by assigning certain entire days to different jobs. Certain high-paid staff, such as safety officers, schedulers, and project control people, who need to spend only one day every week or every two weeks at the job site, may even fly hundreds of miles between jobs. With the advancement of telecommunications tools (phones, internet, video conferencing, etc.) many functions can now be performed from a remote location.

² There is a small error here in the calculation: The normal cost of the engineer to the employer, i.e. \$50/hour, includes taxes and insurance. When working overtime, taxes and insurance do not increase per hour. So the number calculated is slightly inflated, however, the difference was ignored for simplicity.

Assigning Budgets in Computer Scheduling Programs

Without going into accounting details, let us briefly cover budgeting in this chapter—only in the context of project control and resource leveling. In scheduling programs, two methods are available for assigning budgets to activities (this subject is discussed further in chapter 10):

1. Assigning a lump-sum amount without telling the scheduling program how was the number derived or which resources used. You may still need to supply a cost account code in some software packages, which helps track the cost.
2. Assigning a number of units of certain resources (e.g., one foreman, one equipment operator, two laborers, one bulldozer, and one hydraulic excavator) to the activity. The program will calculate the budget for a particular activity from the “resource dictionary” in the project database.

The second method has six advantages:

1. You can level your resources only when you assign resources to the activity.
2. You can produce procurement reports specifying the resources need by type, quantity, date, and cost. You can link your schedule with the accounting (and estimating) system, match your demand with supply, and trace each expense in your project. You can do this, too, with the first method, but you will see only dollar amounts without any breakdown details.
3. This method aids more in project control and earned value management.
4. In case there is a change in the cost or availability of a resource that is being used for one or more activities, the scheduling program will reflect the impact of the change at the entire project level.
5. You may be able to use a “resource calendar.” This type of calendar is defined for a specific crew. For example, if a plumbing crew is available for work on a project Wednesday through Saturday only, the program will automatically schedule work only during these days in the activities with this crew assigned to.
6. **Resource-driven schedules** are possible. Under certain conditions, you can allow your resources to control the duration of an activity. For example, if a **resource-driven activity** requires four painters for 10 days, the program uses a total of 40 man-days, or 320 man-hours, for its basis. Depending on the painters’ availability and logic, the scheduling program may assign a fluctuating number of painters to the activity to finish the job in the most efficient way (from a resource management perspective). The result may be an increase or a decrease in the duration, with the same bottom-line 320 man-hours. This option may also be turned off to maintain the original duration.

One interesting scenario that pertains to point 4 is when resources are priced through a certain date, then increase. Suppose that a union contract calls for a carpenter's pay rate of \$24 per hour through 30 June 2010. After this, it will increase to \$26.50 per hour. Assume that a particular activity requires 128 carpenter man-hours and is scheduled to take place in June 2010. The total cost for the carpenters is $128 * \$24 = \$3,072$. Now, suppose that the activity schedule slips to July. The cost will increase by $128 * \$2.50 = \320 , for a new budget of $\$3,392$. You have to be careful in such cases as to whether to allow the resource dictionary to drive the budget or to treat the budget as a fixed amount.

Leveling Resources in a Project

Resource leveling is a mathematically complex process. The resource-leveling method is called the *minimum moment algorithm*, as it was discussed by Robert B. Harris (1978) in his classic textbook, *Precedence and Arrow Networking Techniques for Construction*. Fortunately, computer programs eliminated the difficult part of this process. Let us deal with resource leveling manually for a small, simple example.

Example 6.2

A subcontractor needs to install flooring in two areas:

1. Area 1: This area has old vinyl tile that must be removed and replaced with new vinyl tile.
2. Area 2: This area has a concrete slab that needs to be topped with ceramic tile.

This simple project is broken into the activities shown in the following table, along with the logic, the duration, and the required number of laborers for each.

Activity ID	Activity Description	IPA	Duration (Days)	Laborers
A	Purchase & Deliver Materials	—	5	2
B	Remove Old Vinyl Tile	—	7	4
C	Install Ceramic Tile	A	3	3
D	Install New Vinyl Tile	A, B	5	3
E	Clean Up & Inspect	C, D	2	2

Do the following:

1. Draw the precedence network and perform the CPM calculations.
2. Allocate the required resources, then level them so that the subcontractor does not use more than six laborers at any time.
3. Find ways to improve the labor usage profile.

For the sake of simplicity, assume that any laborer can perform any task.

Solution

Figure 6.1 shows the precedence diagram for this example, and Figure 6.2, the bar chart and **resource usage profile**, or laborer usage profile.

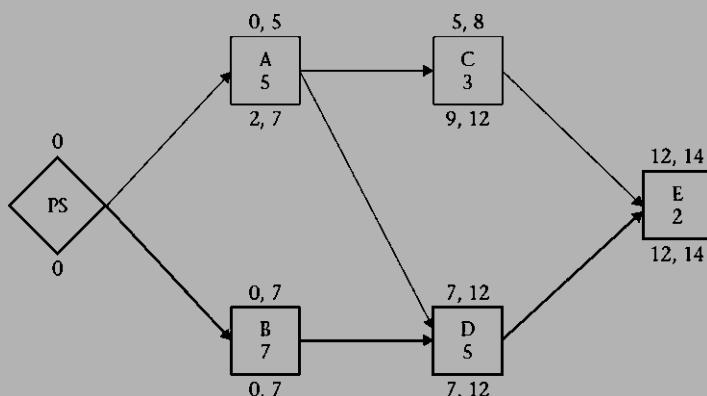


Figure 6.1 Precedence diagram for example 6.2 (PS, project start)

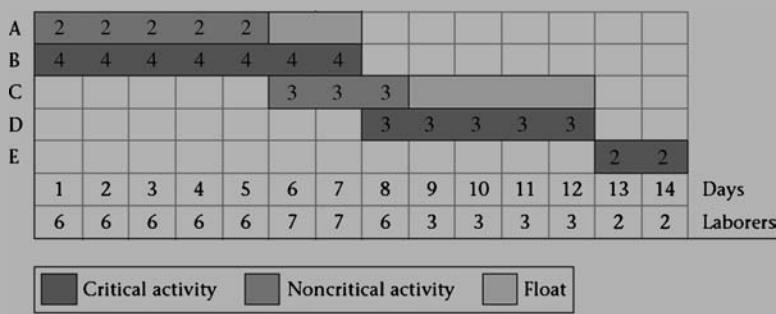
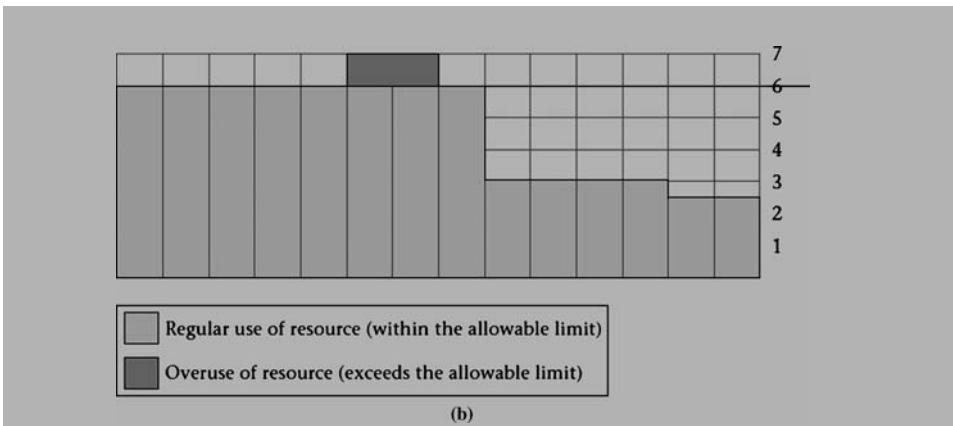
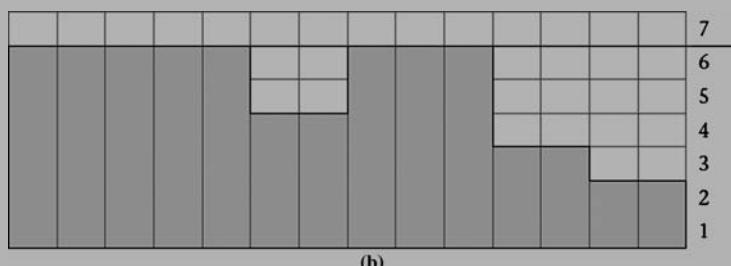
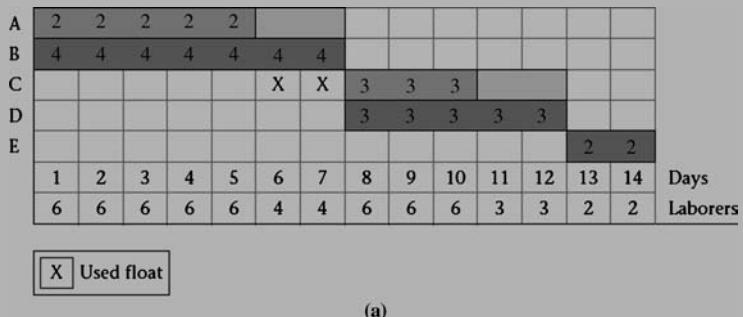


Figure 6.2 (a) Bar chart for example 6.2 with an unleveled labor assignment (typically following early dates); (b) resource, or labor, usage profile for example 6.2, showing overallocation

**Figure 6.2 (Continued)**

Using the early dates, we note that on days 6 and 7, the subcontractor needs seven laborers, one over the limit. He or she then decides to use 2 days of the float for activity C (Figure 6.3). This shift eliminates the labor-use spike

**Figure 6.3 (a) Bar chart for example 6.2 with a leveled labor assignment (within the allowable limit); (b) resource, or labor, usage profile for example 6.2, with a labor assignment within the allowable limit**

on days 6 and 7 and increases the laborers' use on days 9 and 10 from three to six.

The subcontractor observes that even though he or she did not exceed the limit on the number of laborers per day (six) in Figure 6.3, he or she can improve the labor usage profile by minimizing the fluctuations, as shown in Figure 6.4.

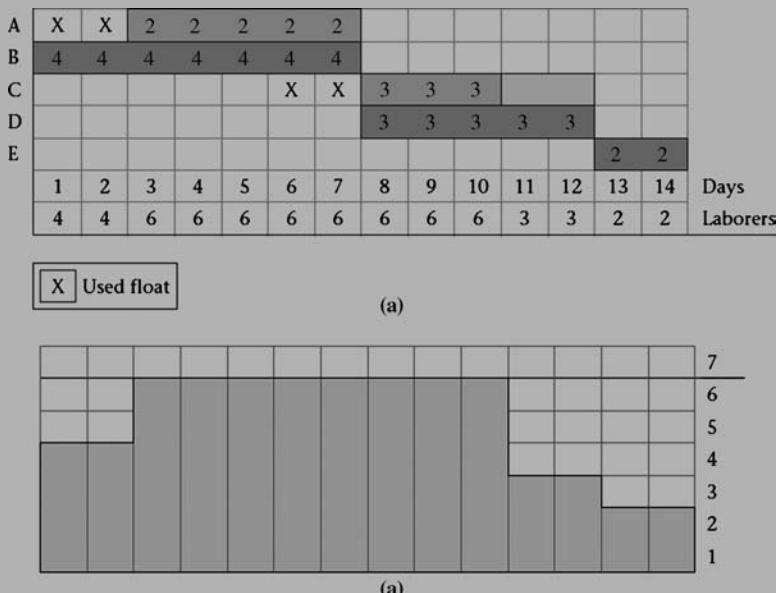


Figure 6.4 (a) Bar chart for example 6.2 with the labor assignment leveled and more efficiently distributed; (b) resource, or labor, usage profile for example 6.2 with the labor assignment efficiently distributed within the allowable limit

Example 6.3

Let us consider a more complicated example, which is still far less complicated than real projects, which have hundreds of activities and tens of resources.

Activity ID	Activity Description	Duration (Days)	IPA	Laborers
A	Excavation & Foundation	6	—	4
B	SOG	3	A	3
C	Framing	10	B	4

D	Plumbing	4	B	2
E	Electrical Wiring	3	C*	3
F	Drywall	5	C*	3
G	HVAC ^{\$} rough-in	3	C*	4
H	Roof	5	C	3
I	Paint	4	F	2
J	HVAC Finish	2	G, H	2
K	Flooring	4	D, I	3
L	Electrical Finish	1	E, H	2
M	Punch List & Cleanup	1	J, K, L	2

*This is a combination SS + FF relationship with no lags.

^{\$}HVAC is an acronym for heating, ventilation, and air-conditioning

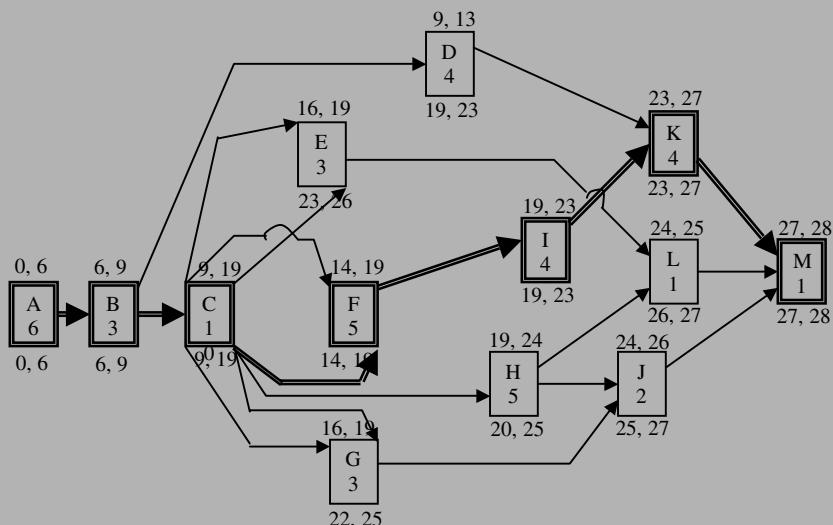


Figure 6.5 Logic network solution for Example 6.3

For each of the following scenarios, determine how to level the resources:

- An unlimited number of laborers
- Only 10 laborers available at any time
- Only 8 laborers available, but a peak use of 10 laborers is allowed for one time (one day) only
- Only 8 laborers available at any time
- Only 8 laborers available at any time, but activities may be interrupted
- Only 8 laborers available at any time, but the laborer resource may drive the durations of activities

Solution

- a. *An unlimited number of laborers.* As shown in Figure 6.6, the project finishes in 28 days. Using the early dates results in a maximum labor use of 14 laborers per day on days 17, 18, and 19.
- b. *Only 10 laborers available at any time.* Only one adjustment is necessary: Delay activity G by 3 days (it had 6 days of total float), as shown in Figure 6.7.
- c. *Only 8 laborers available but a peak use of 10 laborers is allowed for one time (day) only.* This was possible only if a one-day delay is allowed for the project, finishing on day 29, as shown in Figure 6.8. We can finish in 28 days if activity M is allowed to overlap with last day of activity K.
- d. *Only 8 laborers available at any time.* Note that in this case, the project must be delayed by 1 day (Figure 6.9). This is an example of **forward resource leveling**, in which resources are not available to both satisfy the demand for all activities and finish on time. This situation is discussed at the end of this example.
- e. *Only 8 laborers available at any time but allow activities to be interrupted.* Even with interruptible activities, we could not satisfy the activities' need for resources and maintain the total resource daily usage within 8 laborers, yet finish in 28 days. We need 29 days. In Figure 6.10, we managed to do it in 28 days with one minor violation of the logic: We allowed activity K to start one day before the completion of activity I.
- f. *Only 8 laborers available at any time, but the laborer resource may drive the durations of activities.* We show two scenarios in Figures 6.11a and 6.11b. Other scenarios can lead to the same project duration: 22 days. In this case, we "played with" activity resource allocations, allowing durations to fluctuate on the basis of supply (available resources) and demand (total resource requirements for activities). Even though we did not allow resource use to exceed 8 laborers per day, we were able to finish the project in 22 days (vs. 29 days in case d). Note also that we did not interrupt activities. If we allow activity C to start on the last day of activity B, we can cut the project duration to 21 days, as shown in Figure 6.12. Also, if we allow activity M to occur in parallel with activity L, we cut another day of the duration without going over the 8 laborers per day limit.

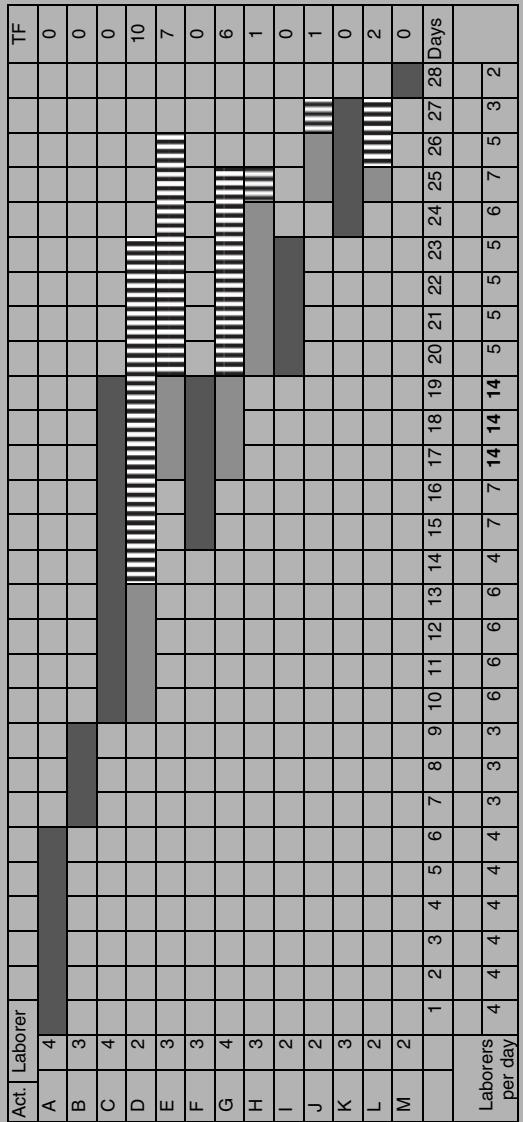


Figure 6.6 Bar chart for example 6.3 with an unleveled labor assignment

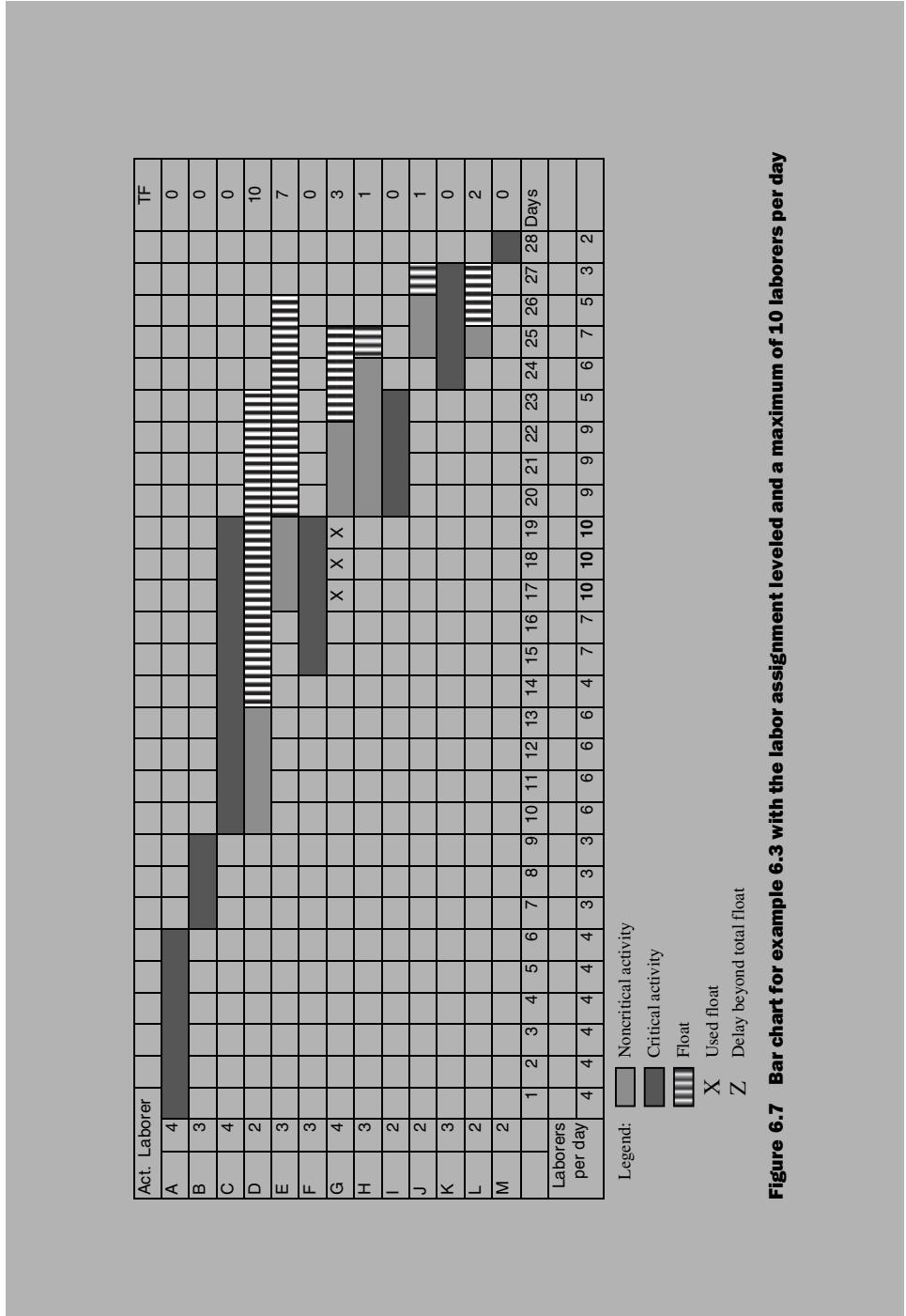


Figure 6.7 Bar chart for example 6.3 with the labor assignment leveled and a maximum of 10 laborers per day

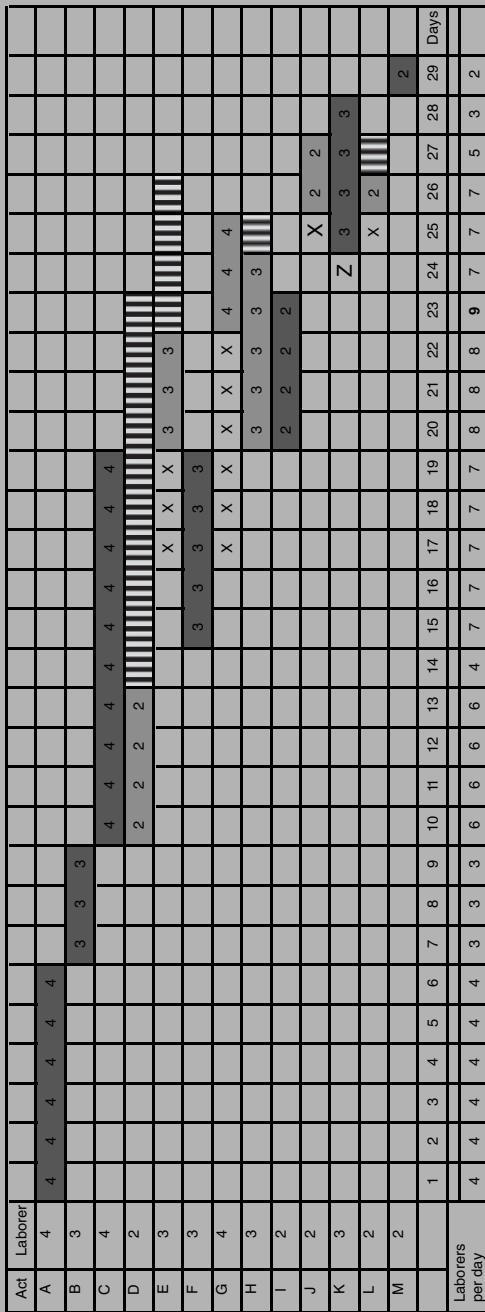


Figure 6.8 Bar chart for example 6.3 with the labor assignment leveled, a normal limit of 8 laborers per day, and a one-time peak of 10 laborers per day

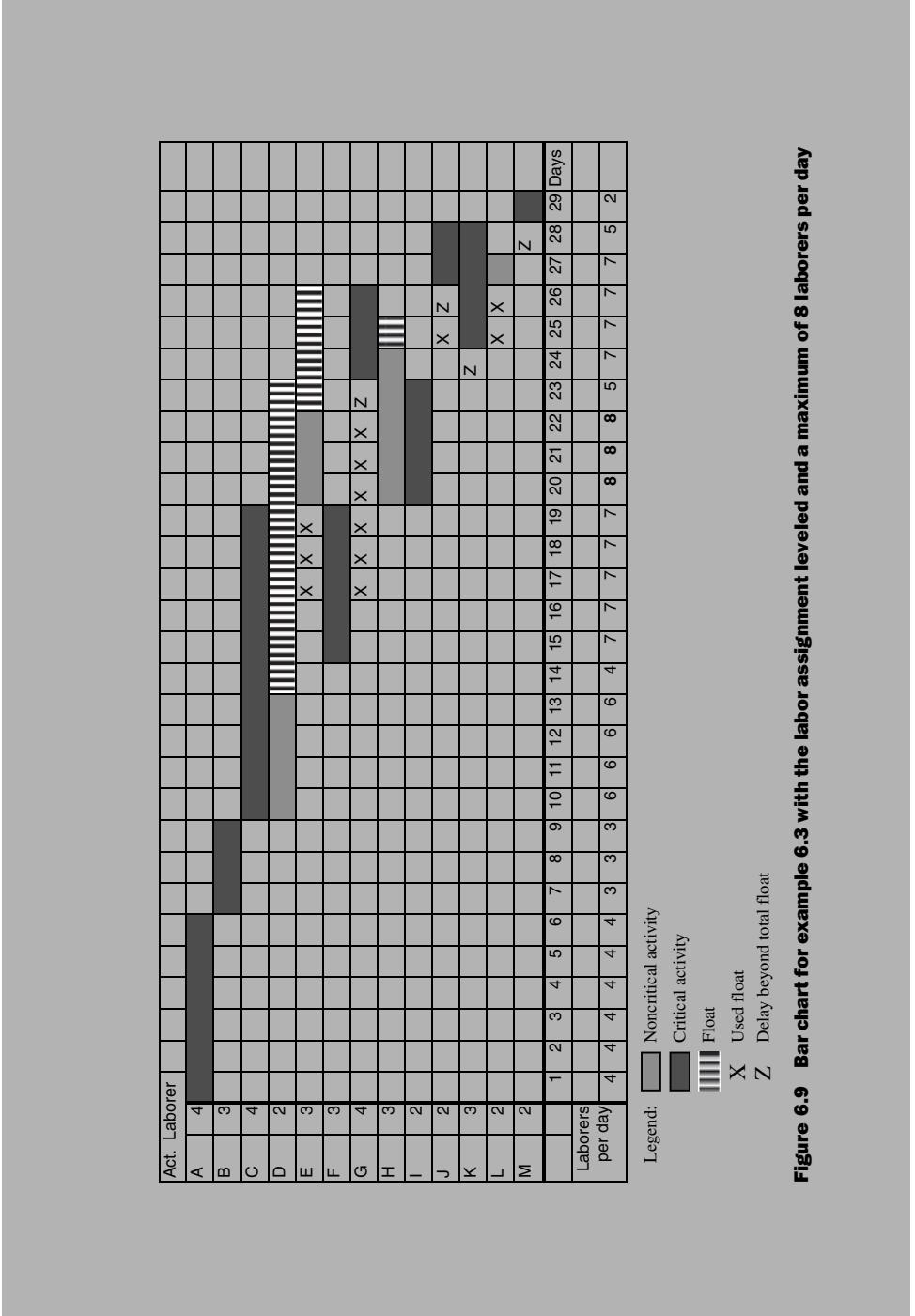


Figure 6.9 Bar chart for example 6.3 with the labor assignment leveled and a maximum of 8 laborers per day

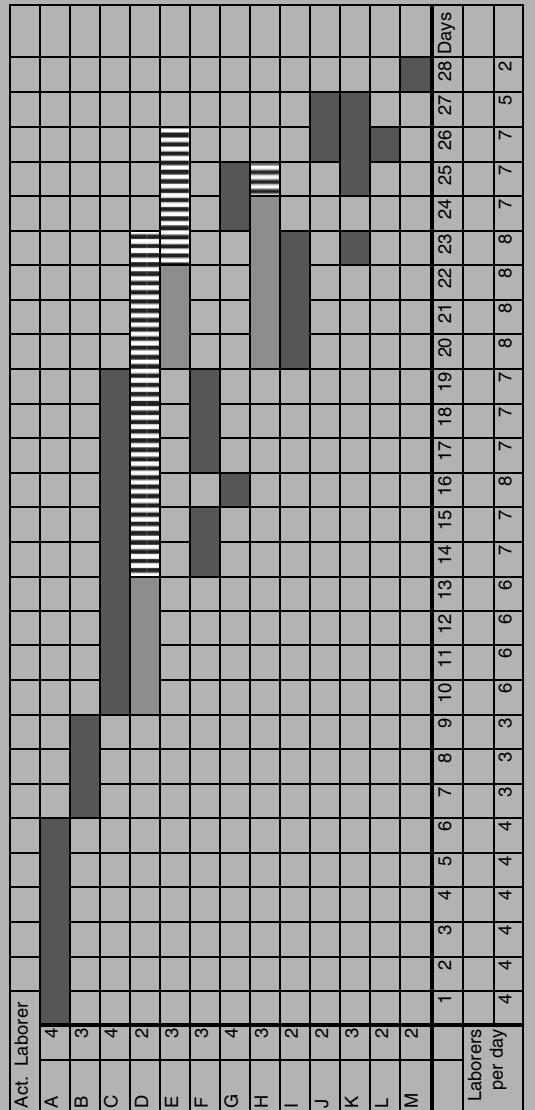


Figure 6.10 Bar chart for example 6.3 with the labor assignment leveled, a maximum of 8 laborers per day, and interruptible activities

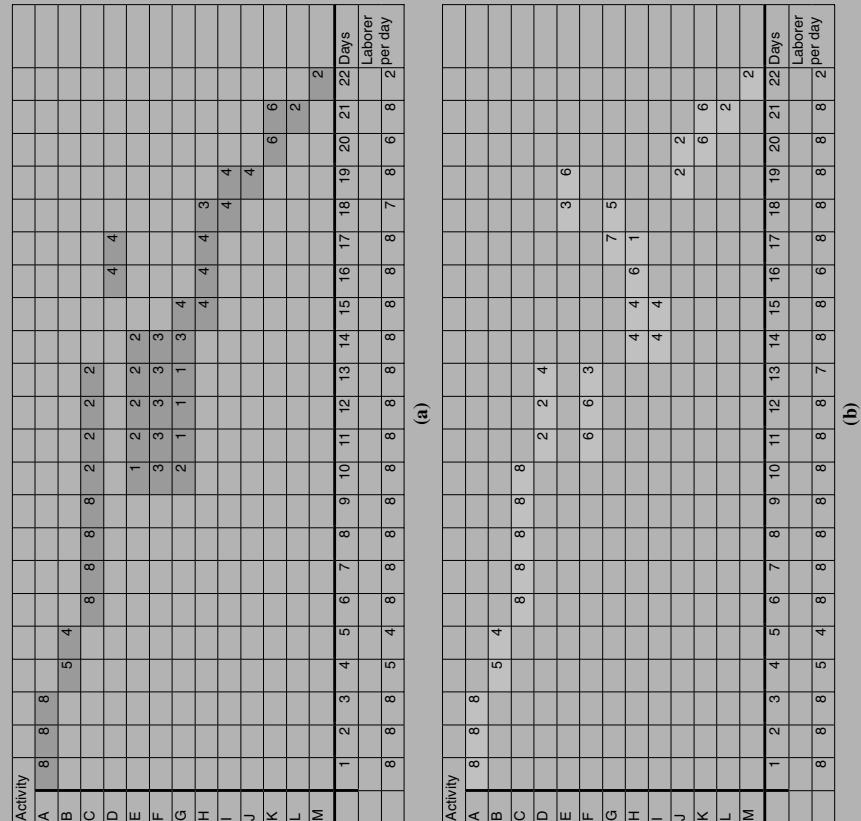


Figure 6.11 Bar charts for example 6.3 with the labor resource driving the durations of activities and a maximum of 8 laborers per day (a) for scenario 1 and (b) for scenario 2

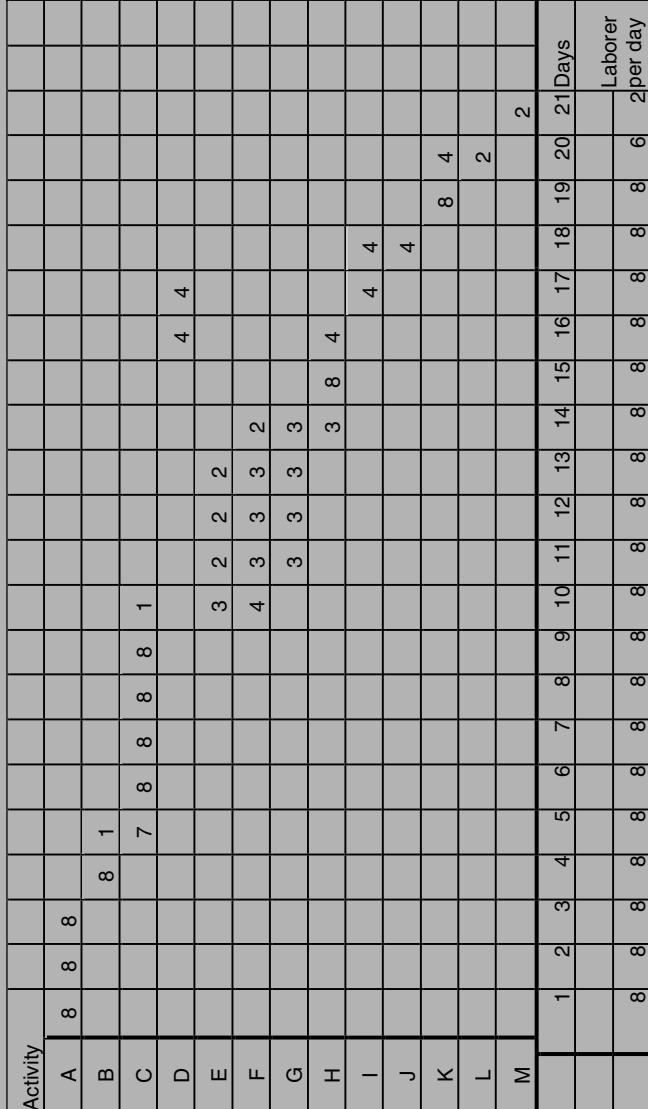


Figure 6.12 Bar chart for example 6.3 with labor resource driving the durations of activities, a maximum of 8 laborers per day, and activity C is allowed to start on the last day of activity B.

Discussion of Example 6.3 You may notice that in some of the figures of example 6.3 we did not use notation on the bars to indicate critical and noncritical activities. In fact, all activities may be considered “critical” in a way, but not necessarily unique. Moving an activity—even if doing so does not violate the logic—may disturb the resource allocation and may result in overallocation in certain periods. Therefore, logic and resource constraints must be met at the same time. You can use different combinations of resource allocations to maintain the following four criteria:

1. No more than 8 laborers used on any day
2. A correct total labor-day (or labor-hours) allocation for each activity
3. Satisfied logic
4. The earliest possible project finish date

If we classify activities as critical and noncritical and then try to use the total float of a noncritical activity, we may impair the resource leveling and cause a delay. The author believes that this area of current commercial software needs more research and development before it can reach a stage at which the user is given all options, in a user-friendly way, to make educated decisions. The software should be able to display different scenarios (in layman language), such as the following:

- You can finish the project in 92 days with no resource leveling (unlimited resources) and no activity interruption.
- You can finish the project in 83 days with no resource leveling (unlimited resources) but allowing activities to be interrupted.
- You can finish the project in 98 days with a certain limit for resource use.
- You can finish the project in . . .

More Discussion As defined previously, leveling resources involves shifting activities within their float to minimize the fluctuations in daily resource use. This “shifting” may involve any, or a combination of, the following:

- Delaying the start of an activity to any date up to and including its late start date.
- Interrupting an activity and resuming it later (breaking the activity into two or more segments) but finishing it no later than its late start date. The idea is to put “chunks” of the activity in the “schedule gaps” where resource use is low.
- Fluctuating the amount of resources assigned to an activity, day to day, according to resource availability, until the activity gets all the required resources.

Important Note that the last two options often require special rules settings in computer programs. These programs may be set for default rules that do not allow such practices.

As mentioned previously, in some cases, staying within the available resource limits yet completing the project by the finish deadline is not possible. In such cases, the project manager must choose one, or a combination, of the following:

- Increase the limits on the available resources. This increase may be across the board (for the entire duration of the project), for one-time use, or for an assigned period. It may also be for one or more particular resources.
- Start the project on the planned start date but maintain the resource limits and allow the project to finish later than the finish deadline. This option is typically considered **forward resource leveling**.
- If feasible, start the project earlier than the planned start date by a number of days so that you can finish the project on the required finish date without raising the resource limits. This method usually levels resources starting from the project finish date, then working backward till the required start date. It is referred to as **backward resource leveling**.
- The preceding three practices are all based on the assumption that the logic cannot be changed. In reality, the relationships of some activities can be relaxed somewhat. The most common reason for this is when, for example, activity B requires only a portion of activity A to be finished before it can start. Project managers tend to assign finish-to-start (FS) relationships for all types of cases. A more in-depth inspection of the schedule by the scheduler and the project manager may reveal some of these cases. Changing the FS relationship to an SS relationship (possibly with a lag) may open the schedule a bit by giving some activities more float, and, hence, more flexibility. In Figure 6.13, the two-activity setup in part (a) takes 18 days, whereas the one in part (b) takes only 11 days.
- Make some activities interruptible. To the author's best knowledge, commercial software-scheduling programs do not give the user the option of having certain (but not all) activities be interruptible, then allowing the program to interrupt (split) them in the optimum way from a resource-leveling viewpoint. However, most programs allow manual interruption (pause, resume). Primavera P3 (the old Primavera) allows the choice of "contiguous" (the default value) versus "interruptible" at the entire project level. Primavera P6 does not offer this option, at least so far, but allows the user to manually pause and resume activities. The interrupted activity does not show as a group of small bars. Rather, it shows as one long bar that includes work and stoppage/pause periods (e.g., in Figure 6.10 the

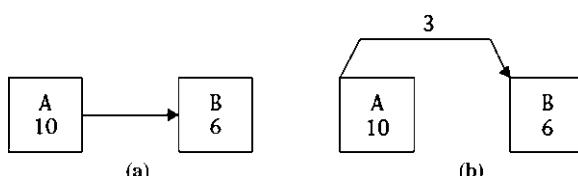


Figure 6.13 The effect of changing (a) an FS (finish-to-start) relationship to (b) an SS (start-to-start) relationship: a decrease in duration from 18 days to 11 days

bars for activities F and K stretch more than their durations). The actual duration may be distributed within the bar without violating logic constraints (such as finishing E, F, or G before finishing C).

- In Primavera Project P3/P6, the resources (or budget) are distributed evenly throughout the duration of the activity. You may change this by assigning another distribution (e.g., triangular, normal, bell-curve). You may define your own type of distribution by dividing the resource (or budget) into 11 increments throughout the duration of the activity. Increment 1 is usually assigned 0% because it represents 0% completion. The next 10 increments represent 10%, 20%, . . . , 100% completion. For example, increments of 0, 1, 3, 8, 15, 23, 23, 15, 8, 3, and 1 represent a bell-shaped curve. Note that the 11 increments must total 100%. With such a tool, you can concentrate the resources at the beginning, middle, or end of the duration of the activity. In the bell-shaped curve, the resources are concentrated in the middle. The contractor may use this feature to concentrate the budget at the beginning of the activity (**front-end loading the cost**).

Resource Leveling from the General Contractor's Perspective

For the past few decades, subcontracting has increased to the point that many general contractors subcontract everything in a project and perform nothing with their own workforce. Yet, the general contractor is still responsible for maintaining the schedule for the owner. In this case, resource leveling no longer becomes a concern to the general contractor because the resources are not his or hers. The general contractor instead must manage the overall work of his or her subcontractors. However, he or she may still be concerned with the following four issues:

1. Keeping up with the subcontractors' schedules and the number of workers each subcontractor has, each day, is one concern. The general contractor must make sure the site is not congested to the point of impeding work or causing safety problems. The general contractor must also be convinced that his or her subcontractors have sufficient resources to make adequate progress.
2. If the owner's purchased equipment and materials are to be used, the general contractor must be in full coordination with the relevant subcontractor with regard to the time and method of delivery.
3. When the general contractor is providing equipment such as a crane to the subcontractors, he or she must coordinate the use of this equipment and prioritize the subcontractors' needs.
4. For project control, the general contractor must enter the budget of each activity into the computer, then record and verify the progress of the activity so that the subcontractor is paid in a timely and accurate manner.

In such cases, each subcontractor may do his or her own resource leveling, with one important difference: The subcontractor's schedule is part of the general contractor's

master schedule. As is typical of any critical path method (CPM) schedule, each **subschedule** may contain a range of dates for noncritical activities (i.e., early start, early finish, late start, and late finish). In many cases, the general contractor requires “scheduled dates” for certain activities (i.e., a single set of dates chosen between the early and late dates). This approach is used especially for activities that require coordination with the general contractor or other subcontractors. In such cases, the subcontractor loses the float for such activities and his or her scheduled dates become critical. The subcontractor must then be careful not to change the start or finish dates of these activities—for any reason—without consulting the general contractor.

MATERIALS MANAGEMENT

Materials management is defined as the planning and controlling of all necessary efforts to ensure that the correct quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed (Construction Industry Institute [CII] 1986b). A materials management system includes the major functions of identifying (project planning and material takeoff), acquiring (vendor inquiry and evaluation, purchasing, expediting, and transportation), distributing (field material control and warehousing), and disposing of materials needed for a construction project (Construction Industry Institute 1986b, 1988b). Four important objectives of materials management are as follows (Construction Industry Institute 1988b):

1. Ensure that materials meet the specifications and are on hand when and where required.
2. Obtain the best value for purchased materials.
3. Provide efficient, low-cost transport, security, and storage of materials at construction sites.
4. Reduce any surplus to the lowest level possible.

Materials management is an important component of the project schedule. This function starts early with the planning phase of the project. When developing the materials plan, the general contractor must consider various factors, such as project size, scope, and location; cash-flow requirements; schedule and lead times of critical purchases; the owner’s philosophy; owner approvals; the number of project participants; inspection roles; use of owner purchase agreements; acceptable bidders’ or suppliers’ list; and extent of prefabrication (Construction Industry Institute 1988b).

Some authors (Ahuja, Dozzi, and Abourizk 1994; Hendrickson and Au 1989) have identified four materials cost categories, as follows:

1. *Purchase costs:* Purchase costs are what the vendor charges for the materials, including transportation and freight costs. Usual practice is for vendors to give a volume discount as well as an incentive for quick payment. For example, the

invoice may have the term *2/10 NET 30*, which means a 2% discount if the bill is paid fully within 10 days of the delivery date, or else the full amount is due in 30 days. After 30 days, interest and/or a penalty may apply.

2. *Order costs*: Order costs are the administrative costs for preparing the purchase order, which may not be a simple task. It may involve making requisitions, analyzing alternative vendors, writing purchase orders (with required specifications), receiving materials, inspecting materials, checking on and expediting orders, and maintaining records of the entire process.
3. *Holding costs*: Holding costs include held capital (interest or lost opportunity) and handling, storage, obsolescence, shrinkage, and deterioration costs. Many of these costs are difficult for the project manager to predict, especially those that involve high-tech items, such as computers and computerized equipment. Insurance and taxes may be added to the holding costs as well.
4. *Shortage (unavailability) costs*: A shortage cost is the cost (or the loss as the result) of not having the required materials on the job site when needed. Shortages may delay work, which may result in the loss of labor resources or delay the entire project.

Theoretically, there are two extreme materials management theories:

1. The **just-in-time theory**, which calls for delivering materials at the time of installation only. Thus, materials are not stored at the site.
2. The **inventory buffer theory**, which calls for all materials to be purchased, delivered, and stored on-site prior to installation.

The advantages of the first theory are less handling, no storage, no frozen capital, and less vulnerability to theft, vandalism, obsolescence, shrinkage, and deterioration—in other words, fewer handling costs. The disadvantages are higher order costs (more orders) and higher shortage costs (higher probability of not having materials on time). Conversely, the advantages of the second theory are lower purchase, order, and shortage costs. The disadvantage is higher holding costs.

In real life, somewhere between the two extreme theories must be chosen for the general contractor to strike a balance that will result in the least total cost. This balance varies from one project to another, depending on several factors, such as the size of the project, the location of the project³, the type and availability of materials, the locations of vendors, and weather. To illustrate this point, let us imagine two projects, one in the middle of nowhere (desert or countryside); call it *project A*. The other project is in the downtown of a major city; call it *project B*. Project A has plenty of space for organized storage and is away from urban areas. Thus, it is less vulnerable to theft and vandalism but far away from vendors and suppliers. In this case, ordering most or all materials in advance (as in the inventory buffer theory) makes sense. In the case of project B, we are in the

³ Location of the project influences many aspects such as availability of space for storage, access to project site, proximity to vendors and suppliers, likelihood of theft or vandalism, local authority's restrictions, and others.

downtown area of a major city, so storage space is scarce and theft and vandalism occur frequently. At the same time, plenty of vendors and suppliers are located within a 10-mile radius and can deliver on short notice and for little cost. In this case, we probably want to manage materials by using an approach closer to the just-in-time theory.

Other factors influencing which theory should predominate are the type and the availability of materials. For instance, ready-mix concrete must be delivered on time in all cases because it cannot be stored. In fact, for projects at remote locations, it may be more practical and economical to have a concrete mix plant on-site, especially if the project is large. Expensive equipment may also need to be delivered on time for security reasons. Materials that are susceptible to deterioration are less likely to be stored for long period of time.

Weather (rain, snow, ice, wind, temperature, humidity) may be a factor that influences the delivery and storage decision. The 1976 Montreal Olympic Games experience reminds us of what can happen with poor planning. The precast post-tensioned concrete beams were left on the ground (because of a labor strike), and water got into the tubes and froze before the cable had been threaded. Removal of the ice required expensive drilling and contributed further to a loss of time (Neil 1982).

Another interesting weather-related case was a large project in northern Canada. The location was remote from any urban area or even paved roads. Moving equipment and materials was possible only by air, which was expensive. Work was planned to take place only during the warm months because of the harsh winter conditions. An efficient plan was prepared to move equipment and materials on sleds during the winter. Some icy roads and bridges had to be prepared for this purpose, but the transportation cost was a fraction of the alternative: airlifting. The equipment and materials were kept in shelters till the weather permitted work to start.

For further information on materials management, refer to the books listed in the Project and Construction Management section of the Bibliography (especially see the Construction Industry Institute, 1986b, 1988b books).

CHAPTER 6 EXERCISES

1. In the context of scheduling, what do we mean by *resources*?
2. What is *resource allocation*?
3. What is *resource leveling*?
4. Why level resources in construction projects?
5. Do all resources have to be leveled? Why or why not?
6. Discuss resource leveling in a multiproject environment.
7. Can you level resources in a multiproject environment? If so, what are the factors that influence your decision?
8. Two methods are used to assign a budget to an activity in the schedule. Explain both methods and mention the pros and cons of each method.

9. In the following network, manually level your resources so that you may not use more than nine laborers per day at any time.

Activity	Duration (Days)	IPA	Laborers
A	2	—	3
B	4	A	2
C	6	A	4
D	9	A	3
E	5	B	4
F	7	B, C	2
G	3	D, E, F	4

10. In the following network, try to reduce the maximum resource need to less than eight laborers per day. Can you do this? If not, can you manually shift activities so that you improve the daily resource use? (We try to start low, increase the resource use gradually till it peaks around the middle of the project, and then gradually decrease it toward the end of the project.)

Activity	Duration (Days)	IPA	Laborers
A	6	—	2
B	2	—	3
C	8	A	3
D	5	A, B	5
E	3	B	4
F	6	D, E	3
G	5	C, D	2
H	2	F, G	3

11. In the following network, manually level your resources with a maximum of eight laborers per day. Also, improve the daily resource use (start low, increase the resource use gradually till it peaks around the middle of the project, then gradually decrease it toward the end of the project).

Activity	Duration (Days)	IPA	Laborers
A	6	—	2
B	2	—	3
C	9	—	3
D	4	A, B	3
E	7	B	4
F	5	D	2
G	10	D, E	3
H	8	C, F, G	1
I	3	C, G	2
J	2	H, I	3

12. In exercise 9, can you improve the resource use by making the resources driving (i.e., they control the durations of activities)? Activities are still contiguous (noninterruptible).
13. In exercise 9, can you improve the resource use by making the resources driving and the activities interruptible?
14. In exercise 10, can you improve the resource use by making the resources driving (i.e., they control the durations of activities)? Activities are still contiguous (noninterruptible).
15. In exercise 10, can you improve the resource use by making the resources driving and the activities interruptible?
16. In exercise 11, can you improve the resource use by making the resources driving (i.e., they control the durations of activities)? Activities are still contiguous (noninterruptible).
17. In exercise 11, can you improve the resource use by making the resources driving and the activities interruptible?
18. In exercise 10, you are given only six laborers (rather than eight). Write a memo to the project manager discussing the situation and giving him or her the available choices (along with the consequences).
19. With regard to resource leveling, how does the role of a scheduler differ between working for a general contractor who does almost all his or her work with his or her own workforce and working for a general contractor who subcontracts everything?
20. Assume that you are the scheduler for a large project. You work for the construction manager (CM), whose function is to manage the project and to coordinate the work of the subcontractors involved (there is no general contractor). You required each subcontractor to submit his or her schedule to you on a disk in Primavera Project Manager format. Where do you go from there? Write an itemized plan.
21. Why does materials management differ in principle from labor and equipment management? Briefly explain the concept of materials management.
22. What are the main objectives of materials management?
23. What types of costs are associated with materials management?
24. Materials management is a balance between two extreme theories. Explain this statement, mentioning the factors that influence your decision to lean more toward one theory than the other.

Chapter 7

Schedule Updating and Project Control



Cladding works Dubai Mall, Dubai, United Arab Emirates

INTRODUCTION

Project schedules are, without a doubt, useful tool for managing and controlling projects. However, this tool can be effective only if used properly. Colorful bar charts can be no more than decoration on the walls of the job trailer. They can also be a mere fulfillment of bid or contract requirements. But if well prepared and then used seriously, consistently, and intelligently throughout the life cycle of the project, they can be the effective tool that informs the project management team of the project status at any point during the life of the project and the foundation for corrective actions. The most important use of schedules is *project control*. The scheduler compares actual performance with baseline performance and discerns any deviation. The project management team then deals with this deviation, analyzes it, and suggests solutions to bring the schedule back on track, if possible.

Using critical path method (CPM) scheduling as an effective tool requires a serious commitment from upper management to adopt and use the schedule throughout the project. There is a difference in attitude between a contractor who is using the schedule because he or she is convinced that it is an effective and powerful tool for project management and a contractor who is using the schedule because the owner requires doing so.

THE NEED FOR SCHEDULE UPDATING

Construction projects rarely—if ever—go as planned. Thus, we expect some deviation from the baseline. We need to know where, how much, and why; then take corrective action whenever and wherever needed. Consider the following example: The army fires a long-range missile at a target 500 miles away. The missile is given the coordinates of the target, so it flies at a certain accurate angle at a certain velocity. For various reasons, the missile goes astray by a fraction of a degree. Central command tracks and communicates with the missile, reads the actual location, and compares it with the destination location. Central command makes adjustments to the direction of the missile. This process occurs continuously to ensure that the missile hits its target accurately. An early uncorrected error of a few minutes (a minute is 1/60th of a degree) in the direction may mean missing the target by a few hundred feet or even several miles.

PROJECT CONTROL DEFINED

Project control comprises the following continuous process:

1. Monitoring work progress
2. Comparing it with the baseline schedule and budget (what it was supposed to be)

3. Finding any deviations, determining where and how much, and analyzing them to discover the causes
4. Taking corrective action whenever and wherever necessary to bring the project back on schedule and within budget

Along with these four basic functions, another function of project control may be to help identify areas in which to improve work efficiency, to help accelerate the schedule, to help reduce cost, or to help the project in other ways.

Project control in the context of this book involves both budget control and schedule control. It can also include quality control and safety control, but they usually occur in separate departments and are analyzed differently. A significant correlation exists between budget control and schedule control, as described later in this chapter.

The term **project monitoring** is sometimes used in lieu of *project control*. Project monitoring, by definition, is passive. Although some people may use this term to mean more, it simply means “observation.” The term **project tracking** is also used in the same context (Oberlender 2000). Depending on the intention and the role of the “tracker,” tracking may or may not be equivalent to project control. The owner or construction manager (as an entity separate from the constructor) may “monitor” or “track” the project by observing the work progress and comparing it with the baseline budget, schedule, and quality. However, only the party who is physically doing the work—namely, the constructor—can “control” the project by not only monitoring or tracking it but also taking corrective measures whenever and wherever necessary.

SCHEDULE UPDATING

Schedule updating is just one part of the project control process. Schedule updating must reflect actual work and involves incorporating approved changes into the baseline schedule.

What Is a Baseline Schedule?

A **baseline schedule** is a schedule prepared by the contractor, usually before the start of the project, and used for performance comparison. If approved by the owner, the baseline schedule usually becomes a part of the contract documents.

The baseline schedule is also called a **target schedule**. The *as-planned schedule* is the schedule submitted by the contractor—as usually required by the contract—and approved by the owner before the start of the project (and sometimes before the signing of the contract). Sometimes, the baseline schedule is the same as the as-planned schedule, but not always. In many situations, the as-planned schedule is submitted and approved. Later on, some changes are implemented before the project starts, as a result of debugging, the owner’s changes, or both. The baseline schedule should not be delayed beyond the start of the project, particularly if the contractor uses actual dates to build such a schedule. Otherwise, it will not be baseline.

The baseline schedule may be used by both the general contractor, who will execute the work, and the owner (or his/her representative), whose work is being executed. Sometimes both parties will use the baseline schedule for project control, each from his or her own perspective. A third party (professional construction management firm) may also monitor the schedule and compare it with the baseline. The baseline schedule, when part of the contract documents, binds not only the general contractor but also all subcontractors, even if they were not part of the preparation of the baseline schedule. A general rule is that any condition or requirement in the contract between the owner and the general contractor automatically applies to all parties working under the general contractor and involved in the construction of the project.

In many cases, the as-planned schedule is also a part of the contract documents that bind both the owner and the contractor. It may provide a foundation for resolving any subsequent delay-claim disputes. It may also be used as a legal document in case of litigation.

In ill-planned projects, many change orders may be issued, and the baseline schedule will keep changing. Such changes may shift the critical path and, thus, the focus of effort. Such a situation can be counterproductive to the project management. The baseline schedule must incorporate design and other changes for fair and realistic comparisons. Therefore, a project may have two or more baseline schedules: one before and one after changes. It is strongly recommended that one of them be adopted for periodic comparison with actual performance. In some cases, it is possible and helpful to compare the current update with both the baseline schedule and the previous update. For example, if the current update shows the critical path with –10 days of float, this may be interpreted as bad news with regard to the “absolute measure” (as compared with the baseline schedule). However, if the previous update indicated –16 days of total float, the contractor is on the right track, bringing the project back to the baseline schedule.

Just like cost estimates, baseline schedules are predictions. Slight and sporadic deviation is always expected in construction projects. An open eye and an expert mind can discern a serious deviation from a minor “normal” variation.

Baseline schedules are prepared on the basis of expectations and previous experience. Thus, it is advisable to keep an accurate record of previous work to use for future estimates. As discussed in chapter 4 (in the “Steps Required to Schedule a Project” section), the scheduling team must not only crunch numbers (calculate durations and dates) but also deal with real work conditions and make reasonable adjustments whenever and wherever needed.

Baseline schedules must be reasonable and realistic. They must take into consideration work and weather conditions; the size and complexity of the project; local codes and regulations; the location of and access to the project site; the labor market; materials and equipment availability, prices, and delivery; and other issues. Sometimes an overlooked activity such as Obtain Permits can hold up the entire project for a month or more. Likewise, a long-lead or custom item may need to be ordered several months before the required delivery date. A contractor’s acceptance of an unrealistically ambitious schedule may hurt his or her reputation and pocket, even though his or

her fieldwork may have proceeded at a normal and decent pace. The famous proverb “Expect the worst and hope for the best” can be modified in this context as “Be conservative in your expectations and strive for the best.”

Baseline schedules may initially be prepared as summary schedules. A **summary schedule** may contain only a few major components; the details are left for a later stage. For example, a schedule prepared by the architect may include the different design activities and milestones, with Construction represented by a single 9-month activity. Later, when construction details are known, this activity is divided into reasonable-sized activities that have a combined duration of 9 months. Summary baseline schedules are not usually used for project control. However, such schedules may be prepared along with design development; the more we know about the project, the more details we have in the design, and the more detailed the schedule becomes. This case applies particularly to fast-track projects (discussed in chapter 5). With such projects, the project manager can use the following approach: The project is typically divided into several phases (see Figure 5.9), with the initial (preliminary) design done for the entire project. Later, when the detailed design for phase I is finished, the detailed construction plan, including scheduling, must be prepared for phase I while phase II is still being designed. In this case, the detailed schedule for any phase is done before actual construction starts on that phase. This process provides a baseline schedule, phase by phase.

The entire discussion on the baseline schedule applies to the **baseline budget**, with the obvious difference that a schedule deals with time, whereas a budget deals with money. The correlation between the two areas is explained subsequently, when the project control concept is discussed. Another difference is the level of detail: In scheduling control, activities are connected by logical relationships. A delay in an activity may have an effect on other activities. In budget control, the effect of a budget overrun in an activity is mostly local and may not have a ripple effect on other activities (unless it is attributed to an increase in the price of resources, then all activities using these resources will be affected).

Primavera Project Manager, P6 (Primavera Systems, Inc., Bala Cynwyd, Pennsylvania) create baselines as copies of project updates. These “baselines” are more snapshots than baselines. This concept, which Primavera Systems introduced, is extremely useful. It allows the scheduler to keep copies of the schedule at different points in the life of a project and to store them as inactive copies along with the active, most recently updated schedule. The only caution is the name; Primavera Systems calls them *baselines*, but they are not baselines according to our—and the industry’s—definition.

What Is an Updated Schedule?

Schedule updating is simply reflecting actual performance information—including time of occurrence and amount (or percentage) of work completed—on the schedule and indicating on the schedule any changes to future work. Popescu and Charoennagam (1995) defined an **updated schedule** as “a revised schedule reflecting project information at a given data date regarding completed activities, in-progress activities,

and changes in the logic, cost, and resources required and allocated at any activity level” (p. 566).

What Is the Data Date?

The **data date** is the date as of which all progress on a project is reported. It is also called the **as-of date** and the **status date**. It is *not* the “current date” or the “time now” because the word *current* or *now* is moving along with time and is not tied to a specific time or date. For instance, the latest data date may be Friday 19 FEB 2010. This means the update contains all work completed up to and including that day. The report may not reach the scheduler till Monday 22 FEB 2010, or later, and the scheduler may not actually update the schedule till a day or more after that. Thus, it would be wrong to call the data date the *current date* or the *time now*. The data date is similar to the closing date on your checking account or credit card statement. By the time you receive the statement, several days have passed, and the statement reflects the account activities to that date. However, that date is not “current” or “now.”

What Kind of Information Is Needed for Updating Schedules?

Any new information that was not known for the previous update and relates to the schedule must be recorded on and implemented in the schedule. This information falls into two main categories:

1. *Past information:* What has happened since the last update? Past information includes the following:
 - a. Activities that have started, and the actual start date, percent complete, and remaining duration of each
 - b. Activities that are complete, and the actual completion date of each
 - c. On-going activities and their new percent complete and remaining durations
 - d. The actual budget spending or resource consumption for each activity

This information can be further divided into *past* and *current* categories, in which *past* represents information about work that occurred prior to the previous update. Such information is considered history and must not be changed during the present update.¹ *Current* represents information about work that occurred between the last update and this update. This category is the main focus area for updating past information.

2. *Future information:* The *future* category comprises any changes to the schedule or schedule-related items, such as the following:

¹Although sometimes project managers “revise” dates or other data that were reported previously, this practice may be considered falsification of records if the owner is not fully informed of such revisions.

- a. Any activities that have been added, along with their information (duration, logic, budget, resources, constraints, etc.)
- b. Any activities that have been deleted (the scheduler must be sure to maintain proper logic after the deletion)
- c. Activities that have changed in duration, logic, budget, resources, constraints, or otherwise
- d. Any change to the imposed finish date for the entire schedule or the constraint date for certain milestones
- e. Any schedule-related, but not activity-specific, change, such as a change in the cost or availability of resources, a change in calendar workdays, or a change in responsibility (e.g., a subcontractor took over a portion of the general contractor's work, or a subcontractor was replaced)

Note that added or deleted activities could also be in the *Past*. This can happen when a change order comes on a short notice: The activity is approved and added to the schedule and then performed (started/finished) between two updates, that is, after previous update and before current one.

Figure 7.1 defines the three information zones discussed above: “past” (prior to or to the left of previous data date), “current” (between previous data date and current data date), and “future” (after or to the right of current data date).

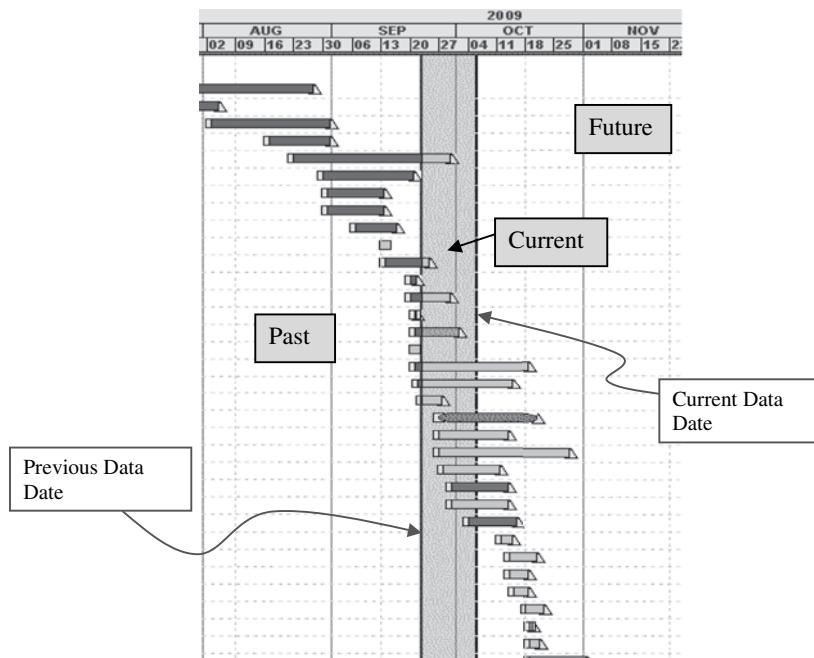


Figure 7.1 Data date and update zones: past, current, and future

Future changes are of two types:

- Logic-driven changes:* Logic-driven changes are those that are not made directly by the scheduler but that occur as a result of changes in planned dates or logic. For example, the four activities shown in Figure 7.2a were planned to overlap and take an overall 14 days. When updating, four days after the first activity Framing has started, it was found out that the Framing activity will take two more days than originally planned (see Figure 7.2b). As a result, succeeding activities will be delayed by the same amount, that is, two days. It is like the domino effect: A delay in one activity will trigger a delay in the succeeding activities.
- User's changes:* User's changes are those that are made directly and deliberately by the scheduler. They may not have anything to do with past events. Let's imagine in the example shown in Figure 7.2a that everything was going as planned; however, the contractor (or owner) decided to delay the start of one activity (Painting, in our case) for two days using a constraint (see Figure 7.2c). This is a user-induced change that was not caused by predecessors, but may have an impact on its successors.

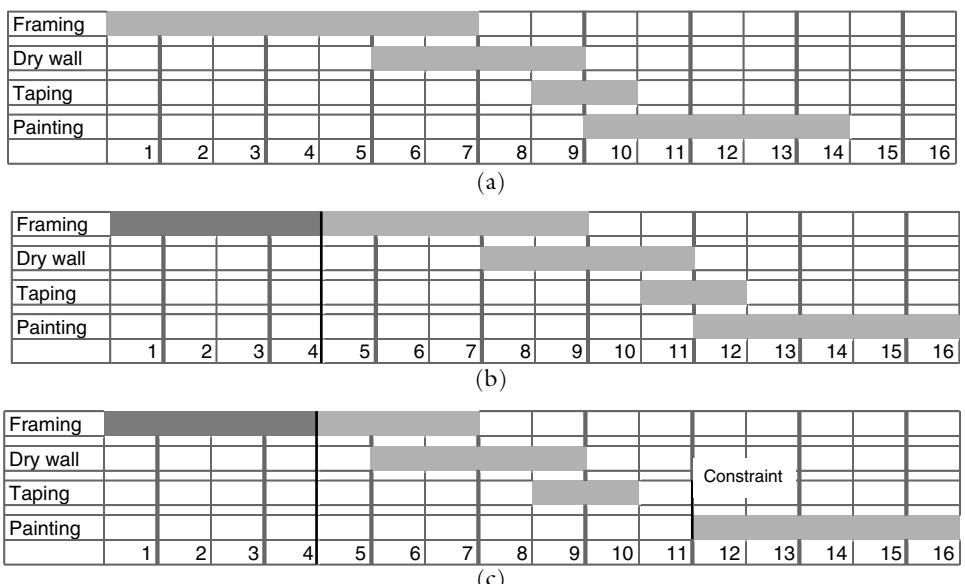


Figure 7.2a (a) Four overlapping activities, planned to take 14 days overall; (b) When updating, the Framing activity is taking two more days than planned, triggering a 2-day delay in all successors; (c) When updating, the Framing activity is proceeding as planned, but the start of “Painting” activity is deliberately delayed.

Frequency of Updating

Construction schedules may be updated monthly, biweekly, weekly, or according to another time interval. Weekly and biweekly are probably the most common frequencies. Project managers must achieve a delicate balance between a period between updates that is too long and one that is too short. The former case may yield negative consequences such as the following:

- Waiting too long to update a schedule may eliminate the effectiveness of updating as a control tool. By the time work progress is reported and analyzed, managers may not have the time or opportunity to take corrective action. This factor can be demotivating for them.
- The amount of work progress that occurred during the period may overwhelm the scheduler. Also, the superintendent or project manager may forget when an activity actually started or finished if the activity occurred a month ago and was not formally documented.
- Having a long reporting period may encourage procrastinators to put off corrective measures by using the logic “We’ll do it later. There is plenty of time!”

Conversely, a reporting period that is too short may be costly in terms of time consumption, overhead, and reporting costs. It may also become a nuisance to the management team.

Typically, the frequency of updating increases at certain times, such as in the last month or two of a project, or during a “crunch time,” such as before a deadline.

Retained Logic or Progress Override

As explained previously, project managers often overuse the finish-to-start (FS) relationship. In many practical cases, an FS relationship is assigned between two activities, A and B, such that activity B cannot start until activity A is completed. In reality, when work starts, activity B starts shortly after activity A has started and prior to its completion. This situation violates the logic. In the “execution report” of Primavera Project Planner (P3) and Primavera’s P6, such a violation is reported (more as a warning than as an error). However, the question the user will be faced with is: Will the remainder of activity B depend on the completion of activity A, or is the FS relationship no longer required? For example, look at activities A and B in Figure 7.3a. Suppose that 6 days after the start of the project, 6 days worth of work is done on activity A (remaining duration = 4) and 2 days’ worth of work is done on activity B (remaining duration = 6). Would we choose Retained Logic (the default value; Figure 7.3b) or Progress Override (Figure 7.3c)? The decision between the two choices may mean not only difference in the project’s completion date but perhaps also the start and finish dates of some succeeding activities. In this example, the decision means a 4-day difference in the completion date of activity B, and possibly the entire

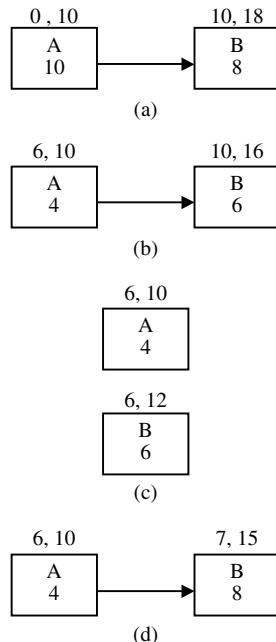


Figure 7.3 (a) Activities A and B of a project; (b) Retained Logic after 6 days' work; (c) Progress Override after 6 days' work; (d) Actual Dates after 6 days' work

project. Primavera P6 also gives a third option: Actual Dates. This option works only if the scheduler assigns an actual start date that is after the data date.²

Auto-Updating

Some software scheduling programs offer an option for automated updating. Although this option makes updating easy and saves time, a potential danger exists. Along with such options comes the assumption that everything that was supposed to have happened, between the last and current updates, did happen—on the planned dates and within the planned budget and resources. This assumption may be true in most but not all cases. The potential danger is that the scheduler will become accustomed to using this convenient tool and use it all the time. The scheduler should exercise extreme caution in using such automated procedures.

Updating Schedules and Pay Requests

In many cases, project updating is tied to **payment requests** (*pay requests* for short). The subject of pay requests is a broad one that is discussed in detail in other project

² It is like past in the future! The author does not like such practice as it may lead to reporting false information if that event does not occur on the specified date.

management books. What concerns us in this chapter is how pay requests tie to schedule updating. In general, a pay request is a document submitted by the contractor (using his or her own form, the owner's form, the American Institute of Architects [AIA] Document G702, or other form) to the owner, asking for payment for work actually performed (whether finished or not) during the period since the last pay request. Materials stored on-site but not yet installed are generally ineligible for inclusion in pay requests unless the contract allows for such payment. Typically, the owner verifies the amounts in the pay request (quantities and unit prices), then, after approval, issues a payment to the contractor that is equal to the approved amount minus any **retainage**.³

Pay requests are usually done at the end of each month. Subcontractors usually submit their pay requests to the general contractor, who rolls these requests in with his or hers and submits it to the owner. The owner requests a lien release or waiver from the general contractor and all subcontractors and vendors before issuing the payment. This document assures the owner that the signer paid his or her subcontractors, workers, and vendors for work performed on the project for the period covered in the document. Once the general contractor receives payment, he or she pays the subcontractors.

When updating every 2 weeks, you could start by doing the pay request every other update (i.e., every 4 weeks). However, the problem with doing so is that a month is slightly longer than 4 weeks. Schedulers and project managers like to update schedules on a certain day of the week (e.g., Wednesday). To circumvent the conflict between the biweekly update and the monthly pay request, schedulers choose one of the following five options:

1. If feasible for the project team, the updates are done on the 1st and 16th of each month. If either of these dates falls during a weekend or a holiday, the update is done on the closest workday.
2. When the update date is near the end of the month (say, within 1 or 2 days), the project manager estimates the work “to be done” between the current data date and the end of the month and counts this work as if it were done (with its real dates). The main drawback to this approach is approving an amount of work that is not yet physically done. If used within certain limitations, this approach will not cause a problem. However, the project manager and the owner must agree on this practice. One argument may be made in support of this approach: since reports take a few days and a payment check may take 2 to 4 weeks, the work done during that time almost always offsets the problem of projecting a few days’ work.
3. Suppose that the pay request must include work as of the end of day 30. The scheduler does the routine update on time—say, on the 28th of the month.

³ *Retainage (also called retention)* is a portion of the eligible progress payment that is held by the owner till the contractor fulfills his or her contractual obligations. The contract usually specifies the amount and conditions of a retainage.

A few days later, the project manager sends the work progress for days 29 and 30 to the scheduler for a “minor update” for the sake of the pay request. The scheduler must then separate “pure updates” and “pay request” schedules. This practice is not recommended.

4. When the update date is several days (say, 4 to 6) before the end of the month, the scheduler “skips” a week so that the next update is done during the first days of the next month. For example, an update is done on the 12th of the month. The next update is scheduled for the 26th of the month. It can be postponed to the 2nd or 3rd of the next month, on the same day of the week on which the 12th occurred.
5. If all contracting parties agree, the pay request may be a few days less or more than a month (i.e., you can close it on the 27th, 28th, or 29th of the month, or on the 1st, 2nd, or 3rd of the following month). In this case, the actual data date is reflected on both the updates and the pay request. However, this practice may not please the accounting team because monthly accounts may not be accurate even though the bottom-line total will be correct.

When doing a pay request, you must start the month with a \$0 amount for the **cost this period** by adding the amount remaining from last period to the total **cost to date** (in Primavera P3/P6, it is called **Store Period Performance**).

“Degressing” an In-Progress Schedule to Create a Baseline Schedule

In some cases, the project schedule is developed as work progresses. This is not a good practice. Some activities will have already started or even finished when they are added to the schedule. In this case, only an as-built schedule exists; there is no as-planned or baseline schedule for comparison. The scheduler may need to create a baseline schedule at this late stage (better late than never). He or she may do so by taking a copy of the schedule and reversing all work progress in it to “go back in time” to the starting point. Doing so requires reversing progress on all activities, plus going back from the data date to the starting point of the schedule.

This practice is acceptable (even though it is not the best). However, one important pitfall exists. When entering completed (or even started) activities, the scheduler may ignore their relationships, since they are “history.” Consider the following partial schedule, for example.

Activity ID	Activity Description	Duration (Days)	IPA
1000	Mobilize	2	—
1010	Clear Land	5	1000
1020	Excavation	6	1010
1030	Dewatering	20	1020
1040	Drive Piles	7	1030 SS-5
—	—	—	—

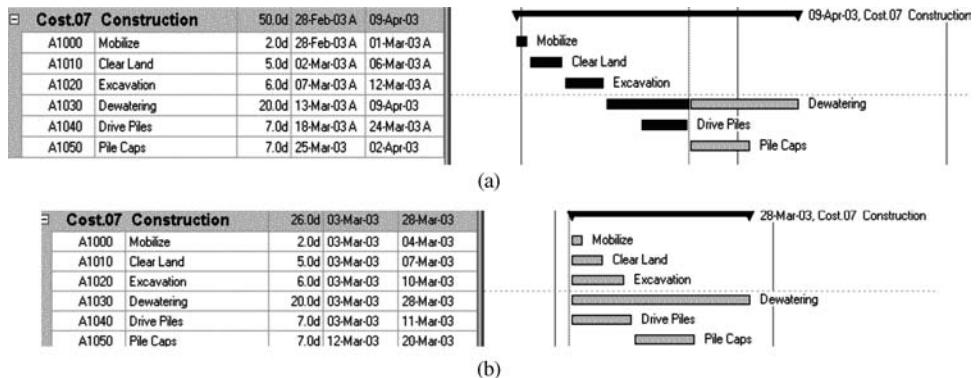


Figure 7.4 (a) Schedule created after piles have been driven (actual durations given as “original durations” and no relationships entered); (b) “degressed” schedule

Suppose that this schedule was being created after the piles have been driven. The project manager or scheduler might just enter actual dates into the schedule without adding the relationships. He or she might also give actual durations as “original durations,” not those estimated; see Figure 7.4a. Now, imagine that we “degress” the project; that is, reverse all work progress and take the data date back to the start date; see Figure 7.4b. In this case, you can see all these activities starting simultaneously at the beginning of the project. There is no need for an explanation; there is no logic. For this reason, the logic must always be input, along with estimated durations. Never forget that this schedule can be—and in most cases is—a legal document that may be dissected later to prove or disprove a delay claim. Accuracy is always important.

Effect of Adding or Deleting Activities on Logic

An activity in a schedule is usually like a link in a chain; removing a link may disturb the whole chain if it is not done properly. For example, deleting activity AS250 in the partial network shown in Figure 7.5 will remove any link between activities AS210 and AS245 on one side, and activities TL160 and AS260 on the other side. This may have a devastating effect on the schedule if removing such links was not the scheduler’s intent. Therefore, it is strongly recommended that the scheduler review the logic before making any change by first printing a logic report showing all predecessors and successors for the activity to be deleted. Some computer programs, such as Primavera Project Manager, have a function called **Dissolve an Activity**, which automatically assigns the predecessors of the dissolved activity to its successors (see Figure 7.6). The user must be careful when dissolving an activity that is tied to other activities with relationships other than the FS relationship or that has lags, and make sure that the logic is still correct after dissolving the unwanted activity. Regardless of the situation, the scheduler should neither let the computer make decisions for him or her nor let the computer execute commands with which he or she is unfamiliar.

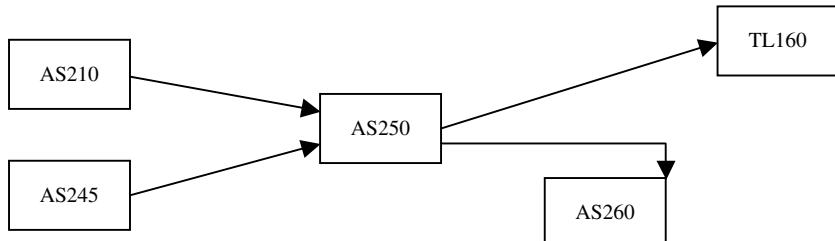


Figure 7.5 Effect of removing an activity from a schedule: removal of AS250 would disturb entire chain

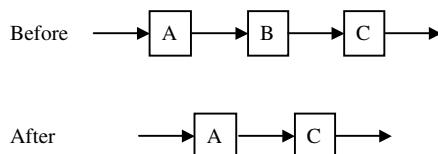


Figure 7.6 Dissolving activity B

Adding a new activity usually has less potential for harming the logic than does deleting an activity. The common problem with adding an activity is redundant relationships. For example, we wanted to add activity FL225 to the partial network shown in Figure 7.7a. We assigned activity FL220 as a predecessor and activity FL230 as a successor but did not pay attention to the existing relationship between these two activities. The result was a redundant relationship, as shown in Figure 7.7b. As mentioned previously, redundant relationships are not logically incorrect. They are just meaningless pieces of information. The redundancy in our example can be removed as shown in Figure 7.7c.

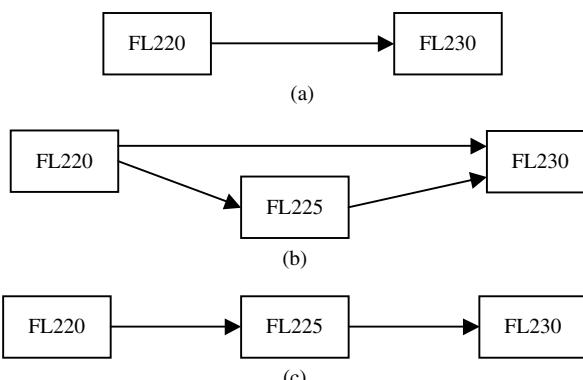


Figure 7.7 Adding an activity to the schedule: (a) original logic; (b) resulting redundant relationship; (c) redundancy removed

Example 7.1

In example 4.3, 10 days after the project has started, you receive the following report:

Activities A and D are complete, actual dates: A (0, 2), D (5, 9).

Activity B started on day 5. Remaining duration = 2 days.

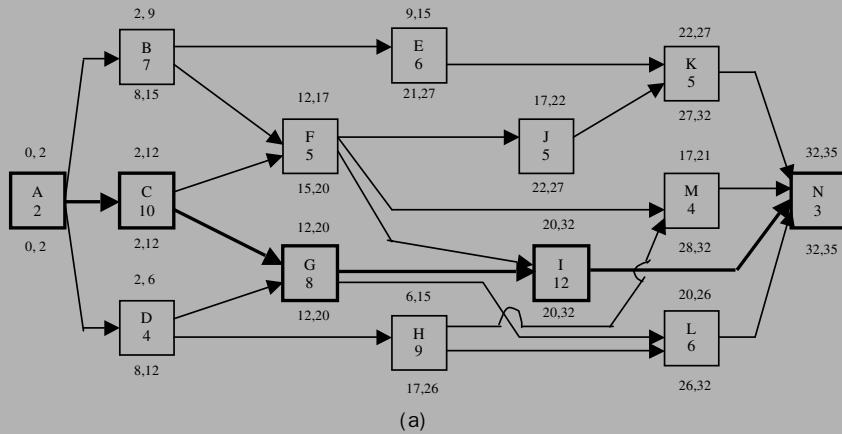
Activity C started on day 2. Some problems were encountered. Remaining duration = 4 days.

The duration for activity F was adjusted to 8 days.

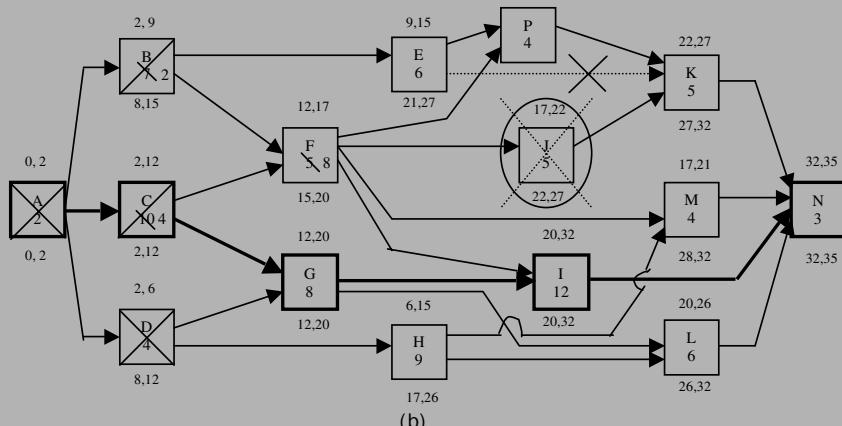
Activity J has been canceled.

The duration for new activity P is 4 days. IPA = E and F. ISA (immediately succeeding activity) = K.

Update the logic. Note: When we delete activity J, the schedule must verify whether we should assign its predecessor to its successor. In other words, would activity F become a predecessor to activity K?

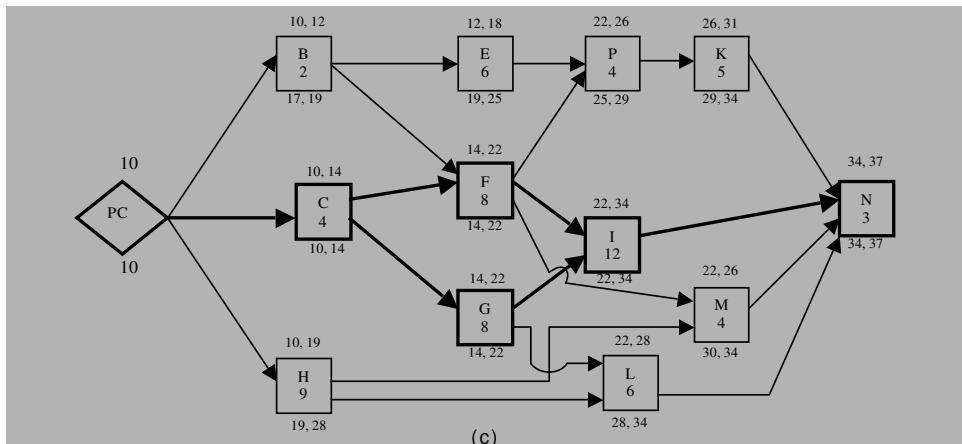


(a)



(b)

Figure 7.8 (a) Original schedule; (b) updating the schedule; (c) updated schedule

**Figure 7.8 (Continued)****Solution**

Example discussion: As we observed, the project in Example 7.1 slipped by two days. This is the first part of the information. The other part is why. There were several changes in the update, that is, departures from the original schedule:

- Activity C took two more days than originally planned.
- Activity F's duration increased from 5 to 8.
- Activity P was added.
- Activity B has not been completed yet even though its early finish date is day 9.
- Activity H has not started yet even though its early start date is day 6.

Which one of these factors caused the two-day delay in the completion of the schedule? Or, is it a combination of these factors?

The answer is “a. Activity C took two more days than originally planned.” Activity C was and still is on the critical path. The increase in the duration of activity F consumed its total float and made it critical but did not add days to the duration of the project.

Steps for Updating a Schedule

Updating a schedule includes the following six steps:

1. The project manager (or superintendent) prepares a list of actual progress, changes for individual activities, and all related information, as detailed previously.

The author has had experience with both private companies and public agencies. In the private company experience, the scheduler represented the construction manager, CM at risk (which is similar to a general contractor). The author used a simple tabular report with a project title, a data date, and a current date displayed at the top (Primavera Project Planner layouts, rather than reports, were used). The table contained columns for the activity ID, activity description, original duration, remaining duration, percent complete, and three empty columns with these titles: Actual Start, Actual Finish, and Notes (Figure 7.9 shows a sample report). Other columns could have been added, such as **Actual Cost This Period** or **Resources Consumed This Period** (Figure 7.10). Activities that were completed prior to this report are usually filtered out. The superintendent fills in (preferably in red ink) the percent complete and actual start and finish dates. Alternatively, he or she may cross out the remaining duration and provide the new remaining duration in lieu of the percent complete. Another option is to provide an expected finish date. One good practice is to adopt a *single criterion*—percent complete, remaining duration, *or* expected finish date—for updating activities. Computer programs can calculate the other two variables (unless percent complete and remaining duration are untied). It is important for each page of the report to be numbered so that any missing pages can be discovered. Also, a ruler or a straightedge should be used to aid in reading the information. This hand-marked progress report stays with the superintendent as part of the project records, but the scheduler should keep a copy.

In the experience with the public agency, the author was responsible for using Primavera P5/P6 software to monthly update a large number of public works projects. The schedules are similar and do not contain much detail. Rather, they ensure—from the public agency’s viewpoint—that the contractor meets important deadlines. The data date is the last day of every month. The scheduler sends an e-mail reminder about 2 workdays before the data date to all project managers and their section managers reminding them of the update. All update reports are due 2 workdays after the data date. A second reminder e-mail is sent on the morning of the due date. The monthly update includes two reports from each project manager:

- a. A checklist (see Figure 7.11) that includes a list of all projects managed by the project manager. Next to each project, the project manager must check one of two choices: “As Planned” or “Schedule Change.” If he or she chooses the first, no further paperwork is needed for that project. The scheduler assumes that everything was planned to happen during this update period, did happen on the planned dates.
- b. If the project manager chooses Schedule Change, he or she must submit a Schedule Update Form (see Figure 7.12) for the project. The form lists all project activities, with a Start Date column, an “A” column, a blank Start Date Change column, and similar columns for the end date. If an activity

ACTIVITY ID	ACTIVITY DESCRIPTION	ORIG DUR	REM DUR	% COMP	EARLY START	ACTUAL START	EARLY FINISH	ACTUAL FINISH	BUDGETED COST	COST TO DATE	COST THIS PERIOD	NOTE
Traffic control												
Southbound Outer Lane												
F1N2100	PLACE CONST. BARRIER	12	3	75	05JAN00		18JAN00		17,799.84	13,349.88		
Northbound Outer Lane												
F2N3100	PLACE TEMP. CONST. BARRIER	6	6	0	30MAR00		05APR00		9,999.12	0.00		
F2N3254	REMOVE TEMP. CONST. BARRIER	5	5	0	07APR00		13APR00		8,332.60	0.00		
F2N2196	STRIFF ROADWAY	9	9	0	11AUG00		23AUG00		10,000.08	0.00		
F2N2198	REMOVE TEMP. BARRIER	4	4	0	24AUG00		29AUG00		6,666.08	0.00		
Signage												
General Construction												
F1N100A	PROCUREMENT OF NOISE BARRIER POST & INSTALL SIGN SUPPORT STRUCTURE	10	3	70	02JUN99A		18JAN00		12,000.00	8,400.00		
F1N2190	INSTALL SIGNS	8	1	88	05JAN00		14JAN00		6,895.36	6,033.44		
F1N2195	ERECT SIGNS	3	3	0	17JAN00		19JAN00		5,371.56	0.00		
Earthwork												
Southbound Outer Lane												
F1N2115A	GRUB & STRIP TOPSOIL	8	8	0	19JAN00		28JAN00		12,533.12	0.00		
F1N2105B	INSTALL EROSION CONTROL DEVICES	15	15	0	31JAN00		18FEB00		3,763.32	0.00		
F1N2200	INSTALL TEMP. SHEETING	12	12	0	21FEB00		07MAR00		9,347.04	0.00		
F1N2210	EXCAVATE RETAINING WALL	12	12	0	08MAR00		23MAR00		7,542.24	0.00		
F1N2240	PLACE POROUS FILL BEHIND WALL	9	9	0	23MAR00		02JUN00		11,107.98	0.00		
F1N2250	BACKFILL RETAINING WALL	7	7	0	05JUN00		13JUN00		7,770.84	0.00		
Northbound Outer Lane												
F2N2115B	REMOVE GUIDE RAIL	4	4	0	24MAR00		29MAR00		3,115.68	0.00		
F2N2125A	EXCAVATE FOR ELECTRICAL	10	10	0	30MAR00		12APR00		6,141.20	0.00		
F2N3110	REMOVE TEMP. PAVEMENT	9	9	0	07APR00		19APR00		6,772.68	0.00		
F2N3120	REGRADE AREA	7	7	0	20APR00		28APR00		6,902.84	0.00		

Figure 7.9 Updating a report without costs listed (most common type of report)

ACTIVITY ID	ACTIVITY DESCRIPTION	ORIG DUR	REM DUR	% COMP	EARLY START	ACTUAL START	EARLY FINISH	ACTUAL FINISH	NOTES
Traffic control									
Southbound Outer Lane									
PIN2100	PLACE CONST. BARRIER	12	3	75	06JAN00			18JAN00	
Northbound Outer Lane									
P2N3100	PLACE TEMP. CONST. BARRIER	6	6	0	30MAR00			06APR00	
P2N3225A	REMOVE TEMP. CONST. BARRIER	5	5	0	07APR00			13APR00	
P2N2196	STRIPE ROADWAY	9	9	0	11AUG00			23AUG00	
P2N2198	REMOVE TEMP. BARRIER	4	4	0	24AUG00			29AUG00	
Signage									
General Construction									
PINP100A	PROCUREMENT OF NOISE BARRIER POST &	10	3	70	02JUN00			18JUN00	
PIN2190	INSTALL SIGN SUPPORT STRUCTURE	8	1	88	06JAN00			14JAN00	
PIN2195	ERECT SIGNS	3	3	0	17JAN00			19JAN00	
Earthwork									
Southbound Outer Lane									
PIN2115A	GRUB & STRIP TOPSOIL	8	8	0	19JAN00			28JAN00	
PIN2105B	INSTALL EROSION CONTROL DEVICES	15	15	0	31JAN00			18FEB00	
PIN2200	INSTALL TEMP. SHEETING	12	12	0	21FEB00			07MAR00	
PIN2210	EXCAVATE RETAINING WALL	12	12	0	08MAR00			23MAR00	
PIN2240	PLACE POROUS FILL BEHIND WALL	9	9	0	23MAY00			02JUN00	
PIN2250	BACKFILL RETAINING WALL	7	7	0	05JUN00			13JUN00	
Northbound Outer Lane									
P2N2115B	REMOVE GUIDE RAIL	4	4	0	24MAR00			29MAR00	
P2N2125A	EXCAVATE FOR ELECTRICAL	10	10	0	30MAR00			12APR00	
P2N3110	REMOVE TEMP. PAVEMENT	9	9	0	07APR00			19APR00	
P2N3120	REGRADE AREA	7	7	0	20APR00			28APR00	

Figure 7.10 Updating a report for a cost-loaded schedule (less common type of report)

Washington County, Florida					
List of Projects by Project Manager					
Data Date: 3/15/2003					
Project Manager: John Doe					
Proj. No.	Project Name	Schedule		Cost	
		As Planned	Change	No change	Change
ABC1200	Washington Street Drainage Improvement, Phase I	X		X	
FGH3211	Road Resurfacing, Main St between 42nd and 52 Ave.		X	X	
LMN4500	Bridge No. 10345, US 41 over Hillsborough River	X		X	
XYZ7812	Traffic Signal at Intersection of Busch Blvd and Florida Ave.		X		X

Figure 7.11 List of projects by project manager

started, the project manager writes an *A*, indicating an actual date, next to the start date. If the actual start date differs from the planned date, the project manager writes the updated start date in the Start Date Change column. If a future start date is changed (say, postponed for 2 months), the new start date is written in the Start Date Change column without writing an *A* in the *A* column. The same is done for the end date columns. The project manager may or may not use the Original Duration, Remaining Duration, and Percent Complete columns. Some project managers prefer to give an expected finish date rather than the remaining duration or percent complete. The scheduler has to check if these numbers are accurate.

2. The scheduler feeds the information into the computer scheduling program and updates the schedule.
3. The scheduler discusses the new situation with the project manager and makes sure that no more changes or adjustments are needed (in other words, he or she obtains the project manager's approval for producing the reports).
4. The scheduler prints new reports that show the updated schedule and delivers them to the project manager (who, in turn, distributes them to the involved parties: different reports to different parties). The scheduler may also give the project manager a short descriptive analysis report. For example, if the expected finish date of the project was pushed back a few days, the scheduler

Schedule Update Form

Data Date: 3/15/2003

PM Signature:

Date:

Schedule Signature:

Date:

PM: John Doe		Project No.: FGH2133		Project Name: Office Building, downtown Tampa						
	Activity name	Start Date	A	Start Date Change	End Date	A	End Date Change	Orig Dur	Rem Dur	% Comp
1	NTP	1/3/2003	A			A		0	0	100%
2	Mobilize	1/6/2003	A		1/8/2003	A		3	0	100%
3	Dewatering	1/9/2003	A		1/19/2003	A		11*	0	100%
4	Excavation - North Side	1/20/2003	A		1/29/2003	A		9	0	100%
5	Excavation - South Side	2/3/2003	A		2/25/2003	A		10	0	100%
6	Drill Piles - North Side	1/30/2003	A		2/28/2003	A		13	0	100%
7	Drill Piles - South Side	3/3/2003	A		3/19/2003			13	3	77%
8	Concrete Piles - NS	3/3/2003	A		3/11/2003	A		7	0	100%
9	Concrete Piles - SS	3/20/2003			3/28/2003			7	7	0%
10	Pile Caps - North Side	3/12/2003	A		3/28/2003			13	10	23%
11	Pile Caps - South Side	3/31/2003			4/16/2003			13	13	0%
12	Footings - North Side	3/24/2003			4/4/2003			10	10	0%
13	Footings - South Side	4/7/2003			4/22/2003			12	12	0%
14	Elevator Pit - NS	3/31/2003			4/9/2003			8	8	0%
15	Elevator Pit - SS	4/14/2003			4/23/2003			8	8	0%

(*) This activity is on a 7-day per week calendar.

Figure 7.12 Sample Schedule Update Form

may give the reason (e.g., a predecessor activity was supposed to finish by a certain date but did not). The scheduler tracks the delay from the end and works his or her way back to the activity or activities that caused the delay.

- After producing the reports, the scheduler may receive feedback from different parties, some of which may have an impact on the schedule. The scheduler must filter any such feedback through the project manager. Only one point of contact (usually the project manager) should have the authority to approve any information before it is implemented in the schedule. Some schedule feedback received after the reports are printed may be kept till the next update. When the next updating cycle is due, the same steps are repeated.

It is possible to include a cost estimate update in the process. In this case, the checklist will include two choices for each project: Cost estimate change or No cost estimate change. Similar to the process explained in part 1 earlier, if there is a cost estimate change for a certain project, the project manager must attach a cost estimate change form for that project clearly showing the changes.

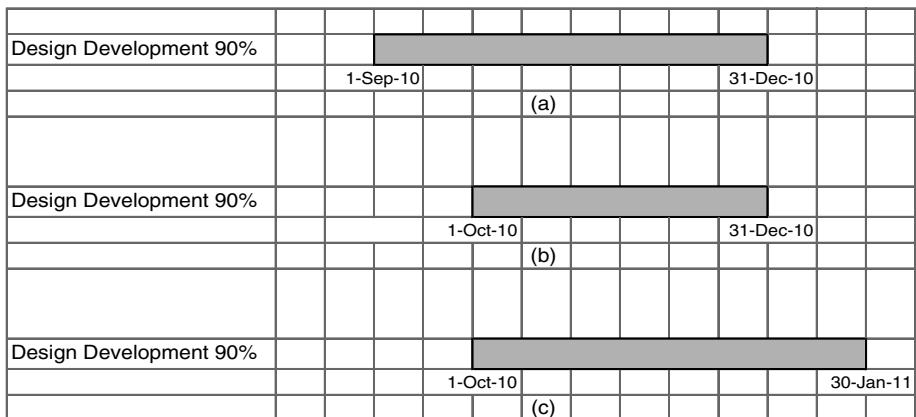


Figure 7.13 Design development: (a) 90% activity as originally planned; (b) 90% activity with start delayed one month and finish date kept as planned, (c) 90% activity with start delayed one month and original duration maintained

Keep Duration or End Date? In some instances, the project manager indicates—on the update report—a delay in the start of an activity. What he/she fails to inform the scheduler of is: what happens to the end of the activity. For example, the “Design Development 90%” activity’s start was delayed 1 month (see Figure 7.13a). Unless the scheduler is told explicitly by the project manager, there are two possibilities:

- Keep the end date, 31 DEC 2010, which means the duration will shrink by 30 days (Figure 7.13b), or
- Keep the original duration, which means the end date will slip by 30 days to 30 JAN 2011(Figure 7.13c).

This case emphasizes the importance of communication and that the scheduler cannot and must not make assumptions without the knowledge and consent of the project manager.

Importance of Updating Remaining Duration: When updating a schedule, some activities may be in progress, that is, started but not complete. Actual duration is calculated automatically as:

$$\text{Actual duration} = \text{Data Date} - \text{Actual Start Date}$$

The finish date of the activity is usually determined when the scheduler inputs one of these three variables:

- Remaining duration
- Percent complete
- Expected finish date

If the activity is progressing as planned, remaining duration and percent complete will agree with each other. Scheduling computer programs such as Primavera P3/P6

tie them together—by default—but allow the user to untie them. This untie is necessary when the activity is *not* progressing as planned. For example, activity Install Doors had an original duration of 8 days (5 workdays/week; Monday through Friday). It started on Wednesday 14 OCT 2009. Data date is (end of) Friday 16 OCT 2009. If the activity is progressing as planned:

$$\text{Actual Duration} = 16 \text{ OCT 2009} - 14 \text{ OCT 2009} + 1^4 = 3 \text{ days}$$

$$\text{Remaining Duration} = 8 - 3 = 5 \text{ days}$$

$$\text{Percent Complete} = \text{Actual Duration}/\text{Original Duration} = 3/8 = 37.5\%$$

Now in a different scenario, let's assume that 3 days after its start, things are not going well. Activity Install Doors is only 25% complete, but the foreman believes he can pick up the slack and finish on time. The remaining duration is still 5 days. The scheduler has to untie the remaining duration and percent complete and then input them independently. The At Completion Duration is still 8 days. However, if productivity will keep going at the same pace as the first three days, then there is no need to untie percent complete and remaining duration. When the scheduler inputs percent complete = 25%, the computer automatically calculates remaining duration as 9 days. In this case, the At Completion Duration will be $3 + 9 = 12$ days.

The Expected Finish date is a nice option in Primavera P6. The scheduler tells the program when the activity is expected to be finished. This input will then determine both remaining duration and percent complete. Let's assume that, in the previous Install Doors activity, the scheduler was informed that it is expected to be completed on 27 OCT 2009:

$$\text{Remaining Duration} = \text{Expected Finish date} - \text{Data Date}$$

$$= 27 \text{ OCT 2009} - 16 \text{ OCT 2009} = 7 \text{ days}^5$$

$$\text{Percent Complete} = \text{Actual Duration}/\text{At Completion Duration} = 3/10 = 30\%$$

The scheduler has to be careful the computer program calculates percent complete using At Completion Duration, not the Original Duration (a discussion on this issue will follow later in this chapter). Otherwise, percent complete will be incorrect.

Updating remaining duration is an important, but often overlooked, issue. Some schedulers or other scheduling software users focus more on the actual performance part and ignore updating future expectations. For example, assume that the Install Doors activity, 3 days after starting, was not progressing as planned and needed 9, rather than 5, extra days. Also, assume that this activity is on the critical path. If the remaining duration was not updated correctly, the calculated finish date will be 4 workdays earlier than what it should be. This mistake can lead to inaccurate percent complete (mainly for the activity but with a small impact on the project percent complete). This may lead to inaccurate calculated finish date for the project,

⁴We added one day because the start date in computer software is taken as the beginning of the day. We chose to have the data date as the end of the day. So, three days of the activity duration passed: 14, 15, and 16.

⁵Count only workdays.

overpayment to the contractor, and inaccurate planned start date for successors (adverse consequences on successors' crews' schedules and materials delivery).

More Recommendations: Schedulers may receive verbal instructions from superiors or project management team members to make changes to the schedule such as activities' dates, durations, logic, or cost. Such changes must be formal and in writing. It may be embarrassing for a junior scheduler to ask the project manager to put any requested changes formally in writing, but he must do so. Even with the assumption of good intentions, which unfortunately may not always be true, people tend to forget or misinterpret verbal communications. An alternative way is for the scheduler to send an e-mail to the PM (who requested the change): This e-mail is to confirm your request/instruction to make the change of . . ." This puts the ball in the PM's court.

Another important issue; who has rights to edit the schedule? In organizations with several project managers and many project management team members, it is normal to have many people with access to the database that contains the schedules. Viewing schedules and other data is normal and acceptable, but the ability to edit data must be restricted for two reasons: First, not all users are proficient with Primavera P3/P6 or MS Project. It is easy to mess up the schedule and other data without even realizing the harm done or the impact of such harm. Even when known, it may not be possible to undo such damage or changes. Second, when several people have editing rights and a mistake is discovered, it will be difficult to pinpoint the party responsible for such mistake. The author recommends one of two approaches:

- a. Project managers and other project management team members can view but not edit the schedule. Editing must be exclusively the responsibility of the scheduler.
- b. Project managers can view and edit their schedules, but each project manager has rights only to projects under him/her. The scheduler must review all projects.

Schedule Comparisons: Some commercial software programs on the market compare two schedules. For example, Claim Digger (originated by HST Software, Simpsonville, South Carolina, and later acquired by Primavera Systems) can compare two Primavera P3/P6 schedules. In this case, you can compare the current update with the previous (or another) update and summarize what happened between the two updates. You can select all or certain criteria for comparison, such as added activities, deleted activities, added relationships, deleted relationships, percent complete, used resources, budget, constraints, and so forth. Comparison with the baseline schedule is still important. It tells us where we stand now compared with where we are supposed to be (the baseline), which is—contractually—the bottom line. Nevertheless, comparisons with the previous update are important because they show whether we are moving in the proper direction.

Sometimes, after step 2 in the updating process is complete, negative total float values appear on the schedule for certain activities. This is a red flag that must be addressed. A negative float for an activity means the activity is behind schedule by a number of days equal to the float amount. There could be one of two reasons for this:

1. The entire project (primarily, the critical path) is behind. If the negative float values vary—say, one activity has a total float ($TF = -12$) and another has a $TF = -8$, the critical path is the path with the most negative float.⁶ This is the definition of the critical path (the longest path). You may argue that the activity with $TF = -8$ is “critical” as well. Primavera P3/P6 even allows you to change the definition of critical activities. This issue is discussed further in chapter 8.
2. One particular activity is behind its constrained start or finish date. The entire project may still be meeting its expected completion date. For example, you could have the milestone Building Dry-In with an early finish constraint date of 12 OCT 10. If the calculated early finish date is 15 OCT 10, you will have $TF = -3$ for this activity. Note that there will be activities with similar negative float on a continuous path starting from date date till that activity.

These two scenarios are not mutually exclusive. They could occur concurrently.

The project manager must find solutions to bring such activities back on schedule and eliminate any negative float. In many cases, the project manager meets with the scheduler to discuss some “what-if” scenarios to work out or suggest a solution to the problem. The meeting may include the subcontractors (those whose activities are involved) so that their consent can be obtained for any proposed recovery plan (see the “Recovery Schedules” section in chapter 8).

Change in the Critical Path

Sometimes, the critical path changes after updating. This happens if any of the following occurs:

- The critical path gets shortened if either an activity (or activities) on it takes less time than originally planned or an activity on the critical path is deleted so that the second longest path takes over.
- A noncritical (usually near-critical) path becomes longer if either an activity (or activities) on it takes more time than originally planned or an activity is added to this path so it becomes the longest path.

The project management team must then shift its attention to the new critical path and determine why it became critical (particularly in the last case). For this reason, a wise idea is to inspect “near-critical” activities along with critical activities. In almost every scheduling software package, you can run a filter that selects only activities with a TF less than a certain value. In the absence of a negative float, a number between 3 and 5 is suggested for the filter. Any activity with $TF < 3$ is practically critical and has a better chance than others of becoming critical during construction.

⁶ Mathematicians consider -4 greater than -8 , but using this notion in construction may be confusing. In this book, if we say the “larger” negative float, we mean in terms of absolute value.

Contractor-Created Float

When the general contractor, or a subcontractor, performs at a faster pace than planned, more float may be added to the remainder of the schedule. For example, if an activity finishes 2 days ahead of schedule, the result may be a float increase for some of the succeeding activities. If the activity was critical, the result may be an earlier finish date for the entire project. The author calls this type of float **contractor-created float**. This situation poses some interesting questions: Does the contractor or subcontractor who “created” this float own it? In other words, can he or she later “take back” this float for a succeeding activity? If the float was created by a subcontractor working on a critical activity and resulted in an early finish for the entire schedule, who gets the “bonus,” if any? Does it work both ways? If the subcontractor delayed work and this delay resulted in a delay for the entire project, is the subcontractor responsible for any liquidated damages? The answers to these questions depend mostly on the contract. In many public projects, in which time is critical and the public’s convenience is at stake, the government puts both “carrots” and “sticks” in the contract. In the aftermath of the Northridge earthquake, Caltrans (the California Department of Transportation) used this policy heavily. Penhall, an Anaheim-based demolition contractor, signed a contract that had a clause for a \$75,000 bonus per day for each day finished ahead of schedule and a similar amount in liquidated **damages** for finishing late (Rosta 1994a; Tulacz 1994). C. C. Meyers received a \$14.8 million bonus (the largest in the history of public contracts) for finishing 74 days ahead of schedule. This amount was based on a \$200,000 per day bonus–liquidated damages clause in the contract (this story is discussed in more detail in chapter 8). In some bonus–penalty contracts, a limit is put on the bonus but not on the penalty. In 1995, Yonkers Contracting Co. Inc., Yonkers, New York, won the contract to modernize a four-lane, 2.5-mile stretch of the Northern State Parkway across Long Island. The contract included a \$20,000 penalty for each day of delay after the deadline and a similar bonus amount for finishing ahead of schedule, with a \$2.4 million cap on the bonus. There was no cap on the penalty (Cho 1997). You may want to refer to the legal references listed in the “Construction Scheduling Law” section of the Bibliography for more details.

Data and Information

Some people like to reduce the role of scheduling to just crunching numbers and producing colorful bar charts. In some simple, straightforward cases, the numbers may be sufficient. For example, suppose that an activity was scheduled to take 6 days. When updating, you observe that 3 days of work have elapsed and the activity is 50% complete. Not much explanation is needed. However, other cases are not as straightforward. For example, suppose that an activity was scheduled for 8 days; 6 days have elapsed, but it is only 25% complete. Maybe an unforeseen condition occurred, maybe the work quantity was increased or underestimated, maybe the crew productivity decreased for some reason, or maybe another factor was involved. This observation must be recorded for project control and to prevent skewed estimates for future projects. Likewise, in some construction jobs, work may not be continuous. For

instance, suppose that an activity with only 3 days' duration shows an actual start date that is 20 days ago, yet the activity is not complete. Even though computer programs have provisions for such a work interruption, most schedulers and project managers do not show it on the schedule as an interruption. The important point is the necessity for explanation of the numbers, especially when a situation occurs that is not normal or average. Primavera P3 and SureTrak and Microsoft Project all allow the addition of activity notes for this purpose. Primavera P6 (and its low-end version, Contractor) allow notes for an activity and has multiple notebooks for each project.

PROJECT CONTROL

Measuring Work Progress

Probably the single most important step in schedule updating is measuring work progress, because it has an effect not only on the schedule's status but also on progress payments to the contractor and subcontractors. Measuring work progress is mainly calculating or estimating the percent complete for each activity. It may also include estimating the percent complete for the entire project. This subject is broad. In this chapter, it is covered only briefly.

Methods for Determining Percent Complete for Individual Activities

As discussed in chapter 4 (in the "Steps Required to Schedule a Project section"), the project manager or superintendent can assign a percent complete to a small, simple activity easier and more objectively than he or she can do so for a large, complex activity. Several methods for measuring work progress are suggested. There are no correct and incorrect methods; there are only more and less suitable methods for the specific type of activity under consideration. Six of these methods are as follows (Construction Industry Institute 1987b):

1. *Units completed:* In the **units completed** method, Percent complete = Units completed/Total units. This method works well for activities with small, identical, repetitive components, such as laying bricks or CMUs (concrete masonry units), excavating, fishing electric wire, installing tile or carpet, and so forth. In these activities, the type of work and pace are the same throughout the activity. Percent complete can be calculated simply by dividing units completed by the total quantity. For example, in an activity involving installing 4,000 concrete blocks, 1,200 have been installed. Percent complete = $1,200 / 4,000 * 100 = 30\%$. In some cases, errors may arise despite the similarity in units because of the effect of learning curves or differing conditions. As an example of the second case is when a mason is installing block or brick to an 8-ft high wall. The blocks on the high courses take more time than those in lower courses. When the error is small, it is ignored.
2. *Cost or time ratio:* This method applies to those activities that are continuous and uniform throughout the project, such as Safety Inspection and project

management-type activities. Percent complete is calculated by dividing time elapsed by total duration (if a **time ratio**) or cost to date by total budget (if a **cost ratio**). For example, a project management activity is scheduled for 12 months with a budget of \$80,000. After 2 months, it is $2/12 * 100 = 16.7\%$ complete, or if \$20,000 is already spent, it is $20,000/80,000 * 100 = 25\%$ complete. Another alternative is the **man-hour ratio** (actual man-hours consumed divided by total man-hours budgeted). The time ratio method for individual activities is similar to the duration percent complete and baseline duration percent complete methods for calculating the project percent complete. These methods are discussed in the next section.

3. *Start-finish:* This method works best for small activities or those with no or a short duration. The project manager may assign one of three stages: have not started yet (0%), started but not yet finished (an arbitrary amount; say, 40% or 50%), or finished (100%). Errors usually balance each other. When these activities become too small, we can look at them as “almost events,” either 0% or 100% complete.
4. *Supervisor’s opinion:* The most subjective method is the supervisor’s opinion method. It is used when no other method can be suitably applied, such as in an engine tune-up or dewatering operation. This method relies totally on the foreman or superintendent’s judgment. The contractor may use this method to exaggerate the percent complete for early payment. Because it does not require actual measurements, it is considered the quickest (and dirtiest) and “most convenient” method. The scheduler must be careful not to overuse this method.
5. *Incremental milestones:* The incremental milestones method is more suitable for large and complex or multistage activities. Each stage of a given activity is assigned a “weight” that is approximately equal to its percentage share of effort in the total activity. Then, each stage is treated as “all or nothing.” For example, a contractor is installing 25 doors. Four doors that have not yet been started are 0% complete. Eight doors have had their frames erected. They are considered 30% complete. Another six doors have been hung. They are said to be 50% complete. Four more doors have been painted, making them 75% complete. The last three doors have had the hardware installed. They are now 100% complete. Each door goes through the following stages:

Task	Weight (%)	Cumulative Weight (%)	No. Units	% Complete Weight
Not yet started	0%	0%	4	$4 * 0\%/25 = 0.0$
Erect door frame	30%	30%	8	$8 * 30\%/25 = 0.096$
Hang door	20%	50%	6	$6 * 50\%/25 = 0.120$
Paint door	25%	75%	4	$4 * 75\%/25 = 0.120$
Install hardware	25%	100%	3	$3 * 100\%/25 = 0.120$
			25	Total = 0.456 = 45.6%

6. *Weighted or equivalent units:* The weighted or equivalent units method is used for large and complicated activities that usually comprise several consecutive or overlapping subactivities. The method involves the following five steps:
- Assign a weight to each subactivity so that total weight = 100%.
 - Multiply the weight of each subactivity by the quantity of the total activity. This is the “equivalent weight” in units for each subactivity.
 - Determine the percent complete for each subactivity by using one of the previously discussed methods.
 - Multiply the percent complete for each subactivity by its equivalent weight. The result is the “earned quantity.”
 - Add earned quantities for all activities and divide by total quantity.

This is the percent complete for the total activity. For example, for a wall-framing activity, with a total quantity of 3.5 MBF (1,000 board-feet), the following may be true:

Assigned Weight	Subactivity	Unit ^a	Total Quantity	Equivalent MBF	Completed Quantity	Earned MBF
0.04	Bottom Plates	EA	20	0.14	20	0.14
0.40	Studs	EA	320	1.40	210	0.92
0.08	Corners	EA	12	0.28	8	0.19
0.12	Blocking	EA	160	0.42	92	0.24
0.14	Door Openings	EA	10	0.49	5	0.25
0.16	Window Openings	EA	12	0.56	5	0.23
0.06	Top Plates	EA	40	0.21	0	0.00
1.00	Total	MBF		3.50		1.97

^aEA = each.

$$\text{Percent complete} = 197/3.50 = 56.3\%$$

Only the weights (in the first column) are subjectively assigned. All other columns are either measured or calculated. Following is a sample calculation for the studs:

$$\begin{aligned}\text{Equivalent MBF} &= \text{Assigned weight} * \text{Total MBF} \\ &= 0.40 * 3.50 = 1.40\end{aligned}$$

and

$$\begin{aligned}\text{Earned MBF} &= \text{Equivalent MBF} * \text{Completed quantity}/\text{Total quantity} \\ &= 1.40 * 210/320 = 0.92\end{aligned}$$

The weighted or equivalent units method and the incremental milestones method are similar. Both are used for relatively large and complex activities that comprise several

subactivities. The main difference is that subactivities in the incremental milestones method must occur in chronological sequence. So, when you assign a percent complete to a subactivity, you use the cumulative percent complete—that includes the percent complete for the preceding steps (subactivities). In the weighted or equivalent units method, subactivities may be somewhat independent. Each subactivity has its own percent complete regardless of the percent complete for other subactivities.

You may wonder what the wisdom is for considering a wall-framing “activity” as a single activity with seven “subactivities” rather than simply having seven individual activities. One minor advantage is being able to tell the percent complete for the entire wall-framing activity. The author would prefer to treat the situation as seven individual activities. Many software scheduling programs can calculate the percent complete of a number of activities, grouped under certain criteria. Primavera P6 can do so in one of two ways: (a) you identify the wall-framing activities, for example, with an activity code (e.g., Step = Framing), then group activities by step, or (b) you create a “level of effort⁷” activity (call it Framing) that encompasses all wall-framing activities. Another alternative is to use the WBS (an example of a WBS is provided in Figure 4.1), and then summarize the WBS at a certain level. In Microsoft Project, you can “indent” activities to make them subactivities. If the major activity has a WBS code of 5, its subactivities will have WBS codes of 5.1, 5.2, 5.3, and so forth.

Methods for Determining Percent Complete for the Entire Project

We have shown how to estimate the percent complete for individual activities. The next question is what is the percent complete for the entire project? The answer is not clear. In fact, there might be several answers—substantially different, but none is the “right” one and none is “wrong.”

Most of the methods applied to find out the percent complete to the entire project are the same as those explained earlier to calculate the percent complete for individual activities:

1. *Units completed:* This method may work for the percent complete of an activity, but it is difficult to apply to the entire project because there is no single unit in common to measure. An exception to this statement is projects with simple and identifiable units of measure such as earthwork and highway construction. We can say 82 miles of a total 250 miles are finished. Then, the percent complete is $82/250$, or 32.8%. In this case, we are assuming that “a mile is a mile” in the project (i.e., all paving effort takes the same amount of effort and duration throughout the project). We may still have a problem with “partially finished” units, but the project manager can make an assumption with a small error or apply the incremental milestones method.

Other types of projects, such as residential, commercial, and industrial projects, do not have a common unit of production. Do not confuse this

⁷ Used to be called *Hammock* activity. The author prefers the old name.

“unit” (a unit of measurement, such as a cubic yard of concrete, a linear foot of electric wiring, or a square yard or foot of flooring) with “functional units” (finished usable units used mostly for design and estimating, such as a room in a hotel; a bed in a hospital; a pupil in a school; millions of gallons of water per day, or MGD, in a water project; and the like). Functional units must go through multistage activities to get into their final form, and they are not appropriate, in most cases, as a measure of work progress, or project percent complete.

2. *Cost/budget*: The cost method is actually two methods and it is a good idea to do them both for comparison:

- 2.1. Baseline Cost/Budget Method:

$$\text{Percent complete} = \text{Budgeted cost to date}/\text{Baseline Budget}$$

- 2.2. Actual Cost/Budget Method:

- $\text{Percent complete} = \text{Actual cost to date}/\text{Estimated cost at completion}$

Baseline ratio represents percent complete that is supposed to be achieved at this point.

3. *Man-hours*: This method is similar to the previous one except that we use man-hours in the equation. Obviously, this method produces a number that is focused on labor man-hours (directly related to productivity), while the cost method calculates percent complete based on total cost including labor, materials, and other.

- 3.1. Baseline Man-Hour Method:

$$\text{Percent complete} = \text{Budgeted man-hours to date}/\text{Baseline man-hours}$$

- 3.2. Actual Man-Hour Method:

$$\text{Percent complete} = \text{Actual man-hours to date}/\text{Estimated man-hours at completion}$$

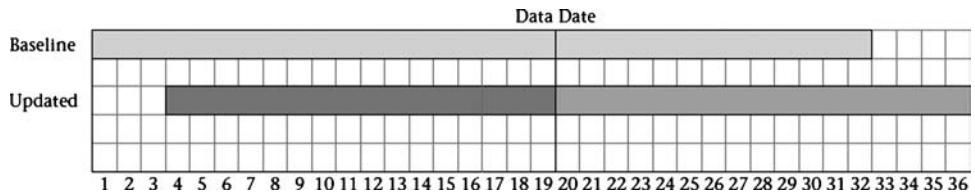
It is important to note that “man-hours” unit is not a time unit. It is, rather, a measure of effort or consumption of a labor resource. Eight man-hours could be produced by one person during an 8-hour period, two persons for 4 hours, four persons for 2 hours, and so forth.

4. *Duration*: Again, this method is indeed two methods—one based on baseline and one on actual duration.

- 4.1. Baseline Duration:

$$\text{Percent Complete} = (\text{Data Date} - \text{BL Start Date})/\text{Total BL Duration}$$

Where BL Start Date is the baseline start date, that is, when the project was *planned* to start.

**Figure 7.14 Percent complete based on duration**

4.2. Actual Duration:

$$\text{Percent Complete} = \text{Actual Duration} / \text{At Completion Duration}$$

$$\text{Where At Completion Duration} = \text{Actual Duration} + \text{Remaining Duration}$$

In Figure 7.14, the project is represented by one summary bar. There are two bars; one representing the baseline project and the other representing the updated project. The project started three days late and is expected to take one more day than originally planned, that is, finish four days past its baseline finish date.

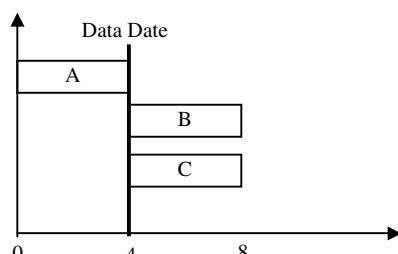
$$\text{Baseline Duration Percent Complete} = 19/32 = 59\%$$

$$\text{Actual Duration Percent Complete} = 16/33 = 48\%$$

Whether using baseline or actual duration, the scheduler has to make sure that he/she is counting work days or calendar days. Both are okay as long as the scheduler knows what he/she is measuring, and is consistent with it.

5. *Workday unit*: The workday unit method is based on the assumption that activities have weights proportional to their durations. As a simple example, let's contemplate a project made of three activities (A, B, and C); each one takes 4 days. Activity A is the predecessor to both B and C. Now, four days after project started, activity A is complete and activities B and C have not started yet (see Figure 7.15). In this case, each activity has a weight of 4 units. The project has a total of 12 units. Actual (or completed) units are 4.

$$\text{Percent complete} = \text{Actual Units} / \text{Total Units} = 4/12 = 33\%$$

**Figure 7.15 Workday unit percent complete**

Activity	IPA	Original Duration	Actual Duration	Remaining Duration
A	—	7	7	0
B	A	12	9	3
C	A	6	4	2
D	B, C	5	0	5
E	D	9	0	9
Total		39	20	19

This method is used in software scheduling programs such as Primavera P6. Another example is the project shown in the table above.

According to this method, the percent complete for this project is $20/39$, or 51.3%. Two simplifying—but not necessarily realistic—assumptions underlie this method:

- All activities have the same “weight per day” and
- Weight within the activity is distributed linearly. Some programs give the user the ability to change this assumption by dividing the activity into “steps” with different weights (similar to the weighted or equivalent units method). This division does not change the first assumption, that activities have weight proportional to their duration.

This method is simple and can be used by contractors who do not cost-load or resource-load their schedules. Its main pitfall is that activities such as procurement or obtaining permits, for example, may have much more weight than they deserve. Obtaining a permit may be a 60-day activity.⁸ There may not be any work occurring on that activity during these 60 days and few or no resources allocated to it (not to underestimate the importance of the activity). It will have 30 times the weight of another activity with 300 CY of concrete placement that takes only 2 days. However, with hundreds or even thousands of activities in the schedule, the errors on both sides tend to cancel each other.

Discussion of the Methods

So, which method—of the five (or practically seven)—is better? Again, there is no unique answer; it depends on what you are looking for and what data is available. It is important for the project manager to know the options and then select the appropriate percent complete method. Once the management team picks one (or more) method for measuring the percent complete for the project, it should be used consistently throughout the life of the project for project control. The contractor may use more than one percent complete measure at the same time, each for a different purpose.

⁸Some schedulers, including the author, prefer to assign a 1-day duration to such an activity with 59 days lag, or even make it as a milestone with 60-day lag.

In reality, the project percent complete may not be very important. It can be used for a general idea about how close the project is to completion, but it is not normally used for project control or progress payments. The percent complete of individual activities is more important because it provides the basis for progress payments.

The cost and man-hours completed methods have their proponents, who believe such methods are the best way to control a project. They might be, if used with the proper understanding of what they mean. Whenever the cost, man-hour, or duration method is used, it is a good idea to calculate both the actual and baseline percent complete for comparison. The Earned Value Analysis (explained later in this chapter) builds on this concept.

The duration method (both actual and baseline) and the workday method both measure time one way or the other. The duration percent complete method does not look at how much work is being done at certain interval, while the workday method does. In the duration method, work on the project is treated as a linear variable (i.e., each day is the same).

The most important recommendations are: Know what you (or the computer software) measure and be consistent with it.

Percent Complete and the Computer Software:

Computer software packages define their own percent complete types. Some of them are simple and self-explanatory; others are not or are given a peculiar or misleading title by the software manufacturer. Even worse, some computer software packages do not give the equations or basis for calculations for such percent complete types. For example, the author had an interesting experience when third-party reporting software was used, pulling the raw data out of the scheduling software database. Some activities had percent complete exceeding 100%, although they were still incomplete. Other activities had negative percent complete. What was interesting that such numbers showed as 100% and 0% in the reports of the scheduling software, that is, they got an artificial “correction.” After investigating and contacting the scheduling software’s technical support, the author discovered that equations and even terminology were used differently in the software. These three equations were presented earlier:

$$\text{Percent Complete} = \text{Actual Duration}/\text{Total Duration} \quad (\text{A})$$

$$\text{Percent Complete} = (\text{Total Duration} - \text{Remaining Duration})/\text{Total Duration} \quad (\text{B})$$

$$\text{Percent Complete} = (\text{Data Date} - \text{Actual Start Date})/\text{Total Duration} \quad (\text{C})$$

The definition of Total Duration was pivotal: while the software used Original Duration as Total Duration, the author believes Total Duration = updated duration = Actual Duration + Remaining Duration.

To dramatize this point, suppose that an activity was originally estimated at 10 days. For some reason, work has taken much more time than estimated. After 13 days of actual work, it was found that Remaining Duration = 12 days. If we keep the total duration as the original duration, which is 10 days, we will get the following results:

With equations A and C, the percent complete is $13/10$, or 130%.

With equation B, the percent complete is $(10 - 12)/10$, or -20%.

The real percent complete is $13/(13 + 12)$, or 52%.

Example 7.2

Assume that a “project” with three activities: The first two activities are identical and can be performed simultaneously. Each one requires the installation of an interior hollow-core wood door, which costs \$200 each (including hardware). Installation of these doors requires one laborer for 2 hours for each door. The third activity requires the installing of hand-carved decorative exterior door that costs \$2,200 and takes three laborers for 3 hours. Assume a man-hour costs \$40.

$$\text{Total cost of first or second activities} = 200 + 2 * 40 = \$280 \text{ each}$$

$$\text{Total cost of third activity} = 2,200 + 3 * 3 * 40 = \$2,560$$

$$\text{Total cost for project} = 2 * 280 + 2,560 = \$3,120$$

$$\text{Total man-hours for project} = 2 + 2 + 3 * 3 = 13 \text{ man-hours}$$

$$\text{Total duration for project} = 2 + 3 = 5 \text{ hours}$$

Now, assume that the first and second activities are completed and the third one has not started yet (see Figure 7.16), what is the percent complete of the “project”? Use all applicable percent complete methods. Assuming that project is on budget and on schedule.

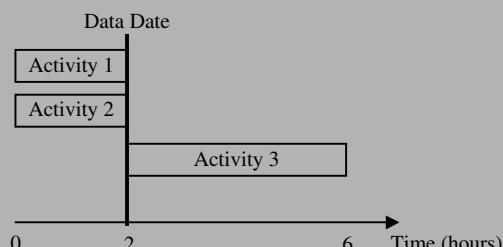


Figure 7.16 Example 7.2 Installing three doors

1. *Units completed:* This method assumes that a door is a door, that is, each door is a “unit” and all units have the same weight in the calculation of the percent complete.

Percent Complete = Units completed/Total units = 2 door/3 door = 66.7% complete

2. *Cost/Budget:* Percent Complete = Actual budget/Total budget = \$560/\$3,120 = 17.9% complete
3. *Man-hours:* Percent Complete = Actual man-hours/Total man-hours = 4/13 = 30.8% complete
4. *Duration:* Percent Complete = Actual duration/Total duration = 2 hours/5 hours = 40% complete
5. *Workday Unit (becomes here workhour unit):* Percent Complete = Actual Units/Total Units = 4/7 = 57% complete

Methods 2, 3, and 4 are calculated based on baseline (budget, man-hours, duration). They are also correct based on actual work if everything went on budget and on schedule. Now, to make things little more complicated, let's assume that the hollow-core doors actually cost the contractor \$230 and took an extra hour for installation (each). Also assume that the expectation for the third activity did not change.

Actual cost for first or second activity = $230 + 3 * 40 = \$350$

Total cost for project = $2 * 350 + 2,440 = \$3,260$

Total man-hours for project = $3 + 3 + 3 * 3 = 15$ man-hours

Total duration for project = $3 + 3 = 6$ hours

New percent complete estimates will emerge based on methods 2, 3, and 4:

6. *Actual Cost/Budget:* Percent Complete = $\$700/\$3,260 = 21.5\%$ complete.

7. *Man-Hours:* Percent Complete = $6/15 = 40\%$ complete.

8. *Duration:* Percent Complete = $3/6 = 50\%$ complete.

If this is not confusing enough, let's say that the foreman "believes" the project is about 30% complete!

This example dramatizes the concept of percent complete for a reason: A percent complete is not just a percent complete! Make sure that you know exactly what you are measuring.

Percent Complete for a Work Package: A work package (or assembly) is somewhere between an activity and a project. It is made of a collection of related items. A continuous footing work package may include excavation, formwork, reinforcement, and concrete mix placement for that footing. A wall work package may include framing, electrical wiring, insulation, drywall, and painting. The percent complete for a work package can be obtained by selecting an appropriate methods among those explained earlier, both for an activity or the project.

Progress Payments and Percent Complete

Payment requests depend completely on the percent complete for each activity and the unit prices submitted and approved in the **schedule of values**.⁹ The five standard steps for progress payment requests are as follows:

1. The project contract usually specifies the frequency of progress payments, usually monthly, and the closeout date for each period. This closeout date—say, the 25th of the month—is set for the general contractor to bill the owner. The general contractor sets another date, usually 2 or 3 days earlier, for his subcontractors to bill him or her. All charges that miss the closeout date must wait till the next billing cycle (i.e., next pay request).
2. The general contractor lists all activities that were worked on. Each activity will have information such as actual start, actual finish (if completed), percent complete (if > 0 but $< 100\%$), original budget, cost this period, cost to date, and **cost to complete**. The owner may have other stipulations in the contract such as retainage. The general contractor must include work performed either by his or her own workforce or by his or her subcontractors.
Materials purchased but not yet installed may or may not be included in the pay request, depending on the contractual agreement between the owner and the general contractor.
3. This report goes to the owner, who usually verifies the information delivered in it. The owner's representative must verify the completed quantities, unit prices, and totals in the payment requests. Contractors sometimes front-end load the cost, which means they get their money earlier than normal. This is done by two means: First, contractors increase the unit prices of early items and decrease the unit prices of late items, in a way that retains the same total. This is usually done when the general contractor submits the schedule of values to the owner and is called *bid unbalancing*. The other method of front-end loading the cost is by exaggerating the percent complete for certain activities. Most owners do not like, and may not approve of, such practices. Thus, the owner's verification of the numbers in the contractor's payment request is important.
4. The payment request can be approved as is or rejected with some numbers disapproved. Once the owner approves the payment request, it is processed and a check is issued payable to the general contractor for the total amount of the payment request minus any retainage and/or penalties. The owner's verification of the pay request and the issuance of the check usually takes 2 to 4 weeks. When the owner pays the general contractor, he or she then pays the subcontractors.
5. The schedule of values must be updated with the cost items in any change order.

⁹ In the British system, schedule of values is referred to as bill of quantities (BOQ).

Standard forms for pay requests, such as AIA G702 (Application and Certification for Payment) and G703 (continuation to form G702), are used in the industry. In Europe and some other parts of the world, FIDIC (International Federation of Consulting Engineers) and NEC (New Engineering Contract) forms are used.

Earned Value Analysis

Earned value analysis (EVA) is an integrated cost-schedule approach used to monitor and analyze the progress of a project. Popescu and Charoenngam (1995) defined it as “the performance measurement to report the status of a project in terms of both cost and time at a given data date” (p. 252).

Earned value management (EVM), started in the 1960s as a method for integrated project cost and schedule control, was designed by the U.S. Air Force and named the *cost/schedule planning and control system*. In 1967, it became Department of Defense (DoD) policy and was renamed the **cost/schedule control systems criteria (C/SCSC)**. The objectives of the C/SCSC policy were (a) for contractors to use effective internal cost and schedule management control systems, and (b) for the government to be able to rely on timely data produced by these systems for determining product-oriented contract status. C/SCSC implementation was governed by DoD Instruction 7000.2, “Performance Measurement for Selected Acquisitions,” issued by the comptroller in 1967 in the financial management regulatory series. The C/SCSC and DoD Instruction 7000.2 had several implementation problems and went through several cycles of research and redefining. The name changed several times, from cost/schedule planning and control system to cost/schedule control systems criteria, or C/SCSC, then to earned value management.¹⁰

The concept of **earned value (EV)** is simple; at any given point, take the following five steps:

1. Determine how much work you have done and how much you should have done according to the plan.
2. Determine how much money you have earned and how much money you have spent.
3. Calculate the time (schedule) and money (budget) deviations (variances) so far.
4. Analyze the causes for the major deviations and determine possible remedies.
5. Extrapolate these deviations to the end of the entire project.

To understand the math involved in EV analysis, consider the following simplistic example.

¹⁰For more information, see the Earned Value Management Web site (<http://www.acq.osd.mil/pm>) and the papers “Earned Value Management and Acquisition Reform” (<http://www.acq.osd.mil/pm/paperpres/standown.html>) and “Earned Value Management Rediscovered” (http://www.acq.osd.mil/pm/newpolicy/misc/abba_art.html), both by Wayne Abba.

Example 7.3

A contractor agreed to build 30 doghouses in 90 days at a price of \$800 per unit. Twenty days later, the contractor has finished 8 doghouses with an actual total cost (that includes his overhead and profit) of \$6,800. What is the status of the project?

Solution

The following analysis applies only if work is sequential and not parallel (that is, the contractor works on one unit till it is finished then starts the next unit and so on). Linearity of production and no learning curve effect are also assumed.

Total planned budget (TB) = 30 units * \$800 each = \$24,000,

Daily planned production = 30 units/90 days = 0.33 units/day (or 3 days per unit),

Daily planned budget = \$24,000/90 days = \$266.67

= 0.33 units/day * \$800 each = 266.67,

and

$$\text{Percent complete} = 8/30 = 26.7\%.$$

After 20 days, the contractor's plan calls for 0.33 units/day * 20 days = 6.66 units to be finished, with a total cost of 6.66 * \$800 = \$5,333. We call this amount the **budgeted cost for work scheduled (BCWS)**. In other words, if everything (schedule and budget) worked according to plan, in 20 days the contractor would have finished 6.66 units and earned \$5,333.

The contract price was \$800 and the contractor actually finished 8 units, so he earned 8 * \$800 = \$6,400 from the owner (disregarding what it actually cost him). This is called the **earned value (EV)**, or **budgeted cost for work performed (BCWP)**.

However, the contractor's actual cost was \$6,800. This is called **actual cost for work performed (ACWP)**.

$$\text{Cost Variance (CV)} = \text{BCWP} - \text{ACWP} = 6,400 - 6,800 = -\$400$$

$$\text{Schedule variance (SV)} = \text{BCWP} - \text{BCWS} = 6,400 - 5,333 = \$1,067$$

$$\begin{aligned}\text{Schedule variance in days (SV, days)} &= \text{SV (\$)} / \text{Daily planned budget} \\ &= \$1,067 / \$266.67 = 4 \text{ days}\end{aligned}$$

$$\text{Cost performance index (CPI)} = \text{BCWP} / \text{ACWP} = 6,400 / 6,800 = 0.94$$

$$\text{Schedule performance index (SPI)} = \text{BCWP} / \text{BCWS} = 6,400 / 5,333 = 1.20$$

$$\text{Forecasted cost variance (FCV)} = \text{CV} / \% \text{ Complete} = \$400 / 26.7\% = \$1,500$$

$$\text{Forecasted schedule variance (FSV)} = \text{SV} / \% \text{ Complete} = 4 / 26.7\% = 15 \text{ days}$$

The results are tabulated as follows:

Activity	Dog houses
TOTAL BUDGET (\$)	24,000
% COMPLETE	26.7
ACWP (\$)	6,800
BCWP (\$)	6,400
BCWS (\$)	5,333
CV (\$)	400
SV (\$)	1,067
SV (DAYS)	4
CPI	0.94
SPI	1.20
FCV (\$)	1,500
FSV (DAYS)	15

From simple observation, we can tell the following:

- The project is 26.7% complete.
- The project is ahead of schedule by 4 days (planned to finish 6.66 units in 20 days but finished 8).
- The project is over budget by \$400 (earned \$6,400 but spent¹¹ \$6,800).
- If work continues at the same pace and pattern, the contractor will finish this project 15 days ahead of schedule but with a budget deficit of \$1,500.

Several factors must be taken into consideration when interpreting the preceding numbers. One factor is the effect of the learning curves. It is possible that slightly below average productivity is expected and acceptable if the crew is “learning” this task and the project manager expects an improvement later that will erase this negative variance. It is also possible that the contractor is accelerating the project and that is costing him extra money. It is very possible that this extra cost is justifiable to the contractor.

The BCWS represents the baseline schedule and budget. The BCWP represents the “earned value” (i.e., the contract earning for performed work). The ACWP represents actual budget spending.

Both the variances and performance indexes are measures of deviation from the baseline. The variances are absolute measures in units of dollars and days. The performance indexes are relative measures in percentages. To “dramatize” the

¹¹The contractor’s overhead and profit are part of the “expenses.”

difference between absolute and relative measures, let us consider two activities: the first with a \$100 budget, and the second with a \$10,000 budget. If we have a cost variance, CV, of $-\$25$ in *each* activity, the CPI for the first is 0.75 (seriously low) and 0.998 for the other (consider it perfect). Contractors strive for a nonnegative cost and schedule variances, and cost and schedule performance indexes at or exceeding 1.0.

In most cases, the forecasted amounts are used to raise a red (or yellow) flag rather than to accurately predict future amounts. For example, in the previous example, the contractor can tell his crew, “We are running \$400 over budget and we are just 27% complete. If we don’t do anything about it, we will end up with a \$1,500 deficit.” In projects in which a penalty is imposed for finishing late and/or a bonus for finishing early, forecasting can be a key tool for making a decision to accelerate the project.¹² Analysis of the causes for variance is beyond the scope of this book. However, it is important to point out four issues:

1. Minor variances are usually expected and tolerated (although discouraged when negative). Major variances should be investigated.
2. For a negative variance (schedule or cost), something must have gone wrong in the actual work or in the baseline. For example, labor productivity may have been lower than expected. This could be due to uncontrolled circumstances (whether forgivable or not) or due to underestimation in the baseline. Material prices could have risen unexpectedly or waste may have taken a larger-than-expected percentage. This causes major concern, especially in fixed-price contracts.
3. A large positive variance may not be a reason for celebration. It may indicate an error or an overestimation in the baseline budget and/or schedule.
4. Schedule performance and budget performance are independent. The contractor may find him- or herself operating under the conditions in one of the four quadrants shown in Figure 7.17. Quadrant I means the project is ahead of schedule and under budget (where you want to be). Quadrant II gives you bad news (you are behind schedule) and good news (and under budget). Quadrant III is the worst: you are behind schedule and over budget. Quadrant IV is the opposite of quadrant II: you are ahead of schedule but over budget.

Another parameter that was suggested is the Cost-Schedule Index (CSI), which is the product of the CPI and the SPI. The main problem with this parameter is the possibility that good performance in one area masks substandard performance in the other. For example, in our previous sample project, the CSI was $0.94 * 1.20 = 1.13$, which is good but misleading.

¹² For example, see the discussion on *contractor-created float* previously in this chapter or the introduction to chapter 8.

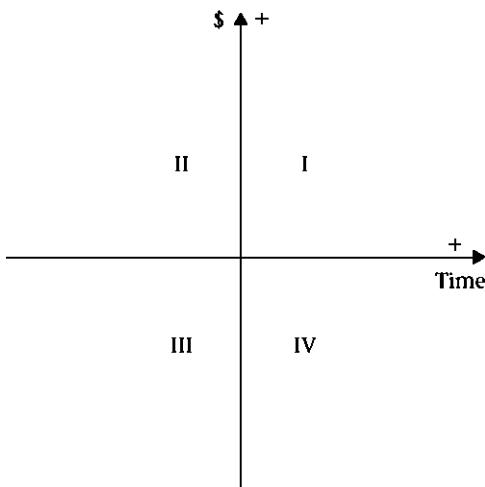


Figure 7.17 Schedule performance versus budget performance: quadrant I, ahead of schedule and under budget; quadrant II, behind schedule and under budget; quadrant III, behind schedule and over budget; quadrant IV, ahead of schedule but over budget.

Earned Value versus CPM: It is important to note that EV analysis and schedule updating may yield conflicting results. The schedule variance (SV) may be positive, but the schedule update may show that the project is behind, or vice versa. This situation occurs mainly because the EV analysis is budget-driven, whereas schedule updating focuses on the critical path, without regard to monetary issues. For example, the contractor may get a positive schedule variance in Earned Value Analysis by completing noncritical activities ahead of schedule while the critical path may be behind. CPM still gives the most accurate readings on whether the project is ahead of or behind schedule. Several authors suggested schedule variance (SV) that is time-based with several approaches¹³ Such suggestions are beyond the scope of this book.

S Curves

Earned value (BCWP) and actual cost (ACWP) may be plotted against the baseline (BCWS), as shown in Figure 7.18. Both curves, representing the ACWP and the BCWP, are usually extrapolated to forecast an **estimate at completion (EAC)** and the date of completion.

EV Analysis at Different Levels When using the WBS, project managers may look at work at different summary levels.

¹³Warburton and Kanabar (2008), Anbari (2003).

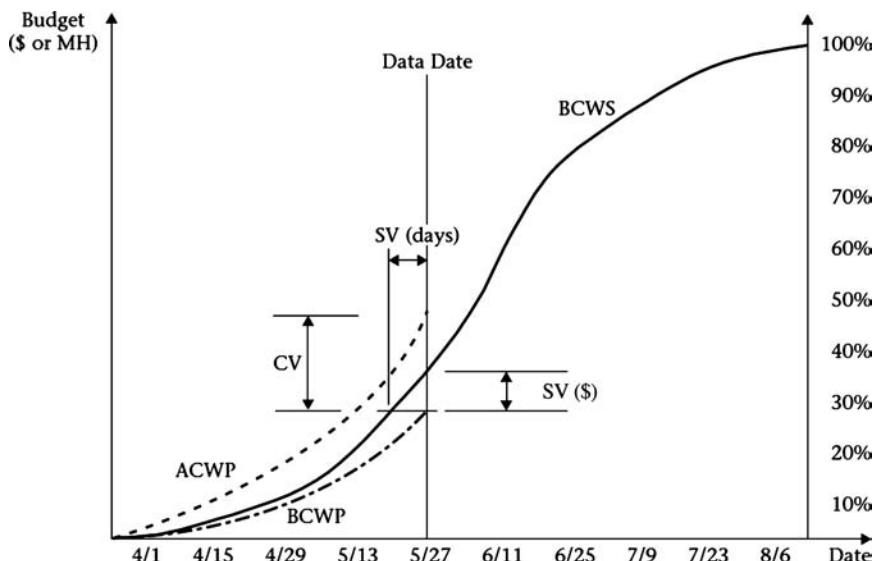


Figure 7.18 Earned value (budgeted cost for work performed, or BCWP) and actual cost (actual cost for work performed, or ACWP) plotted against the baseline (budgeted cost for work scheduled, or BCWS).

Example 7.4

The total estimated duration of the mass excavation activities in an office building project is 40 days. After 15 days, the project manager receives the following information:

Type of Excavation	Task No.	Total Quantity (CY)	Unit Price (\$)	Total Budget (\$)	Actual CY	Actual Cost (\$)
Mass Excavation	TOB11110	39,000	—	176,500	13,200	59,700
Common Earth	TOB11111	20,000	2.50	50,000	7,800	17,950
Clay	TOB11112	8,000	5.50	44,000	1,200	5,850
Rock	TOB11113	11,000	7.50	82,500	4,200	35,900

Perform an EV analysis. Note that the “Mass Excavation” line is a summary of the 3 lines below.

Solution

The solution, using the equations given in example 7.2, is tabulated as follows:

Activity	TOB1110	TOB1111	TOB1112	TOB1113
TOTAL BUDGET (\$)	176,500	50,000	44,000	82,500
% COMPLETE	32.63	39.00	15.00	38.18
ACWP (\$)	59,700	17,950	5,850	35,900
BCWP (\$)	57,600	19,500	6,600	31,500
BCWS (\$)	66,188	18,750	16,500	30,938
CV (\$)	-2,100	1,550	750	-4,400
SV (\$)	-8,588	750	-9,900	562
SV (DAYS)	-1.95	0.17	-2.24	0.13
CPI	0.96	1.09	1.13	0.88
SPI	0.87	1.04	0.40	1.02
FCV (\$)	-6,436	3,974	5,000	-11,524
FSV (DAYS)	-5.96	0.44	-14.96	0.33

In the analysis of the results, we can make the following six comments:

1. Looking at the overall budget, we find that the Mass Excavation operation is slightly (\$2,100) over budget. With further investigation, we find that the main reason for this budget overrun is the Rock excavation, which is \$4,400 over budget. In fact the other two excavation activities, Common Earth and Clay, are slightly under budget. This is an example of when above-standard performance masks below-standard performance. The CPI for Rock excavation is 0.88 (substantially low), when it is 0.96 for the whole operation.
2. When we look at the schedule, the only meaningful number is the overall schedule variance, which tells us that the Mass Excavation operation is almost 2 days behind schedule. Looking at individual schedule variances may be misleading. It is possible that the contractor planned to focus effort on one area at the expense of other areas. In this case, both Common Earth and Rock are on schedule; Clay is behind.
3. Let us consider the Mass Excavation activity as part of the total excavation operation, TOB1110, which includes, in addition to TOB1110 Mass Excavation, TOB11120 Special Excavation, as shown next:

Work Breakdown Element	Level
TOB10000 Tampa Office Building	1
TOB11000 Substructures	2

TOB11100 Excavation	3
TOB11110 Mass Excavation	4
TOB11111 Common Earth Excavation	5
TOB11112 Clay Excavation	5
TOB11113 Rock Excavation	5
TOB11120 Special Excavation	4
TOB11121 Confined Areas Excavation	5
TOB11122 Other Special Excavation	5

If the same subcontractor is in charge of the TOB11120 Special Excavation operation, he or she may also be concentrating effort on one operation at the time expense of the other (Mass Excavation and Special Excavation). In this case, we will not be able to tell how much the contractor is ahead or behind schedule till we look at the entire excavation operation, TOB11100. In contrast, the cost variance is activity specific and is a true indicator at any level.

4. Looking at forecasted variances indicates that, if work continues at the same pace and in the same pattern, the Mass Excavation operation will finish 6 days behind schedule and with a \$6,436 deficit. This situation is certainly a reason for concern for the project management team. The project manager must try to prevent or mitigate this outcome.
5. In the WBS shown in comment 3, we have five “levels of control.” A typical superintendent or project manager may want to look at earned value at level 4 or even 5. Someone in upper management may look at level 2 or 3, but if an unsatisfactory number is spotted, he or she may want to go to a lower level, such as level 4 or 5, for the specific activity with unsatisfactory numbers to pinpoint the trouble source. It is very important to look at EV numbers as part of, but not the entire, picture. They are only indicators and possibly red flags. Once a flag is raised, more information must be collected to explain the substandard results. Once that analysis is done, and the source of the problem is identified, a remedy must be prescribed.
6. We can describe activities with negative variance as “substandard performance” as compared with “above-standard performance” for those with positive variances. We do not use the term *bad* or *good* performance because the analysis may show—for an activity with negative cost variance—that the performance was satisfactory but another reason caused the negative variance. The reason could be an unexpected work problem (not caused by the field crew in charge of the activity), an error or unrealistic assumption in the original estimate, or something else. The possibility of poor performance also exists.

CHAPTER 7 EXERCISES

1. Define schedule updating.
2. Why is schedule updating needed for construction projects?
3. Define project control and discuss the roles of schedule updating as part of project control.
4. Are the terms project monitoring and project tracking equivalent to project control? Explain.
5. Why is project control needed in construction projects?
6. What is a baseline schedule? Discuss how to adopt a balanced baseline schedule—one that is not too optimistic and not too pessimistic.
7. What is an updated schedule? What does schedule updating mean?
8. What is the data date? What other names are used for it? Which are inaccurate? Why?
9. What kind of information is needed for updating schedules?
10. How frequent should schedule updating be performed?
11. Why is schedule updating important for progress payments?
12. What does the term degressing a schedule mean?
13. When you are updating a project, an activity may be added or deleted. What are the mishaps that may occur and how do you avoid them?
14. What are the steps involved in updating a schedule?
15. Refer to exercise 4 in chapter 4. Ten days after the start of the project, the following information is received:

Activities A and B	Completed on time
Activity C	Started; 3 days left.
Activity D	Started; 2 days left.
Activity E	Has not started yet but duration adjusted to 5 days.

Draw the updated network. Calculate the new project completion date. Check whether any change in the critical path occurred.
16. Refer to exercise 5 in chapter 4. Fifteen days after the start of the project, the following information is received:

Activity A	Completed 2 days later than planned.
Activity B	Completed on time.
Activity C	Started; 4 days left.
Activity D	Completed. Took 5 days to finish.
Activity E	Completed.
Activity F	Canceled.

Activity G Started 3 days late. Project manager hopes to cut 1 day of its duration.

Activity K Added. Duration = 4 days. IPA = C.

Activity L Added. Duration = 3 days. IPA = K, G.

Activity I Adjusted: IPA = L.

Draw the updated network. Calculate the new project completion date.
Check whether any change in the critical path occurred.

17. Refer to exercise 6 in chapter 4. Twelve days¹⁴ after the start of the project, the following information is received:

Activities A and D Completed on time.

Activity B Completed by end of day 11.

Activity C Started on time; finished 1 day late.

Activity E Not started yet.

Activity F Duration changed to 7 days.

Activity G Canceled

Activity I Started; 1 day left.

A change order was issued with three new activities:

Activity N Duration = 4 days. IPA = None.

Activity O Duration = 3 days. IPA = N, H.

Activity P Duration = 5 days. IPA = O, L. No successor.

Draw the updated network. Calculate the new project completion date.
Check whether any change in the critical path occurred.

18. “If the logic used in creating this schedule was accurate, there should be no difference between the Retained Logic and Progress Override options.” How much do you agree with this statement? Explain.
19. How is project updating tied to pay requests?
20. Explain what is meant by the term *contractor-created float*.
21. Explain the steps usually taken in a monthly update of a schedule.
22. Does the scheduler have to “explain” the results of the update to the project manager? When? Why or why not?
23. During the life of a project, the scheduler receives a lot of feedback on the schedule from different parties such as the architect, the engineer, the owner, the subcontractors, and others. As a scheduler, how would you take and implement or reject such feedback?
24. Can the critical path in a project change during the life of the project? How can such a thing happen? Give an example.

¹⁴ Assume this project is updated biweekly, but the crews are working 6 days per week.

25. Management must pay attention not only to critical activities, but also to near-critical activities. Explain this statement from a practical point of view.
26. List each of the six methods for measuring the work progress of a certain activity. Under what conditions would each be recommended? Give an example for each method.
27. A roofer is working to cover a 2,500-square-foot roof. He must first install rafters, then sheathing, then felt, and finally shingles. He assumes the previous tasks compose 35%, 20%, 15%, and 30% of the total roofing activity. At a certain point, he gets the following information on the subtasks:

Subtask	Unit ^a	Total Quantity	Installed Quantity
Rafters	EA	150	102
Sheathing	SF	2,720	1,200
Felt	SQ	27.2	10
Shingles	SQ	27.2	5

^a EA = each; SF = square feet. SQ (square), is 100 square feet; a unit used mostly in roofing jobs.

- Calculate the estimated percent complete for the roofing activity.
28. Which method of measuring work progress is suitable for each of the following activities?
 - a. Laying bricks for an exterior wall
 - b. Safety inspection
 - c. Installation of a furnace
 - d. Project supervision
 - e. Multiple reinforced concrete footings
 - f. Setting up a patented formwork system for a wall
 - g. Hydration of a concrete slab on a grade (assume a small slab)
 - h. Fishing¹⁵ an electric wire for an entire floor
 - i. Excavation of earth (assume one type of soil)
 - j. Excavation of earth (assume several types of soil)
 - k. Dewatering
 - l. Installing ceramic tile for a large area (involves a few subactivities)
 29. When you are calculating the percent complete for an entire project, more than one answer might be possible. The project manager says the percent complete is about 60%, the cost engineer says it is 65%, the computer program says 57%, and the owner says it should be 50% (according to his or her representative's feedback). You calculate it on the basis of how much time has

¹⁵To run an electric wire through a conduit by using resilient “fish tape” or a “snake.”

elapsed and how much time is given in the contract; your result is 70%. Can you explain these confusing and “conflicting” numbers?

30. On the basis of the information given in the previous exercise, do you think the project is in trouble (with regard to the budget and the schedule)? How did you conclude this?
31. Explain the procedure for initiating and processing pay requests.
32. This exercise is for persons who use Primavera P6 software: You created a project without feeding the program any budget or resources information. After the first update, the scheduling report says the project is 16.7% complete. Do you know how the program determined this number? How accurate is this number?
33. The earned value (EV) analysis involves comparing what happened with what should have happened. Explain this statement with regard to both the budget and the schedule.
34. A mason contracted with a general contractor to build an exterior wall from 8-inch CMUs. The wall is 82 feet long and 8 feet high.¹⁶ The mason must finish the wall in 3 days and gets paid \$4 per block. At the end of day 1, the mason has installed 220 blocks. Her actual cost (including overhead and profit) was \$836. Analyze the situation with regard to both the budget and the schedule.
35. Draw the S curve for the masonry job in the previous exercise.
36. A flooring subcontractor must install three types of flooring in an existing building:

Type	Quantity (SF)*	Unit Price (\$/SF)	Total Price (\$)
Carpet	2,600	2.30	5,980
Vinyl tile	1,200	2.95	3,540
Ceramic tile	3,330	4.95	16,484
Total	7,130		26,004

^a Carpet is usually sold and installed by the square yard. We used square foot (SF) here for conformity with the other flooring types.

The subcontractor is given 10 days to finish all the work. Assume he has crews to start all three jobs concurrently. Four days after the start of the work, he discovers the following:

¹⁶ Do not forget the CMU face dimension (including the mortar joint): 8 inches by 16 inches.

Type	Quantity Installed (SF)	Actual Cost (\$)
Carpet	1,500	3,150
Vinyl tile	800	2,488
Ceramic tile	750	3,638

Perform an EV analysis of the preceding task:

- a. Analyze each subtask (carpet, vinyl tile, ceramic tile) individually; determine its status with regard to the budget and the schedule.
- b. Analyze the entire flooring activity as one unit; determine its status with regard to the budget and the schedule.
- c. How do you combine the answers for parts A and B?
- d. On the basis of performance so far, do you believe the subcontractor will finish the job on time? Within budget? Justify your answer.
- e. Draw the S curve for the entire task.

Chapter 8

Schedule Compression and Time-Cost Trade-Off



West Orange High School, Winter Garden, Florida

On January 17, 1994, a 6.7-magnitude earthquake caused heavy damage and many casualties in Northridge, California. The immediate major concern for Cal-trans (the California Department of Transportation) was reopening the public highways in one of the busiest areas in the United States.¹ Part of the damaged highways was two sections of Interstate 10 in Santa Monica. C. C. Meyers, Inc., of Rancho Cordova, California, was awarded the contract to repair these sections. C. C. Meyers' bid of \$14.7 million was significantly less than the Caltrans engineer's \$22.3 million estimate. The contract gave the contractor 140 days to finish the project and included a liquidated damages² clause of \$200,000 for each day of delay and a similar bonus amount for each day finished early. The contractor finished the project in only 66 days, 74 days ahead of the stipulated deadline. This early finish was possible because the project was fast-tracked. In addition, C. C. Meyers worked around the clock, putting large amounts of resources into the project, making this project the focus of the company. Excellent cooperation between Caltrans and the contractor also helped. Caltrans did its part to help push the project, assigning 10 engineers on the day shift and 4 on call at night to inspect work and answer questions.

In the process of expediting the schedule, C. C. Meyers may have gone over the original budget, but with about a \$14.8 million bonus, the company was certainly ahead of the game. Despite the large bonus paid, Caltrans seemed pleased with the results. The public's convenience was well worth the effort and the money. Caltrans and C. C. Meyers both believe that despite the schedule compression, work quality was not compromised.

INTRODUCTION

Construction projects almost always have finish deadlines assigned by the owner and stipulated in the contract. Some of these projects have strict deadlines that do not allow for any slippage. An example of such a project is the facilities built for the Olympic Games or international exhibits or conferences. Any slippage in the schedule in such a case could literally mean a disaster: an international embarrassment and a loss of large sums of money. Other, mostly public, projects have strict deadlines because of the interest of or convenience to the general public. An example is a highway, a school, or a water treatment plant. Any delay in such a project may not be assessed by a monetary amount; however, the consequences are still severe. Other projects may have deadlines that are rigid, but a slippage would not result in such disastrous outcomes. An example of such projects is a hotel or a shopping center for a certain tourist or shopping season. Finishing late in this case would mean a loss of revenue for the season. Still other projects, not tied to a specific event or season, may have "normal" finish dates, which means the contractor can work at a "normal" pace. In most cases, a normal schedule means 5 days per week, 8 hours a day, but the schedule depends on the contract.

¹ The next major concern for Caltrans was retrofitting bridges and other structures to be earthquake resistant.

² *Liquidated damages* are a stipulation in a contract of a monetary amount that must be paid by the contractor if he or she fails to satisfactorily complete the project by the contract finish date. They are discussed in more detail in chapter 13.

Slipping a few days or weeks in this case may be acceptable to the owner and may not cause serious consequences.

For all these types of projects, the contract may or may not contain a liquidated damages clause. The damages usually include an estimated loss of revenue as a result of a delay and may include **punitive damages**. Punitive damages are difficult to recover in courts, especially in the case of mere breach of contract. To recover punitive damages (also called **exemplary damages**), the owner must prove that the breach was committed maliciously or that an intentional tort or another illegal or wrongful act such as fraud was committed (Wickwire, Driscoll, and Hurlbut 1991, § 11.19).

SETTING PRIORITIES

Finishing on—or ahead of—schedule is an important objective of the contractor and the owner. Finishing on—or under—budget is another important objective. Achieving these two objectives simultaneously is desirable—and usually possible—but often the contractor must rank them in order of importance: one before the other. As is shown later in this chapter, the project manager may, at a certain point, be faced with a situation in which shortening the duration costs more money. At this point, a decision must be made between two alternatives:

1. Do not shorten the duration anymore and keep the cost to a minimum.
2. Keep compressing the schedule even though the cost will continue to rise.

ACCELERATING A PROJECT

What Is “Accelerating” a Project?

Accelerating a project means shortening the normal duration of the project schedule (also called **schedule compression**). It does not necessarily mean aiming for the shortest possible duration. The term *compressing the schedule* is synonymous and is used throughout this book. The term **schedule crashing** is generally used to indicate maximum acceleration, although it is sometimes used in lieu of accelerating.

Why Accelerate a Project?

A contractor may want to accelerate a project for many reasons, including the following five:

1. The contractor’s “normal” finish date in the planned schedule does not meet the imposed finish date of the contract. The contractor usually knows this situation before starting construction, or, sometimes, even before bidding. In many cases, the owner requires the contractor to submit a construction (critical path method, or CPM) schedule that shows a satisfactory finish date.

Many government agencies even require the contractor to use a specific scheduling software program.

2. After starting construction and completing a certain percentage of the project, the contractor realizes that the project is behind schedule. He or she needs to accelerate the remainder of the schedule to make up for lost time and avoid finishing late (referred to as recovery schedule). In many contracts, penalties (mostly liquidated damages) may be levied on the contractor for a late finish.
3. In some cases, the contractor may have a contractual monetary incentive to finish ahead of schedule. The case study mentioned at the beginning of this chapter is an example.
4. Sometimes, especially when the economy is doing well, finishing early means—to the contractor—starting another job earlier and, thus, making more profit. In many cases, the contractor knows the date when he or she is supposed to mobilize to the next project. This time frame may require him or her to compress the current project to free certain resources so that they can be reallocated to the new project.
5. To a certain point, accelerating a project may prove profitable to the contractor, as is discussed subsequently.

Acceleration can be planned before the start of the project, as in points 1 and 3 and possibly 4 and 5. In other cases, it is not planned but sometime during construction the work situation necessitates it.

How Can the Duration of a Project Be Shortened?

Construction projects may take more or less time than planned (usually more rather than less) for reasons that may be within or beyond the contractor's control. Reasons beyond the contractor's control, such as **force majeure**, differing site conditions, and change orders; draw time extensions from the owner in most cases. These situations are not discussed in this chapter. Instead, the discussion is restricted to the ways the contractor can influence the duration of the project. The Construction Industry Institute (1988a) suggested more than 90 techniques for schedule compression. It further classified them by project phase or function:

- I. Ideas applicable to all phases of a project
- II. Engineering phase
- III. Contractual approach
- IV. Scheduling
- V. Materials management
- VI. Construction work management
- VII. Field labor management
- VIII. Start-up phase

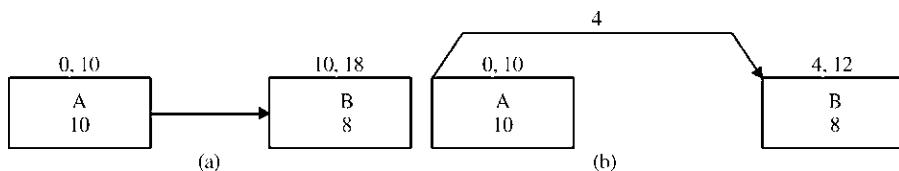


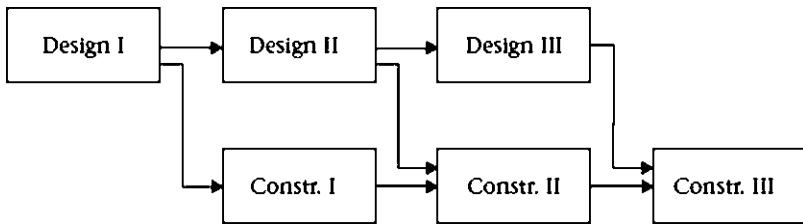
Figure 8.1 Time savings difference between (a) finish-to-start (FS) and (b) start-to-start (SS) relationships

A review of these techniques underscores the importance of early planning. For some projects, the decision to compress the schedule may be made during the construction phase. Other projects, such as the Northridge case study, are carefully planned from the moment the project is conceived through completion.

The author suggests 9 techniques (not in any particular order):

1. *Revisit or study the schedule thoroughly to find any errors or unnecessary logic or constraints:* The most common pitfall is using the finish-to-start (FS) relationship when a start-to-start (SS) relationship with a reasonable lag can work. For example, suppose that the logic is that activity B in Figure 8.1a cannot start until activity A is finished (i.e., day 10). After checking the situation, we find that activity B can start only after a certain portion of activity A is finished (e.g., 40%). In this case (Figure 8.1b), activity B can start as early as day 4, which saves 6 days.
2. *Fast-track the project (as mentioned in chapter 5):* Fast-tracking means starting construction before the design is completely finished. Conceptual design must first be done; detailed design follows in stages. Construction of each phase (or component) follows the detailed design of the phase while the next phase is being designed (see Figure 8.2). This option is not usually available in the middle of construction. It is a major decision that must be made with the agreement of the owner, the designer (architect or engineer, A/E), and the contractor prior to starting the project.
3. *Conduct value engineering and constructability studies:* Value engineering (VE) has been defined as “An analysis and comparison of cost versus value of building materials, equipment, and systems. VE considers the initial cost of construction, coupled with the estimated cost of maintenance, energy use, life expectancy, and replacement cost.” (*RSMeans Illustrated Construction Dictionary*, 4th Edition, 2010). Constructability has been defined as “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives” (Construction Industry Institute 1986a, p. 2)³. R. S. Means Illustrated

³ Wikipedia online defines it as “a project management technique to review construction processes from start to finish during pre-construction phase. It is to identify obstacles before a project is actually built to reduce or prevent error, delays, and cost overrun.”

**Figure 8.2 Fast-tracking**

Construction Dictionary (4th edition, 2010) defines Constructability Review “The practice of peer reviewing the plans and specifications prior to issuing for bid with the intent of correcting errors, omissions, inconsistencies or discrepancies.”

VE is considered an optimization study answering the question “Is it fit or overfit?” It focuses on functional analysis and life-cycle costs. It can be done by the designer (A/E), the professional construction manager, and the contractor. In some cases, the contractor may have a VE suggestion for modifying or changing the design that will achieve the same objectives with less cost, less time, a better product, or a combination of these. Contracts often include a reward clause for contractors who submit creative suggestions. In such clauses, the savings are usually split between the owner and the contractor.

Constructability is mostly a feasibility study performed by the contractor to check for any difficulties with or obstacles to carrying out the design. Unlike VE, this type of study does not cover the “after construction” functions such as operation, maintenance, upgrading, and so forth.

VE and constructability can coexist and even complement each other (Construction Industry Institute 1993).⁴

If the VE study started early enough and schedule acceleration was needed, alternative materials and/or methods could be suggested such as using pre-engineered units and assemblies. Such practices may have an impact on other elements in the project and usually require the approval of the designer.

4. *Work overtime—more hours per day and/or more days per week:* The results of some studies suggest that productivity declines with more hours worked per week than the basic 40 hours. The Business Roundtable⁵ (1980) suggested an immediate, significant drop (1st week, as a result of the initial pattern change), followed by a partial recovery (2nd and 3rd weeks, when the person is starting to adapt to the overtime schedule), then a gradual, slight decline (4th through 9th weeks, as a result of work fatigue), and finally a leveling off (after the 9th or 10th week) (see Figure 8.3). R. S. Means BCCD (2010) showed a more

⁴ You may also want to refer to the summary in two Construction Industry Institute reports (1986a, 1987a).

⁵ Now The Construction Users Roundtable (CURT).

“linear” approach. It gave declining productivity numbers from week 1 to week 4. For example, for 6 days per week and 10 hours per day, productivity was assumed to be 95%, 90%, 85%, and 80% for weeks 1 through 4, respectively. Some researchers (Larew 1998) questioned the reliability of these overtime studies.

As far as cost, overtime pay is almost always more than regular-time pay. If the workers have a union contract, overtime is compensated according to the collective bargaining agreement between the contractor and the labor union. In most construction contracts, hours exceeding 40 per week and any hours on

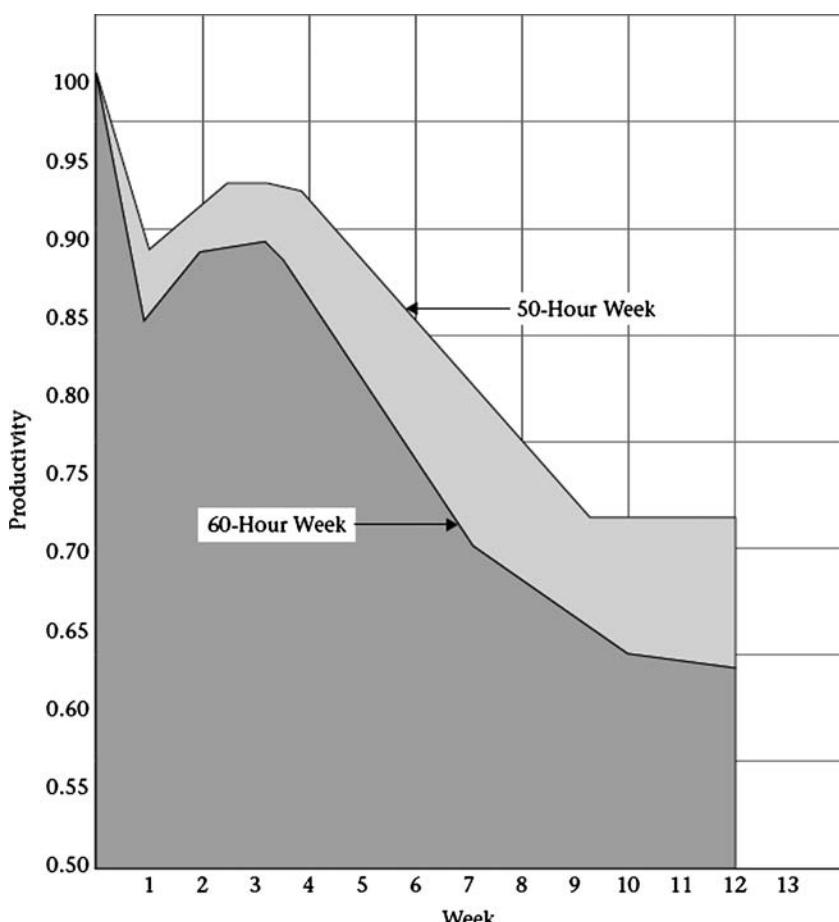


Figure 8.3 Cumulative effect of overtime on productivity (50- and 60-hour workweeks). (From The Business Roundtable, *Scheduled Overtime Effect on Construction Projects* [New York: The Business Roundtable, November 1980], Report C-2, p. 10. Reproduced by permission from The Construction Users Roundtable [CURT; formerly the Construction Committee of The Business Roundtable]; <http://www.curt.org/pdf/156.pdf>)

Saturday are compensated at 1.5 times the regular rate. Other hours, possibly Sunday and night hours, may be compensated at twice the regular rate. If the project involves open-shop labor, overtime pay depends on the contractor's company policy but is always subject to government regulations. For hourly workers, hours in excess of 40 per week almost always cost more than regular hours. In contrast, salaried employees may not receive overtime compensation.

The Business Roundtable (1980) studied the combined effects of reduced productivity and increased cost resulting from overtime. The curves in Figure 8.4 show these effects.

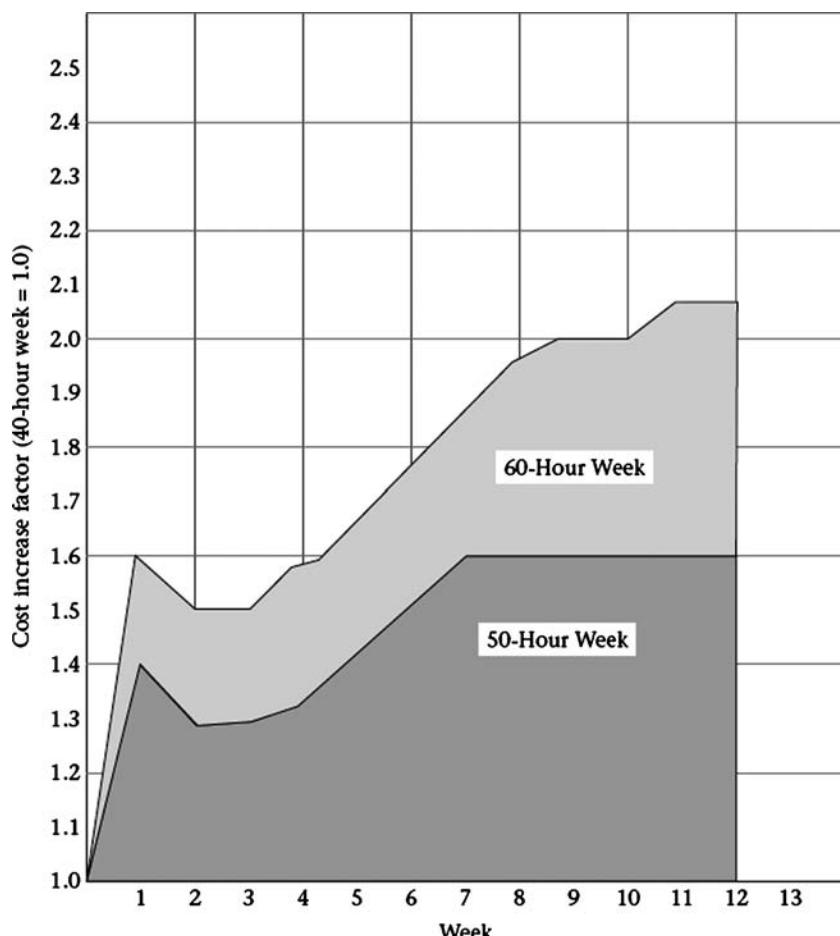


Figure 8.4 Cumulative cost of overtime successive weeks' productivity loss overtime premiums. (From The Business Roundtable, *Scheduled Overtime Effect on Construction Projects* [New York: The Business Roundtable, November 1980], Report C-2, p. 11. Reproduced by permission from The Construction Users Roundtable [CURT; formerly the Construction Committee of The Business Roundtable]; <http://www.curt.org/pdf/156.pdf>)

5. *Offer incentives to workers or crews for improving productivity.*: The contractor usually has an incentive to compress the schedule such as avoiding a penalty or earning a bonus. Workers do not directly pay the fine or get the contract bonus. The contractor must offer them an “internal” incentive, which could be more symbolic (a plaque, certificate, party, baseball cap, bomber jacket, T-shirt, coffee mug, etc.), monetary, paid vacation, or a combination of these.
6. *Acquire more workers*: This may mean adding more workers to the current workforce and/or hiring a second and possibly a third shift. Usually, the number of workers and the amount of equipment allowed on-site are limited. Saturating the job site may lead to site congestion that would adversely affect productivity and safety, which would defeat the purpose of acquiring more workers and equipment. When hiring more shifts, a turnover time will have to be taken in consideration. In multiple shifts, the worker takes some time to identify the work elements and status when starting. Supervisors must ensure work consistency and that all shifts conform to the same standards. Several factors must be balanced in this regard: the cost of the “extra” resources, the cost of not having these resources when needed, and the consideration of what to do with the extra resources after the peak need ends.
7. *Acquire special materials and/or equipment that help speed up the work process*: This may be as simple as adding accelerating agents to the concrete mix or as major as adding a tower crane. Difficult decisions regarding choices may have to be made in this regard—mainly, justifying the cost of such materials and equipment. In some instances, automation results in reduction in number of workers as well as increase in production.
8. *Improve project management or supervision*: In some cases, the contractor may recognize a problem in the project team. There could be an “authority battle” between the project manager (leaning towards pure project organization) and the main office (preferring functional organization). Having everyone on the same page is extremely vital for the success of the project. Replacing the project manager or superintendent in the middle of the job is not an easy decision. However, under certain circumstances, doing so may be less evil than keeping the status quo.
9. *Improve communications among parties, particularly during the submittal process*: Sometimes a structural subcontractor may have an inquiry about a structural detail. The contract stipulates a chain of command requiring the subcontractor to submit his **request for information (RFI)** to the general contractor, who sends it to the architect, who in turn forwards it to the structural engineer. The response then must come in the reverse order across the same chain. Many contracts allow the subcontractor to send an RFI directly to the structural engineer (or whoever the responsible party is) but require him or her to send copies to the contractual parties between (the general contractor and the architect). The structural engineer, in turn, can

answer the structural subcontractor directly but must also copy the architect and the general contractor.

Because of technology, the process of reviewing and approving drawings is faster than ever. Some companies do so online by uploading their drawings to a (usually exclusive) Web site. All parties are informed by e-mail about the new drawings. In many cases, the review can take place online. The entire process can now be completed in a few hours rather than several days with a high accompanying delivery cost. Management software also speeds up the RFI process if all parties have immediate access to the software.⁶

The author also suggests the concept of *optimum scheduling* (discussed later in this chapter) that, when applicable, can result in time saving, among other potential benefits.

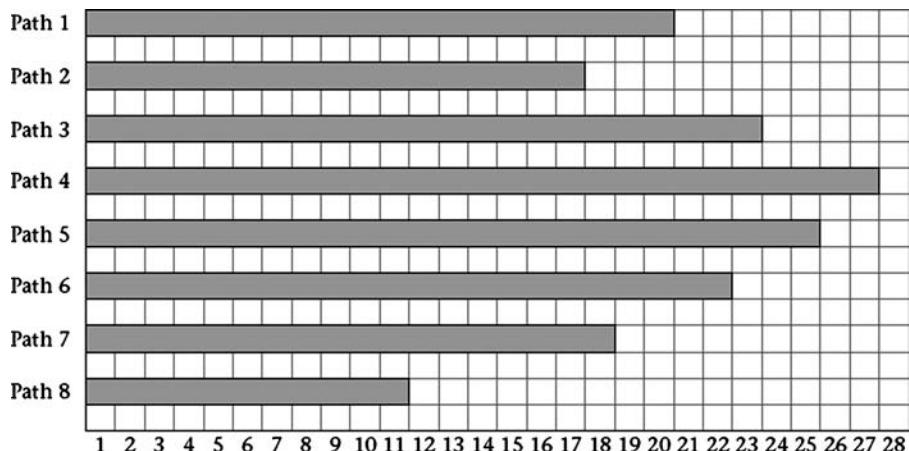
The earlier the need to accelerate the schedule is known, the more options the contractor will have and the lower the cost may be.

How Does Accelerating a Project Work?

The duration of the entire project is equal to the duration of the critical path. Thus, to shorten the duration of the entire project, we must shorten the duration of the critical path. Let us consider a project that has eight paths (whether dependent—for example, they share some activities—or independent), as shown in Figure 8.5. Path 4 is the critical path, with duration of 27 days. To accelerate the project, we do the following:

1. We start accelerating the project by shortening the longest (critical) path (i.e., path 4).
2. To shorten the duration of a path, we cut the duration of one or more activities on the path. As a rule of thumb, we choose the activity with the least acceleration cost.
3. We accelerate path 4 by 2 days (we may have to do so in two steps—one day at a time—or we may be able to do so in one step; this point is explained later). Now, the duration of the project is 25 days.
4. If the shortened activity falls on more than one path, all the paths with the activity will also be shortened.
5. Assuming that the shortened activity was not on path 5, we now have two paths with 25 days' duration: path 4 and path 5. To accelerate the project further, we must shorten *both* paths. If the two paths share one or more activities, cutting the duration of a shared activity will shorten both paths. Otherwise, we must cut the duration of an activity on *each* path. We cut 2 days from each path. Now, the duration of the project is 23 days.

⁶ Most project management software packages provide access to users on the company's server, with the possibility of providing limited access through the Internet.

**Figure 8.5 Project with eight paths**

6. Three paths are now tied as the longest: paths 3, 4, and 5. We repeat step 5 for these paths to cut 1 day from each path and subsequently cut 1 day from the duration of the project. The duration is now 22 days.
7. Note again that when we cut the duration of an activity, several paths may be affected. For example, if we cut an activity that is on both paths 4 and 2, path 2 is now cut—unintentionally—from 17 days to 16 days.
8. Path 6 has now “joined the club” and become critical. We repeat step 6.
9. Clearly, the further we accelerate the project, the more paths must be shortened and the more activities must be involved. Consequently, we may need to compress six or seven activities to cut only one day from the project duration. This fact is why the direct cost of accelerating is not linear (although it may be linear for short intervals).

It is interesting to note that an increase in the duration of the critical path by x days will result in an increase in the duration of the project by x days as well. However, the reverse is not necessarily true. A decrease in the duration of the critical path by x days will result in a decrease in the duration of the project by y days, where

$$0 < y \leq x$$

DIRECT AND INDIRECT COSTS

A contractor's main expenses are as follows:

I. Direct costs

- A. *Labor*, particularly hourly workers, for whom a labor expense can be directly linked to a particular work item

- B. *Materials*, such as concrete, rebar, bricks, lumber, nails, paint, drywall, carpet, structural steel, and *installed equipment*, such as elevators, air-conditioning units, and kitchen equipment
- C. *Equipment*, mainly construction equipment (bulldozers, excavators, cranes, concrete pumps, etc.)⁷
- D. *Subcontractors* (even though subcontractors' charges comprise labor, materials, equipment, overhead, and possibly sub-subcontractors, the general contractor treats these charges as a direct cost)
- E. *Other costs*, such as government permits and fees, and fees for lawyers and consultants hired for a specific task in a project

II. Indirect costs

- A. Project overhead (or **job overhead**), such as the following:
 - 1. Project staff (project manager, project superintendent, project engineer, receptionist or secretary, clerk, etc.)
 - 2. Office trailer and other temporary structures
 - 3. Cars and trucks assigned to the project team
 - 4. Office equipment (copying machine, fax machine, computers, etc.)
 - 5. Temporary utilities (electricity, water, drinking water and ice, telephones, cell phones, gas, portable toilets, etc.)
 - 6. Other indirect project-related expenses, such as power generators and projectors used to provide light during night working hours.
- B. **General overhead**, such as the following:
 - 1. Main office expenses (rent, lease, maintenance, utilities, etc.)
 - 2. Main office personnel
 - 3. Main office equipment and vehicles
 - 4. Main office services, such as lawyers and accountants (not working exclusively for a specific project)
 - 5. Other main office expenses, such as advertising and charity contributions
- C. *Profit* (usually estimated by the contractor before he or she takes on the project; it usually ranges between 5 and 10%, although it can and does occur outside this range; the profit percentage depends on many project-specific factors, prevailing economic conditions, and the contractor's financial status). Profit was given many definitions, but the author's preferred one is "return

⁷ If a power generator was installed to be a permanent part of the building, it counts as materials. If a power generator was used to provide power for construction work only such as night lighting, it counts as equipment. Construction professionals in the U.K. call all equipment used in the construction "plant" to make clear distinction from installed equipment

for taking risk,” thus profit amount (or percentage) is usually proportional to the risk taken.

- D. **Contingency fees** (an additional sum of money allocated for the unknown events that will most likely occur during the life of the project; they are directly proportional to the risk taken in the project)

The main criterion for differentiating between direct and indirect expenses is that a direct-expense item must be directly linked to a specific work item. For example, if you pay someone to set up concrete forms for a shear wall, the expense is direct. If you pay a security guard to look after the project, the expense is indirect. The same simple rule applies to differentiating between project overhead and general overhead. Any overhead expense directly linked to one specific project is project (job) overhead; otherwise, it is general overhead. General overhead is usually distributed among all projects in proportion to their cost and duration. In some cases, certain overhead expenses are shared by multiple, but not all, projects undertaken by a specific contractor. For example, a scheduler or a safety officer may be assigned to two or three projects of the many projects on which the company is working. This cost must be treated as job overhead and divided between the two or three project.

Cost Concepts as They Relate to Schedule Compression

As the schedule is compressed, the direct and indirect costs will be impacted in different and opposite manner. Let us start with what we define as the normal duration and the normal cost for a project. Although the term *normal* may be vague and may be interpreted differently by different people, we define **normal duration** as *the amount of time required to finish the project under ordinary circumstances without any deliberate delay or acceleration*. **Normal cost** is *the cost of a project that is performed within the normal duration*. These definitions also apply to individual activities.

How to Choose the Best Method for Project Acceleration

Using accelerating methods that incur minimal cost (or have the lowest cost-benefit ratio) generally makes sense. Let us consider some of the different methods.

Overtime costs more per hour and, according to the studies mentioned previously, might contribute to lower productivity. This fact does not automatically disqualify overtime as a means for accelerating projects. However, all the pros and cons should be considered before a decision is made to use this method.

Acquiring more workers and equipment may lead to site congestion and less efficiency. In addition, it may create a problem for the human resources and equipment departments: what to do with excess resources after the peak need ends.

Hiring a second, and possibly a third, shift may lead to more turnover time, result in more communication problems, and require more careful management coordination. Extended work hours, because of the second and possibly the third shifts, may require artificial lighting or special nighttime arrangements (for example, services and

security). In addition, second and third shifts may also create a problem for the human resources department: again, what to do with them after the peak need ends.

Acquiring special materials or more efficient equipment must be evaluated on its merits on a case-by-case basis. Such acquisition almost always costs more, but the contractor must look at the cost-benefit ratio and other related factors (for example, public relations, customer satisfaction, and long-term impact). A classic case is when the contractor owns expensive equipment (e.g., an excavator) that is not the most efficient for the job. He or she is faced with the decision to use it even though it is not the most efficient for the job or to acquire the more or most efficient piece of equipment at an extra cost. The market is full of materials, equipment, tools, software, and other gadgets that supposedly make work simpler, faster, or more efficient. All these products come with a cost that may or may not be justified.

Effect of Acceleration on Direct Costs

As explained previously, direct costs almost always increase during project acceleration. However, the more we accelerate, the more the cost of accelerating per day increases. There are two reasons for this phenomenon:

1. At the activity level, accelerating more becomes more difficult and may require different and more expensive techniques. Consider a CIP (cast-in-place) concrete suspended slab activity. Its normal duration is 12 days, but we want to compress it to 6 days. Assume that this activity includes setting up the formwork, placing the rebar, placing (pouring) the concrete, finishing the slab, stripping down the forms and reshoring, and removing the reshores. Compressing the schedule from 12 days to 11 days may be achieved with a simple and inexpensive adjustment, such as having special concrete mix (with accelerators) or having the laborers work 10 hours per day (still no work on Saturday and Sunday). If overtime hours are compensated at 1.5 times the regular rate, workers will work 10 hours per day but get paid for $8 * 1$ (straight time) + $2 * 1.5$ (overtime) hours, or 11 hours. The increase in labor cost will be 10% (we ignored the effect of overtime on productivity). Going from 11 days to 10 days may require working on Saturdays (at 1.5 times the regular pay). The increase in labor cost will be 17%⁸ (we again ignored the effect of overtime on productivity). To accelerate more, we may have to change the method of placement (pumping in lieu of using a crane and bucket) or acquire faster formwork system. In other words, when we start accelerating, we may have many options, and we select those that are least expensive. As we accelerate, we run out of inexpensive options, and we may be left with only those that are expensive.

⁸ In a typical 10-hours-per-day, 6-days-per-week situation, the worker works 60 hours, 20 of which are overtime. If overtime is compensated at 1.5 times the normal rate, the worker will receive 70 hours' worth of pay for the 60 hours' work. The additional pay ratio is $70/60 * 100\% = 116.7\%$.

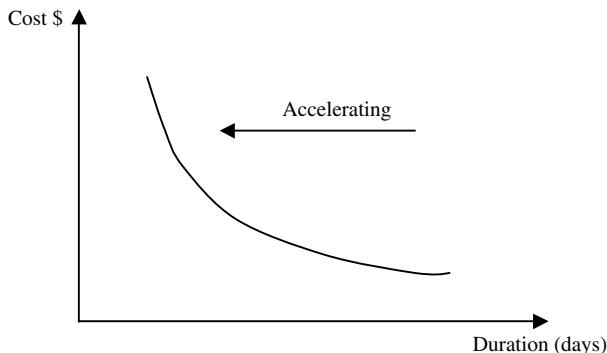


Figure 8.6 Nonlinear increase in direct costs with project acceleration

2. At the entire project level (or, rather, the critical path level), we may have many activities from which to choose. We always choose the activity that has the least cost for crashing. As accelerating progresses, we may have fewer and more expensive choices. Also, as demonstrated previously, in the early stages of acceleration, the compression of one activity may result in the compression of the whole project. In later stages, when multiple paths are tied as critical, we may need to compress several activities (each on a different path) to reduce the project duration by only one day.

For the preceding two reasons, direct costs usually increase nonlinearly (at an increasing rate), as shown by the curve in Figure 8.6. Note that the x -axis represents the total duration of the project in days. For this reason, as we accelerate the project, we move from right to left on the x -axis.

Effect of Acceleration on Indirect Costs

Indirect costs include mainly overhead items, such as the job trailer, equipment in the trailer (copier, fax, etc.), utilities, staff members (salaried employees, not hourly workers), and insurance. These expenses are directly and linearly proportional to the duration, so when the project is being accelerated, they decrease at a constant rate, as shown in Figure 8.7.

Effect of Acceleration on Total Cost

Depending on the shape, slope, and real values, when we combine the curves for direct and indirect costs, we obtain a curve like that shown in Figure 8.8.

We begin with the normal duration and the normal cost. Then, we start accelerating. At the beginning, the total cost decreases at a decreasing rate (because direct cost is increasing at an increasing rate and indirect cost is decreasing at a constant rate) till it hits a minimum point, the **least cost**, with a corresponding **least-cost**

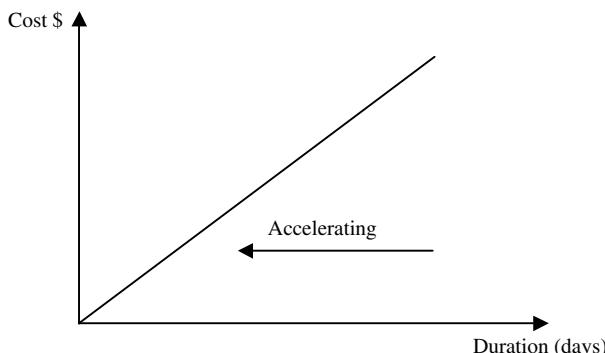


Figure 8.7 Linear decrease in indirect costs with project acceleration

duration. If cost is our priority, we must stop at this point. As we accelerate further, the cost increases till we either reach our desired duration or encounter the least possible duration, or **crash duration**, which has an associated **crash cost**.

As mentioned previously, the shape and slope of the curve differ from one case to another. In some cases, the curve may start going up immediately (i.e., total cost starts increasing as soon as we start accelerating), as shown in Figure 8.9.

In other cases, the curve goes down, then stops at the crash duration point, without going up anymore (see Figure 8.10). In this case, the crash duration point coincides with the least-cost duration point.

When accelerating a project, many issues have to be considered such as design and construction delivery methods (fast-track?), frequency of updating (schedule by the hour?), shift turn over, equipment cost/maintenance, managing subs, procurement/materials management, permits, government regulations (road restriction), cash-flow, job site congestion, and safety and security,. The scheduler may also review activities duration, logic, and allocated resources.

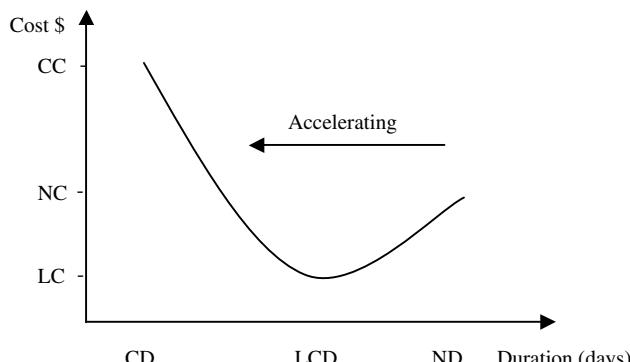


Figure 8.8 Effect of project acceleration on total cost: the general case, in which total cost decreases with acceleration till a certain point then starts increasing—CC, crash cost; NC, normal cost; LC, least cost; CD, crash duration; LCD, least-cost duration; ND, normal duration

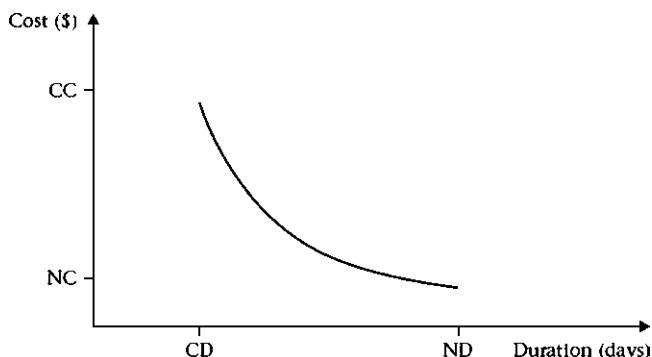


Figure 8.9 Effect of project acceleration on total cost: a special case, in which total cost starts increasing as soon as acceleration starts—CC, crash cost; NC, normal cost; CD, crash duration; LCD, least-cost duration; ND, normal duration

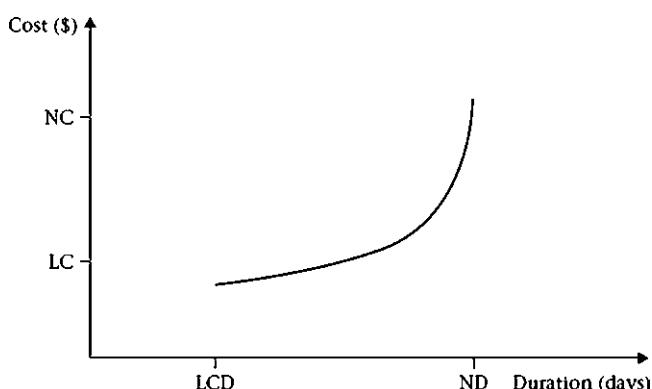


Figure 8.10 Effect of project acceleration on total cost: a special case, in which total cost keeps decreasing until the project is completely crashed—NC, normal cost; LC, least cost; LCD, least-cost duration; ND, normal duration

RECOVERY SCHEDULES

In real-life projects, schedules may slip. This situation may concern the owner, especially if the project deadline is critical. The owner may demand that the contractor adjust the work plan to enable him or her to finish on schedule. The owner must be convinced that the contractor can feasibly do so, or the owner may terminate the contractor and hire another contractor to ensure a timely finish. When the contractor adjusts the schedule, the result is a **recovery schedule**. It can be defined as a schedule prepared during construction, after the project has fallen behind (either the interim target has not been met or serious signs of failure to meet the deadline can be seen), with adjustments by the contractor that expedite the remainder of the project and ensure a timely finish. The recovery schedule may incorporate one or more of the techniques mentioned previously.

Example 8.1

Calculate the normal, least-cost, and crash durations for the following project. Calculate the cost associated with each duration. Indirect (overhead) costs are \$120 per day.

Activity	IPA	Duration (days)		Cost (\$)	
		Normal	Crash	Normal	Crash
A	—	5	4	500	600
B	A	7	5	350	500
C	A	8	5	800	920
D	A	11	7	1,200	1,400
E	B, C	6	4	600	700
F	C	4	4	500	500
G	D, F	7	5	700	1,000
H	E, F	6	5	300	420

Solution

This simple project has five paths (see Figure 8.11). They are listed next, along with their lengths in days:

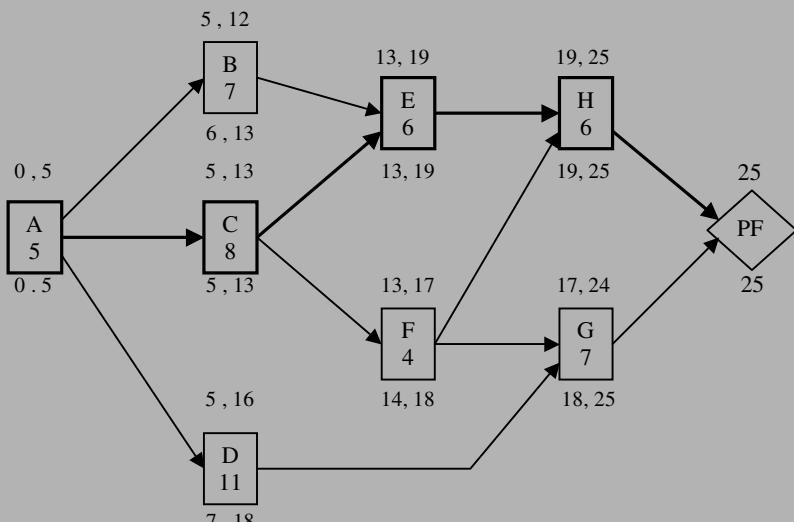


Figure 8.11 Precedence network for project in example 8.1—PF, project finish

Cycle 0 (before crashing)

Path*	Duration (days)
ABEH	24
ACEH	25
ACFH	23
ACFG	24
ADG	23

* When the letter representing an activity is crossed, e.g., F, it means this activity cannot be crashed (such as activity F) or has reached its minimum/crash duration

Let us prepare the time-cost trade-off calculation table (Figure 8.12). We have to start with the critical (longest) path: ACEH. We choose activity C because it costs the least to crash, \$40 per day. We cut the duration of C from 8 days to 7. This action affects three paths:

Activity	Duration (days)		Cost (\$)		Δ Cost (\$)	Δ Days	Δ Cost Days	Days shortened							
	Normal	Crash	Normal	Crash				1	1	1	1	1	1	1	1
A	5	4	500	600	100	1	100								
B	7	5	350	500	150	2	75							1	1
C	8	5	800	920	120	3	40	1				1	1		
D	11	7	1,200	1,400	200	4	50					1	1		
E	6	4	600	700	100	2	50		1		1				
F	4	4	500	500	0	0	—								
G	7	5	700	1,000	300	2	150							1	1
H	6	5	300	420	120	1	120								1
								Days cut	—	1	1	1	1	1	1
								Project duration (days)	25	24	23	22	21	20	19
								Increased cost/day (\$)	—	40	50	100	140	165	225
								Direct costs (\$)	4,950	4,990	5,040	5,140	5,280	5,445	5,670
								Indirect costs (\$)	3,000	2,880	2,760	2,640	2,520	2,400	2,280
								Total cost (\$)	7,950	7,870	7,800	7,780	7,800	7,845	7,950
															8,100

Figure 8.12 Time-cost trade-off calculation table for example 8.1

Cycle 1

Path	Duration (days)
ABEH	24
ACEH	25
ACFH	23
ACFG	24
ADG	23

This action increased the direct costs by \$40 and decreased the indirect costs by \$120. The total impact on the cost is a net savings of \$80.

We now have two paths that tie at 24 days' duration: ABEH and ACEH. We can compress a shared activity (A, E, or H) or a combination of unshared activities (B and C). We choose activity E and compress it from 6 days to 5 at a cost of \$50.

Cycle 2

Path	Duration (days)		
ABEH	24	24	23
ACEH	25	24	23
ACFH	23	22	22
ACFG	24	23	23
ADG	23	23	23

The direct costs increased by \$50, and the indirect costs decreased by \$120. This results in a net decrease of \$70 in the total cost.

Now we have four paths that tie at 23 days' duration: all but ACFH. We can compress a shared activity (A) or a combination of unshared activities (plenty of options exist). We choose activity A and compress it from 5 days to 4 at a cost of \$100⁹. Activity A is now completely crashed.

Cycle 3

Path	Duration (days)			
ABEH-	24	24	23	22
ACEH-	25	24	23	22
ACFH	23	22	22	21
ACFG-	24	23	23	22
ADG	23	23	23	22

With this action, we spent an extra \$100 in direct costs and saved \$120 in indirect costs. The total cost decreased by \$20 (we are still saving money, but the rate is decreasing).

Now we need to compress the same four paths using the least-cost combination. After simple mathematical inspection of the table, we find the best combination to be C, D, and E, with a total combined cost of \$140. We

⁹ If activity A could be crashed by more than 1 day, we could have crashed it to the limit since it is part of any path on the network. This means any day cut from activity A would automatically mean a day cut from the entire schedule.

compress each of these activities by 1 day to shorten the project duration from 22 days to 21 days.

Cycle 4

Path	Duration (days)				
	24	24	23	22	21
ABEH-	24	24	23	22	21
ACEH-	25	24	23	22	20
ACFH-	23	22	22	21	20
ACFG-	24	23	23	22	21
ADG	23	23	23	22	21

Note that path ACEH was cut by 2 days because it contains both C and E. Now, the total cost has increased by \$20 (\$140 increase in direct costs and \$120 decrease in indirect costs). The next step is to find an alternative to activity E because it is completely crashed. The next least-cost combination is B, C, and D, at a total cost of \$165. In this case, the total cost has increased by \$45.

Cycle 5

Path	Duration (days)					
	24	24	23	22	21	20
ABEH-	24	24	23	22	21	20
ACEH-	25	24	23	22	20	19
ACFH-	23	22	22	21	20	19
ACFG-	24	23	23	22	21	20
ADG	23	23	23	22	21	20

Note that the critical paths may change in every round. Now, activity C is also completely crashed. Our next choice is the combination of B and G at a combined cost of \$225, with a net increase of \$105 in the total cost.

Cycle 6

Path	Duration (days)						
	24	24	23	22	21	20	19
ABEH	24	24	23	22	21	20	19
ACEH	25	24	23	22	20	19	19
ACFH	23	22	22	21	20	19	19
ACFG	24	23	23	22	21	20	19
ADG	23	23	23	22	21	20	19

Activity B is now completely crashed. All paths are tied at 19 days. The only remaining option is to combine activities G and H at a cost of \$270, with an increase of \$150 in the total cost.

Cycle 7									
Path	Duration (days)								
ABEH	24	24	23	22	24	20	19	18	
ACEH	25	24	23	22	20	19	19	18	
ACFH	23	22	22	24	20	19	19	18	
ACFG	24	23	23	22	24	20	19	18	
ADG	23	23	23	22	24	20	19	18	

Now the entire project is completely crashed, with a duration of 18 days. The results may be summarized as follows:

- The normal duration is 25 days, at a total cost of \$7,950.
- The least-cost is \$7,780, at a duration of 22 days.
- The crash duration is 18 days, with a crash cost of \$8,100.

Notes

1. Accelerating can become complicated even in a small example. For larger projects, we use computers as explained in the next section.
2. Activity D is not completely crashed, which demonstrates an important point: To accelerate a project, we need not compress all activities. If we did, we would be wasting money for no benefit to the schedule.
3. We assumed linearity within each activity (e.g., it costs the same amount of money to compress activity C from 8 days to 7, from 7 days to 6, or from 6 days to 5). However, we see that the change in total cost for the project is not linear.
4. The project manager may choose project duration between 22 days and 18 days to meet the contract-required finish date (22 days for least cost and 18 days for least duration).

ACCELERATING PROJECTS USING COMPUTERS

Real-life projects usually contain hundreds or thousands of activities. There may be tens or even hundreds of paths, each with 50, 60, or more than 100 activities. Performing calculations such as those done in example 8.1 would be too cumbersome. The practical approach is trial and error. However, nine guidelines follow:

1. Always make a backup copy of the schedule before you make any changes.
2. Focus on the critical path. A good idea is to sort activities by total float (first criterion) and start date (second criterion) in ascending order. You may also apply a filter to only show critical activities (be careful in the software's definition of critical activities).
3. Pick an activity on the critical path and reduce its duration by one day. Schedule the project (perform CPM calculations) and examine the impact on the project's finish date. If the finish date is now one day earlier, move to step 5. If you are applying a filter, you may have to refresh the view.
4. If the project finish date did not change, at least one other critical path must exist, and you reduced only one. Go back to the list of critical activities (those with least total float), pick one, and repeat step 3. Looking at the different paths on either a bar chart or a logic diagram can be helpful.
5. You have reduced the project duration by one day; you now need to reduce it by another day. Repeat step 3. You may find more activities that are critical now. This fact does not mean more options for you. On the contrary, you may have to compress several activities—simultaneously—to reduce the project duration by one day.
6. Repeat the same steps till you achieve the desired duration.
7. Avoid compressing any path by multiple days in one step unless you know the critical path is longer than the next one by several days. For example, if you compress an activity by 10 days, but the project's finish date decreases by only 3 days, you have achieved nothing from the last 7 acceleration days. Only the first 3 days of acceleration were effective. In this case, go back and replace the 10-day compression with 3 days (or the correct effective number).
8. If you are determining the least-cost duration, you may want to do the calculations manually (for every step, you calculate the total net savings by subtracting the increase in direct costs from the decrease in indirect costs). You may also create a simple spreadsheet that performs the calculations.
9. The project manager should give the scheduler the crash duration and crash cost information for the activities. The scheduler must then experiment with the accelerated schedule and submit the results to the project manager. After the project manager approves these results, the scheduler may implement the accelerated schedule.

POTENTIAL ISSUES WITH UNCOORDINATED PROJECT ACCELERATION

As explained earlier, the contractor may accelerate the project schedule responding to instructions from the owner, or he may do so for his own interest. In the latter case, the contractor must discuss such acceleration with the owner to make sure that the owner knows and approves such action. This may sound trivial or unnecessary, as finishing early is generally perceived as a positive achievement. Generally, this is true but not always. Some problems may arise from an uncoordinated early finish such as:

1. *The owner may have a cash-flow problem:* even when the contractor is not asking for extra money, acceleration will result in front-end loading of charges. Owner may receive higher than expected pay requests because more work is being done per pay period than originally planned. If owner was not consulted on this matter and did not formally approve such acceleration, this may cause a delay in payment to the contractor.
2. *The owner may not be ready to take over the facility:* The project may be a hotel, office building, factory, oil refinery, or other facility. Owners always plan for operating the facility when the project is completed and turned over to them by the contractor. Such planning includes, but is not limited to, staffing and budgeting. If the contractor surprises the owner by finishing the project two or three months early, the owner may not have staff and/or budget to run the facility. In addition, such early operation may not go well with the strategic plans for the organization. This may also create a problem with when the warranty on the project and major equipment in it starts.

For the preceding reasons, it is highly recommended that, if the contractor is planning project schedule acceleration for own reasons, he should consult with the owner and get his/her/their written consent.

OPTIMUM PROJECT SCHEDULING

Traditional CPM scheduling mainly aims at completing the project in the shortest *normal* manner, which is identified and defined by the critical path. In certain cases, this schedule is accelerated, as discussed earlier, for time constraint or to minimize cost and/or maximize profit. The project's starting point is usually defined by the contract, based on owner's objective and subjective requirements. Amazingly, this starting point is rarely calculated scientifically (along with activities' durations) to produce an optimum plan (including and focusing on the schedule) to meet the owner's objectives of cost, time, and scope/quality.

Project Scheduling and Prevailing Economic Conditions: Construction projects are subject to a myriad of uncertainties, such as availability and price fluctuations of labor, materials, and equipment; weather; availability of funds; political changes; wars; and natural and man-made disasters. Some of the fluctuations can be predicted fairly

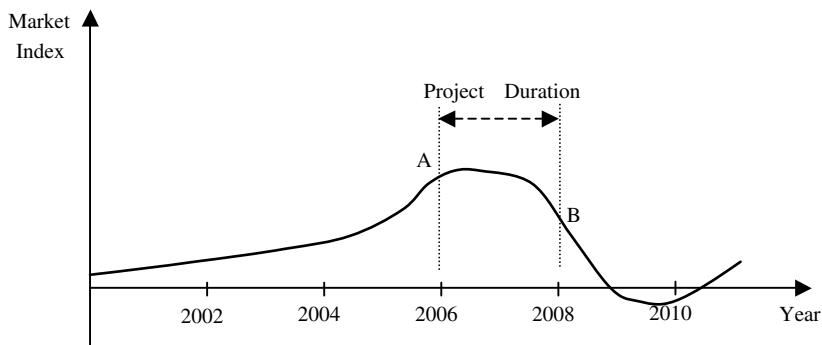


Figure 8.13 Market conditions. This curve does not accurately reflect past market index nor does it accurately forecast conditions. It is for illustrative purposes only.

accurately, such as those induced by seasonal and climatic changes. Other effects are less predictable such as wars, natural disasters, political turbulence, economic recessions, and other local and global events, although some of them have “warning signs” that experts can sense.

Naturally, many developers and investors react to the market conditions and follow the trends. However, the reaction in the construction industry needs a relatively long lead time to deliver the product to the market. By that time, the market condition may have changed. Let’s assume that the market demand is represented by the curve in Figure 8.13.

It took some time to convince an investor that market conditions are encouraging to build a project (say a housing development) and then to get ready to start the project. He started at point “A” when the market was moving favorably (for investors) and demand exceeded supply. It took the investor two years to acquire the land, obtain the permits, design and build the houses, and make them ready for sale. Even though, in most cases, the developer may start selling before construction work is finished, he still has to complete certain portion of the project before he can sell anything. This portion can take one year or more. By the time he can start selling houses (completed or not), the market has hit a saturation point and started to slow down (point B). At this point, the developer’s options are limited. He is “damned if he continues and damned if he does not.” He may have huge financial obligations to the banks or financiers, and he has to make payments for contracts already signed with the designer, contractor, and other parties. A few houses have been sold, and even for those houses sold, he received only a small down payment that—in such situations—buyers may just forfeit to escape worse loss. The survival of the developer depends on his financial strength (mostly how much cash and other liquid assets he has on hand) and how long he can hold on. He may scope down the project or pause it, for example, completing a portion of the entire development and hold the rest till the market starts moving up. Another option is to continue but slow down the work progress using fewer resources and delaying the delivery of the product. If he can’t, he may sell the project as is (perhaps by auction) and use the proceeds to pay off his debts. All these options come with some negative consequences, but the developer/owner may have to choose the lesser

of several evils. Unfortunately, many investors stretch themselves too much—mostly motivated by greed in a situation exacerbated by miscalculations—and these options may be infeasible or insufficient for them. Their only option then is to declare bankruptcy, which does not help in the long run. In other types of projects, where the project is one entity that cannot be partially built (e.g. high rise building, factory, shopping center), completing a portion of the project may not be a viable option.

To minimize the adverse effects of such situation, there are several recommended measures. Since this is *not* a book on economics or risk management, we will focus only on scheduling issues. In brief, when the economy is booming, the response to market demands must be quick. This can be achieved by having a ready plan and accelerated/optimum project schedule. When economy is slumping, it may be a good idea to slow down the pace of the project or even “hibernate” till conditions improve.

In this context, we will discuss the selection of the starting point of the project and its activities durations and timing that determines the optimum duration of the project coupled with optimum (least) cost. Such discussion applies not only in recessions and slow economic times but in all conditions. However, the application of the principle must be adjusted to suit the market and the owner’s conditions.

Project Scheduling in Extreme Weather Regions: In regions with harsh weather conditions (extreme cold/heat, excessive rain, sand storms, hurricane/flood season), it is desirable to have the construction—or at least the first portion, which is mostly outdoors—occur during the preferred season. This can be achieved by applying the idea of optimum scheduling: choosing the starting point of the project and activities’ durations and timing that result in optimum schedule and/or cost.

Optimum Scheduling: Optimum scheduling is defined as selecting the project’s starting point and the composition of the durations and timing of its activities that will result in optimum schedule and least cost while maintaining the project’s scope and quality.

Optimum scheduling is explained here just as a concept. The author is not aware of any book, paper, or software program that performs such optimization. The concept is open to more research, in terms of both theory and application.

Any activity needs resources, mainly labor, materials, and equipment. Each type of resource is subject to a group of influencing factors:

1. *Supply and Demand:* All resources are subject to the supply and demand rule, which usually has predictable and unpredictable sides. For example, many locales have a high season for construction (usually when weather is mild), and demand is heavy at that time. Also, demand may become unexpectedly high following a disaster (war, earthquake, flood, etc.) or economic boom, or as the result of other factors. Demand for special trades may spike following a governmental regulation such as American with Disabilities Act (ADA). Along with demand increase, there is usually price increase. This increase may slowly go back to normal after demand tapers off and/or supply increases to match demand. Avoiding demand spikes, if owner has such luxury, results in lower prices and—in some instances—better quality.

2. *Productivity Fluctuation:* Labor productivity is subject to a host of factors. Weather is one of the most influencing factors, particularly for outdoor activities. During extreme weather, workers' productivity is usually impaired. In addition, they may work reduced hours.¹⁰ Working overtime (extra hours per day or extra days per week) may result in reduction in productivity (as discussed earlier). There are several studies on the effect of overtime, but they do not necessarily agree on the conclusion. However, the author recommends against using overtime for extended periods of time.

Since the construction industry is not fully automated, equipment's productivity is directly linked to labor's productivity.

3. *Weather and Climate:* In addition to its effect on productivity, weather may also affect the behavior of certain materials. Concrete, for example, takes more time to cure in the cold weather and may require heating and/or insulating formwork. In the extreme hot weather, concrete has a different problem. It hardens quickly unless retarding agents are added to the mix and then needs special curing. Extreme weather affects other materials, too, such as asphalt and adhesives. Other materials may become brittle in extreme cold weather, which makes them less workable and more subject to breakage. Excessive rain hampers outdoor activities. Rain may also come with lightening, which poses danger during outdoor activities particularly to those using cranes and tall equipment. Moisture may slow down concrete curing or behavior of adhesives, and may also adversely affect stored materials such as wood. Areas where seasonal monsoon rains, hurricanes, tornados, floods, and other forms of extreme weather occur, may want to avoid outdoor construction during such a season. While scientists may use various methods, such as simulation to forecast the timing and severity of such disasters, no one can make accurate predictions.

Weather may also affect logistics and materials storage. Extreme weather poses difficulties and sometimes hazardous conditions on roads. Stored materials under extreme weather conditions have to be protected with special methods that may be expensive. Time of the year may have an impact on work hours, which differ between summer and winter. Depending on the latitude, there may be fewer daylight hours in the winter than in the summer. This may require the contractor to use artificial lighting.

4. *Locale:* This factor encompasses other factors that are not included above such as local culture and government regulations.

These factors impact both productivity and cost. The impact on productivity will affect duration of the activity and the cost of labor and equipment resources.

¹⁰ In some countries in the Arabian/Persian Gulf, government regulations forbid outdoor work during certain daytime hours in the summer. In extremely cold regions, local law may prohibit outdoor work if temperature dips below certain limit.

Productivity and Cost Multipliers: The scheduler can divide the year into time segments (intervals of 10 days, or months for simplicity in this discussion), assigning productivity and cost multipliers for each segment. The base productivity and cost can be “normal,” “average,” or “optimum.” It does not matter as long as the multipliers are estimated in respect to the base numbers. For example, if we consider January as base for productivity and cost in location X , then we compile productivity and cost multipliers for other months (or time periods) based on past records and future expectations. Let’s suppose that we compiled this table:

Month	Productivity Multiplier (PM)	Cost Multiplier* (CM)
January	1.00	1.00
February	1.00	1.00
March	1.10	0.90
April	1.05	0.90
May	0.95	0.95
June	0.85	1.05
July	0.75	1.10
August	0.70	1.20
September	0.85	1.10
October	1.00	1.00
November	1.10	0.90
December	1.00	0.95

*The cost impact from productivity change is included under the productivity multiplier only. For more accurate results, the cost multiplier should be broken into three multipliers for labor, equipment, and materials, but for the sake of simplicity and to only demonstrate the concept, we will keep it as one multiplier.

Now, when a schedule is created based on base productivity and cost, it has to be recalculated:

$$\text{Adjusted duration} = \sum \text{Dur}_i / \text{PM}_i \quad (8.1)$$

$$\text{Adjusted cost} = \sum \text{Cost}_i * \text{CM}_i \quad (8.2)$$

For example, if an activity is scheduled to start on May 27 and it has 12 days duration (with base productivity), the adjusted duration will be distributed between May and June. We don’t know how long exactly this activity will take but based on Productivity Multipliers < 1.00 , we expect the total duration to be > 12 days. The portion in May will be 5 days (May 27 through 31), but we need to calculate the portion in June, X :

From equation 8.1: Base Duration = Adjusted Duration * Productivity Multiplier
Then, $12 = 5 * 0.95 + X * 0.85 \rightarrow X = 8.53$ days, then total adjusted duration = $5 + 8.53 = 13.53$ days

In other words, this activity, when starting on May 27, is expected to take 1.53 days more than it would take if it is performed in January. This is not as bad as

performing it in July ($12/0.75 = 16$ days) or August ($12/0.70 = 17.14$ days). On the other hand, it will take less than 12 days if performed in March or November ($12/1.1 = 10.91$ days).

Ideally, we would like to do this activity when productivity is at its maximum (i.e., duration is at its minimum) and cost is at its minimum. This may be possible if we are talking about one activity. But in the panoramic view of project scheduling, with hundreds or thousands of activities spread over a year or several years, we should not focus on the local optimal (activity) solution but rather on global optimal (project) solution. The author believes that the solution of this model is possible using optimization techniques, provided that we start with an accurate assessment of multipliers. It will take several iterations because, in each iteration, activities' durations change when applying productivity multipliers. This will trigger shifts in the start and finish dates of succeeding activities, which may push them into different productivity multiplier zones, and so on.

After finding the “optimum” schedule, it is a good idea for the scheduler to conduct sensitivity analysis: If the project start is delayed or moved forward by one day or one unit of time, what would be the impact on the completion date and cost. Such analysis is important because it will help the project management assess different scenarios, including the possibility of change orders, weather delays, and other factors. It is like many of us who experiment with the optimum time to leave home in the morning and arrive at our workplace, consuming time. A delay of ten minutes in departure may mean 30 minutes late arrival.

As discussed earlier in this chapter, even though we tend to like completing projects with least duration and least cost, the user has to set the project's priorities: Time or cost. Then, the scheduler can optimize the schedule using one criterion (time or cost) as the primary objective function and the other criterion as the secondary objective function.

CHAPTER 8 EXERCISES

1. What does the term *accelerating a project* mean?
2. Why would a project manager (or a contractor) accelerate a project?
3. A project manager may shorten the duration of a project in many ways. Mention six of these ways. Discuss each briefly, mentioning its pros and cons.
4. The decision to accelerate a project may be made early, before the project starts, or in the middle of it. The timing may limit your options for accelerating the schedule. Discuss this statement. Mention any example that comes to mind.
5. Discuss the pros and cons of fast-tracking construction projects and using this concept as a means for accelerating projects.

6. Explain how accelerating a project works.
7. Would you advocate using overtime always, sometimes, or never? Explain your answer.
8. Give an example of accelerating a project by improving communications among the parties involved in the construction activities.
9. Your critical path is 128 days long. The next-longest path is 122 days long.
 - a. If you extend the longest path by 5 days, the entire project duration will increase by 5 days. True or false?
 - b. If you reduce the longest path by 5 days, the entire project duration will decrease by 5 days. True or false?
 - c. If you reduce the longest path by 10 days, the entire project duration will decrease by 10 days. True or false?
10. You are the project manager of a construction project. Your project is falling behind. You met with your team (including the scheduler) and discovered that accelerating the schedule to bring it back on track will cost you an additional \$20,000. Would you do it? (*Hint:* You do not know enough to give a definite answer.)
11. You are the scheduler for a large commercial building project. The schedule you prepared (based on feedback from the project manager) falls 15 days short of the owner's deadline. The project manager decides to write a memo to all subcontractors requiring them to work 6 days per week, 10 hours per day. You ask the project manager to wait till you determine the most efficient way to crash the project. Outline your argument to convince him to go with a certain accelerating plan that focuses on the critical path and not all activities.
12. In general, what is the effect of accelerating an activity on the direct costs of a project. Why?
13. What is the effect of accelerating an activity on the indirect costs of a project? Why?
14. In general, what happens to the total cost of a project when you start accelerating and keep accelerating till you reach the least possible duration?
15. Explain your answer to the previous question graphically. Make sure you show the points of normal duration (ND), normal cost (NC), least cost (LC), least-cost duration (LCD), crash duration (CD), and crash cost (CC).
16. Visit a construction site and meet with the project manager. Ask the project manager what it would take to reduce the project duration by 5 days. Try to quantify the extra cost and benefits for such acceleration. Ask the project manager about the means he or she would use to achieve such acceleration.
17. What is a *recovery schedule*?

18. Calculate the normal, least-cost, and crash durations for the following project. Calculate the cost associated with each duration. Indirect (overhead) costs are \$100 per day.

Activity	IPA	Duration (days)		Cost (\$)	
		Normal	Crash	Normal	Crash
A	—	7	5	500	640
B	A	6	5	550	630
C	A	8	5	800	935
D	B	10	7	1,200	1,440
E	B, C	6	4	600	700
F	C	4	3	500	590
G	D, F	4	2	700	1,000
H	E, F	7	4	650	950
I	G, H	2	2	300	300

19. Calculate the normal, least-cost, and crash durations for the following project. Calculate the cost associated with each duration. Indirect (overhead) costs are \$120 per day.

Activity	IPA	Duration (days)		Cost (\$)	
		Normal	Crash	Normal	Crash
A	—	5	4	770	900
B	—	3	2	660	700
C	A	7	4	800	1,070
D	A, B	4	3	1,000	1,110
E	B	6	4	800	920
F	C, D	6	5	560	630
G	D	5	3	700	810
H	F	8	4	1,000	1,260
I	E, G	4	3	500	580
J	H, I	3	2	400	600

20. Calculate the normal, least-cost, and crash durations for the following project. Calculate the cost associated with each duration. Indirect (overhead) costs are \$200 per day.

Activity	IPA	Duration (days)		Cost (\$)	
		Normal	Crash	Normal	Crash
A	—	1	1	800	800
B	A	7	4	1,000	1,600

C	A	6	4	300	500
D	A	3	2	400	800
E	B	3	1	100	200
F	B, C	7	5	500	800
G	D	8	4	1,200	1,400
H	E	7	6	350	600
I	F	5	3	700	850
J	F, G	3	2	500	1,000
K	H, I, J	5	4	450	800

21. When you accelerate projects by using a computer, what steps do you follow?
22. Using *ENR* magazine and other resources, prepare a case study on the Northridge earthquake and C. C. Meyers' project. Determine how the contractor achieved these results (mention them as itemized factors).
23. Arrange a meeting with a project manager and discuss the concept of optimum scheduling. In particular, discuss the choice of the starting point and whether the project could have benefited from shifting the starting point.
24. Pick a few types of materials and prepare a table with productivity and cost multipliers for your locale. You may need to consult contractors and materials suppliers.
25. Finishing the project early is always a reason for the contractor to be happy. Are there exceptions or precautions? Elaborate please.

Chapter 9

Reports and Presentations



Dubai Mall, Dubai, United Arab Emirates

Little John was excited about his new pair of pants, but they were a bit too long for him. He asked his oldest sister, Dorothy, "Would you please take 4 inches off my new pants?" "I would, but I have to go out now," she said. He asked his middle sister, Terry, "My beloved sister, would you please take 4 inches off my new pants?" With a sad smile, she replied, "I am so sorry I can't. I am too busy with house chores." He thought he would never ask his little sister, Lisa, but he had no choice. "I am really sorry, Johnny. I have tons of homework to do," she said. Little John went to bed, upset that he would not be able to wear his new pants to school the next day. Dorothy came back home early that evening. She wanted to surprise her little brother. She quietly went to his room and took the pants to her room. She was good at alterations. She altered them in no time and put them back in their place. Terry finished her house chores and still had some energy. "I feel so guilty letting my little brother down," she thought. Not knowing what her sister just did, she took 4 more inches off the pants. Lisa was sitting in her room doing homework and studying for an exam the next day. She was thinking of little John's disappointment at not being able to wear his new pants to school. Despite her not-so-friendly relationship with him, she closed her book and went to his room, took the new pants, and shortened them by yet 4 more inches. Next morning, the family was having an early breakfast when angry John came in with his new pants reaching barely below his knees and asked, "Who is the idiot who took a foot off my new pants?"

INTRODUCTION

Without a doubt, good communication is an essential component of the successful management effort. This means conveying the right (or proper) information to the right party at the right time and in the right form. Ten characteristics of good communication are as follows:

1. *Clarity*: The information must be clear to the receiving party. Ambiguous and subjective terms such as "as soon as possible," "good performance," and "the changes must be authorized by a responsible person in the architect's organization" must be avoided. Acronyms and abbreviations must not be used in the contract unless they are identified in the contract or they are standard in the industry. Future terms such as "tomorrow", "next Tuesday", or "four days later"; should be accompanied by a date. The speaker or writer must make sure the listener or reader understands exactly what is meant. Technical terms can be used only with people who have compatible technical background and can understand them.

Part of the clarity of communications is the clarity of title, especially when e-mail is used. E-mail has its own protocol and etiquette, however in this context, when a business e-mail is sent; it must have a clear title indicating the subject of the matter.

2. *Simplicity*: Simplicity helps improve understanding. If the information can be efficiently conveyed in one sentence, two sentences or a whole paragraph

should not be used. The contract may contain phrases written by lawyers that may not be easy for the layperson to understand. However, project team members should use simple language in their daily communications. Technical terms must be at the least common denominator.

3. *Accuracy*: Professional communications must be accurate, objective, and up to date. Personal opinion and subjective statements must be limited and clearly labeled so. For example, the project manager *may not* say “I don’t think the project is behind schedule although we have a negative float of 20 days on the critical path.” However, he may say “Despite the fact that the project is behind schedule by 20 days, I believe we can finish on time with a recovery plan.”

When quoting information such as prices and professional opinion, the quote has to be written with all relevant info mentioned (specific description, quantity, name of salesperson, date, length of validity of quote, etc.)

Information quoted out of the Internet may not always be accurate or reliable. It depends on the specific source that has to be always mentioned.

Communications have to be up to date in today’s business world. For example, “general conditions” of a company’s contracts may have been written years before and its technical specifications may have become obsolete.

Timeliness is also important in internal communications. Many issues have deadlines and/or are time critical. If such information is not received in a timely manner, it will lead to negative consequences.

4. *Preciseness and relevance to the subject*: Providing too much or irrelevant information may be confusing and counterproductive. An example of this is what the author of this book calls *lazy designer syndrome*: Some architects and engineers copy and paste information from the drawings and specifications of previous projects or boilerplates. Many sections, details, or paragraphs may not pertain to the current project. For instance, a contract may be written in New York or Chicago that has a clause about the frost line, which never applies in Miami or the Caribbean. Such information will only confuse and aggravate the contractor when he or she is trying to link it to the studied project. People who write contracts may do the same: use forms that belong to previous cases with many clauses that don’t relate to the present contract. This only adds more volume, wasted time, confusion, and frustration.

5. *Legibility*: Some people have handwriting that is illegible or difficult to read. Sometimes only a person’s secretary can read his or her handwriting. Such people should either type their communications using the computer or have someone in their staff type or write them. Legibility also includes “readability” whether on paper, on the computer screen, or on the projection screen. One of the frequent pitfalls for speakers using PowerPoint slides is cramming a slide with a lot of text that viewers cannot read.

6. *Proper support tools (pictures, tables, charts, statistics, etc.)*: The old saying “A picture is worth more than a thousand words” proves to be true when we perform a simple task like assembling a bookshelf. Not only are pictures more

helpful, but they are also unilingual: Anyone can understand them. Tables, flowcharts, bar charts, organizational charts, and so forth are also helpful in conveying information. Current e-mail systems allow users to attach files, pictures, audio or video clips, and so forth to activities in a schedule or to an issue in project management software. When sending a file by e-mail, you must be concerned with two issues (other than the possibility of virus-infected files): the size of the attachments and software compatibility. Some users send e-mails with huge attachments that may clog or slow the recipient's e-mail system. Also, some users send file attachments that are not compatible with the recipient's software and cannot be opened. Some file types (e.g., .doc, .xls, .ppt, .mdb, .txt, .rtf, .pdf, .jpg, .gif, .exe) are universal, and almost any computer user can open them. You should always check with the recipient when the file attachment size is large or when the file type is uncommon.

7. *Proper level of detail:* The communicator must balance the amount of information in an intelligent way. Giving insufficient information or information that is too abstract may not convey the whole picture clearly, in which case one of two situations results: either the information recipient must contact the source to clarify the information, which takes time and perhaps causes aggravation; or he or she must make assumptions to "fill in the blanks," which may lead to wrong conclusions. In contrast, providing too much information may overwhelm and confuse the receiving party. With a strict time limitation and the fact that we receive a multitude of mail, e-mail, fax, and telephone messages every day, we often discard information that does not seem important. The more concise the information, the better the chance it will be read. A message containing too much information may be overlooked, delayed, or trashed.¹ When communication must include a large amount of information, one good idea is to include an abstract or a brief summary paragraph on the issue (the downside is that the recipient may feel content to read only the summary and not read the details).
8. *Good organization and formality:* Good organization implies sorting and organizing the information so that it is easy for the viewer to read, follow, and retrieve. Formality means following the company's procedures, including the use of standard forms. It aims at facilitating reading, searching, storing, and retrieving the information. For example, when the chief estimator needs to find the amount of contingency one of his estimators assessed in an estimate (say in Excel format), he should know exactly where to find it. Such facilitation is important in large companies, especially those with high employee turnover rates. Several software packages, such as Primavera Contract Manager² (Primavera Systems, Inc., Bala Cynwyd, Pennsylvania), Prolog Manager

¹ An example of this is the contract for buying and financing a new car or for applying for a credit card. Contracts are often long and written in complex legal language. Most people sign such a contract without reading it.

² Formerly known as Expedition.

(Meridian Project Systems, Folsom, California), and Project Management (Timberline, Beaverton, Oregon), were developed to help organize project documentation and communications.

On a related subject, the author believes that much of the problem of “weak memory” that many people complain of, is rather a problem of “unorganized memory”. Lack of organization, in all aspects of life, results in wasted time, frustration, high stress, loss of business and profit, and even deterioration of human relations. It is a good idea for each person, particularly professionals, to be organized in every aspect of their lives.

9. *Conformance to industry standards:* As the world grows smaller, the industry is trying to find a common language. Many specifications were written years ago with descriptions of products and services no longer available or supported. The International Organization for Standardization (ISO)³ is a worldwide federation of national standards bodies, one from each of more than 140 countries. ISO is a nongovernmental organization that was established in 1947. ISO’s mission is to promote the development of standardization and related activities in the world with a view toward facilitating the international exchange of goods and services and toward developing cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO’s work results in international agreements that are published as international standards.

Another organization, the International Alliance for Interoperability (IAI), a nonprofit organization, was formed on a much smaller scale, for the interoperability of the different software programs in the construction industry. Its mission statement is as follows: “To develop a standard universal framework to enable and encourage information sharing and interoperability throughout all phases of the whole building life cycle” (for more information, visit <http://www.iai-na.org>).

Whether or not the construction or design firm follows ISO 9000, IAI, or other standards, it must make sure it conforms to the client’s specifications, the local codes, federal standards, other components of the project, and general industry guidelines. For example, U.S. companies that do international work often have to convert their measuring units to the metric system and convert the date convention month/day/year to world’s standard day/month/year.⁴

10. *Retrievable and transformable (from one form to another):* We are no longer in the age of basements full of boxes and file cabinets containing information on

³ The term *ISO* is not an acronym for the name of the organization; it is derived from the Greek *isos*, meaning “equal,” which is the root of the prefix *iso*-that occurs in a number of terms, such as *isometric*. For more details, go to <http://www.iso.ch/iso/en/ISOOnline.frontpage>.

⁴ A safe practice in this regard is to spell the month’s name, or at least the first three letters: 13 JUN 09, for example.

archived projects. Fortunately, we can store, on a single compact disc (CD) or similar media, more than an entire file cabinet can hold. Not only is this possible, but the ease of searching and retrieving is incomparable. Retrieving information for live (current) projects may be performed easily by using computer search commands. Retrieval also includes resurrecting information on closed-out projects that were archived, which may be important in some legal cases. One common practice these days is to store information on an Internet website so that it can be retrieved from anywhere. This can be done either by “renting” a memory space or storing the information on own website. Ownership of data is an important issue that must be addressed by users.

Transferring information from one program to another may not be as smooth as we would like. Information may get distorted or “chopped” when we go from one program to another or even from an old version to a new version of the same program. Although software vendors make claims about the compatibility of their products with Microsoft (MS) Project, Primavera, and other products, glitches and discrepancies should always be expected. The problem may not be in the compatibility per se but in the different functions of and terminology used in the two programs. For example, Primavera products allow combination relationships (start to start plus finish to finish). MS Project limits logic relationship between two activities to only one. So, if you transfer a project from Primavera P3/P6 format to MS Project format, some relationships may be dropped. In addition, products are frequently updated, so their compatibility may not remain intact. You must be careful with any transformation.

The ability to convert and open electronic files and to read the information is extremely important. For this reason, the author advises against using unknown software packages unless you are certain that such products communicate with more common products without problems.

THE DIFFERENCE BETWEEN REPORTS AND PRESENTATIONS

Although reports and presentations are both types of communications that aim at conveying information, one major difference exists between them. The printed materials of a report are the only vehicle for conveying information between the person preparing the report and the person receiving it. For this reason, it should be clear and complete. In contrast, presentations focus on speakers’ persuasive skills, although a printed report (partial or complete, detailed or summarized) is sometimes provided to the audience. The speaker focuses on certain points, using oral, visual, and written or printed tools. In addition, audiences usually have the opportunity to ask the speaker to elaborate on or to explain any point that is unclear to them.

Presentations are used for a variety of purposes, both within an organization and for outside parties. They may carry a lot of weight in influencing the audience’s decision to buy a product or service. Four types of presentations are as follows:

1. *Contract candidate presentations:* Many owners require a presentation as part of the selection process for design, construction, or construction management professionals. The main focus of the presentation is to convince the owner (or the decision maker) that the presenter not only can do the job but also can do it better than other candidates can. This type of presentation should simply answer the owner's explicit or implicit question: "Why should I (we) hire you?" In many cases, contractors and consultants win contracts from owners with the help of a brilliant presentation, even though they may not be the lowest bidders.
2. *Sales and demonstration presentations:* A representative of a manufacturer or vendor may give a presentation to demonstrate a product (e.g., computer software, an office machine, specialized equipment).
3. *Project status presentations:* A project manager or a team member may give a presentation to upper management on a particular project and its status. Such presentations may be conducted both periodically and on an as-needed basis.
4. *Management presentations:* The management of a company may conduct a presentation to its staff to inform them about a new work plan, a new system, a new organization, or something else.

A sales presentation and an educational presentation are significantly different, although they have several characteristics in common. The first two types of presentations just described are mostly the sales type, even though they may have some educational content. A presentation on computer software does not aim at teaching its use to the audience. Rather, such a presentation focuses on the features and points of strength in the software. It attempts to impress rather than educate. It can be biased and subjective for the purpose of making a successful sale. The latter two types of presentations are mostly educational. Their objective is to inform the audience of a certain situation. We can argue that they are also "sales" presentations. In project status presentations, the project manager may try to impress the management for self-promotion purposes. In management presentations, the management is "selling" a new work plan or new system to the employees. Still, the main difference is that the last two types do not usually lead to a direct sale.

Another key difference between presentations and reports is the time constraint. Reports are submitted to a party who can read and review them at his or her own pace (within deadline restrictions). Presentations are time constrained. The information flows at the presenter's pace (within time-limit restrictions), not the receiver's. A large amount of information could be included in the presentation, but the presenter's challenge is to prioritize this information and focus on important issues that have more influence on the audience, particularly the decision maker. In many cases, the presenter refers the audience to a detailed report (which may be available with the presentation) or to an external source (e.g., an Internet Web site or an article in a journal or magazine).

Scientific seminars and short courses are not relevant to this discussion although they are still subject to "good communications criteria." Thus, they are not covered.

SKILLS NECESSARY FOR GIVING GOOD PRESENTATIONS

In addition to learning the characteristics of good communications described previously, presenters should develop seven skills for giving good presentations:

1. *Focus on the client's needs:* The presenter should present his or her product or service in the best way that serves the client (audience). The product or service may have great features that are not relevant to the client's line of work. Elaborating on such features would be a waste of time. The presenter's main focus must be on how to meet the client's needs.
2. *Be honest:* Even though the presenter's ultimate goal—in most cases—is to sell a product or service, he or she should be honest and objective at all times, especially with regard to facts and numbers. For instance, making a statement such as “Our product is the best on the market” is easy to do, but backing up this statement with numbers, such as the sales volume, the number of clients served, and the results of a customer satisfaction poll, would make a better statement. It may be difficult on the salesperson but ethically required to admit to the client that his or her product does not meet the client's needs or that there is another product in the market that meets those needs better.
3. *Ensure that materials are visible:* The presenter must make sure the materials displayed on the screen are comfortably viewable and legible from all sides of the room. If possible, the presenter should test the display from several positions in the room before the presentation. During the presentation, the presenter should stand in a position not blocking the audience's line of sight.
4. *Speak clearly:* The presenter should speak clearly and with authority, occasionally interacting with the audience and sometimes using humor.
5. *Make eye contact:* The presenter should speak to the audience and not to him- or herself or to his or her notes. Eye contact with the audience is extremely important. Eye contact should be made with not just those in the front row or closest to the presenter but with everyone in the audience.
6. *Watch your body language:* Body language and hand and arm gestures are important. General advice on this topic and special advice about body language in certain cultures can be found in the many articles and books written on this subject.
7. *Manage time wisely:* Presentations almost always have time limits. Besides, human beings have limited attention span. It is easy to be side-tracked and lose track of time. A good presenter sets “milestones” for him/herself. For example, when he/she reaches half-time, the presentation must have reached a certain point or slide. Putting a little clock on the podium—preferably unseen to the audience—may be a good idea (but should not be a distraction to the speaker).
8. *Have a backup plan:* Some precautions should be taken in case something goes wrong. Items to have on hand include an electric extension cord, a signal

cord, an electronic copy of the presentation on a USB flash drive, electrical adaptor, and a printout of the presentation. If the presenter is not using his or her personal computer, he or she must make sure the necessary software (e.g., Microsoft PowerPoint) is installed on the computer that will be used. It is important to test everything early enough before the presentation.

In addition to the preceding, there are many hints on how to improve the PowerPoint presentation and/or handouts. Such hints plus more hints on good speaking/good presentations can be found in specialized references. The author recommends Toastmasters International⁵ for those who would like to improve their speaking skills and self-confidence.

THE POWER OF PRESENTATION

Current technology gives us powerful tools with which to create, manage, manipulate, present, disseminate, and store data. When producing reports or presentations, we typically have many options for organizing and displaying information. Any cost estimating, scheduling, project management, or other software has tens if not hundreds of standard reports. Users can also create and customize their own reports. Third-party software packages can provide even more reporting templates. Each report has its own settings, rules, and options. Many features in these reports can be adjusted or turned on and off. Many users use these reports “as is,” without paying careful attention to the default settings and consequently the output.

To create a good report, we should ask ourselves the following questions:

- Does the report include all the information the report user needs?
- Does it include any unneeded information?
- Is the information clear and well organized?
- Is the information presented in the required format?
- Can the look of the report be enhanced?

The report must address the specific needs of the party receiving it. For example, if the report is for an upper-level manager who is responsible for tens or hundreds of projects, it should be brief and precise, containing a powerful summary that is not overly detailed. If the manager needs more information, he or she may request more details on a specific topic.

A progress payment report may not need to show bar charts or technical details such as total float, constraints, and so forth. Likewise, a report issued by the general contractor to one of his or her subcontractors may not show details of other

⁵ Toastmasters International is a nonprofit organization that was established in 1924 to train people to have better communications and leadership skills. It has local clubs in almost every U.S. city and in many other locations worldwide. For more information about this organization, visit <http://www.toastmasters.org/>.

subcontractors' activities that will not affect this subcontractor's work. The general contractor may not want to reveal the total float to subcontractors and, similarly, may not want to reveal certain information, such as the **actual cost**, when presenting a report to the owner.

The report should focus on one main issue or area. For example, the **look-ahead schedule** shows the contractor what is supposed to happen in the next 2 weeks or month. Selecting activities with a total float of less than 3 days, for example, allows the contractor to focus on the critical path. When the project is large, it is divided into several areas, departments, or phases. The scheduler can then produce reports that cover a relatively small group of activities, grouped by building, floor, phase, and so forth; one group at a time. In some reports, the scheduler can show all areas, departments, and the like, summarized by a single bar per code. Use of software filters⁶ and the organize function helps in choosing, sorting, and grouping activities efficiently.

Information comprises text and graphics. Graphics are an excellent tool if used properly. Graphics include bar charts, logic diagrams, flowcharts, pictures, video clips, and other items. Graphics are best used to support a result, a finding, or a recommendation or to just explain a situation (e.g., a bar chart for a project schedule). However, overuse or misuse of graphics may be counterproductive. Text should also be organized. Using tables, bullets, and short paragraphs helps the report reader separate and focus on specific issues.

Careful use of vivid colors can help the report user understand the report more easily. For example, red is customarily used for critical activities. Bars representing completed or underway activities should be clearly identified. Black-and-white graphic reports may not be as powerful as color reports, even with varying grades of shading and/or patterns.

The size of report pages may be specified by the owner (the party to receive the report). Many schedulers print the schedule on regular letter-size 8½-by-11-inch paper, which will fit in a folder or binder with other project documents. It is also a customary practice to print the schedule on 11-by-17-inch paper, then fold it to fit like 8½-by-11 size. However, project managers like to print a complete schedule on a large piece of paper (size D or E) and post it on the wall inside the project trailer. Regular inkjet and laser printers can handle paper as large as 11 inches by 17 inches. Plotters can handle larger sizes of paper.

Any report—text or graphic—should contain the following information:

- Name of the company and department or division; address of the company, especially if multiple offices; company logo
- Name of the person preparing the report and supervisor's approval (initials), if needed
- Name and location of the project

⁶A *filter* is a function in some computer scheduling programs, such as Primavera products. Its main function is to pick certain activities on the basis of specified criteria.

- Date
- Title of the report
- Attachments, if any
- Page numbering (if multiple pages) in a format such as “Page 2/6” so that missing pages can be replaced where they belong
- Legends to explain any graphics and colors in graphic reports
- Definitions of terms and acronyms or abbreviations that may not be known

In some cases, hiring a professional to prepare a report makes sense if the company does not have the expertise or time to produce a high-quality professional report. Always remember:

- The human being behind the computer is more important in making judgment than the computer itself. The computer (including software and printer) is a wonderful tool, but it is still a tool.
- In reports, there is no “one size fits all.” Reports must be made different for different parties in different occasions.

REVIEWING REPORTS BEFORE AND AFTER PRINTING

Since reports often comprise many pages and color printers may be slow, a report should be reviewed on the computer screen (Print Preview) to make sure that it looks fine. If the report comprises many pages, the author recommends printing a sample page: review and approve it, then print the entire report. Remember that, in many cases, what you see on the computer screen may not be what you get.

An error may occur in any report. It may be caused by the software, the hardware (computer or printer), or the user. Thus, the scheduler should be sure to review the report after printing it but *before* submitting it because errors may be found in a report even after it has been successfully reviewed on the computer screen. Many printers in professional offices are shared, and people may pick up their printouts only to discover later on that the printout contains pages that don't belong to it. Some companies with multiple offices enable employees to send printouts to any printer, in any of their offices. This is a great convenience; however, the software usually retains the last used printer as the default one till the application is turned off. So the user may want to print another report and then hit the print icon (or button) thinking that the report will go to the original default printer around the corner. Instead, the report goes to a printer in another office!

GENERAL TIPS ON PRINTING REPORTS

In many cases, the scheduler must repeat the printing process several times because of errors, missing data, or instructions from supervisor or other clients. The result is

multiple printouts of the same report. Although some reports indicate the time and date the report was printed, the scheduler may become confused by the similar printouts and submit an incorrect copy of the report. For this reason, invalid copies of any report should be destroyed or recycled as soon as an error or omission is detected and the decision to reprint is made.

For some projects, certain reports must be printed with every update. Primavera software gives the user the opportunity to combine all these reports in a “series.” In this case, the scheduler chooses one series rather than several individual reports.

While organizing the report, the person preparing the report may want to separate issues, areas, phases, and so forth, and perhaps print each on a page. However, the scheduler must be careful not to waste paper unnecessarily. Several ways to condense a report and save paper are as follows:

- Make sure that only the needed activities and information are included. Use the software filter to help exclude unwanted information.
- Margins may be slightly reduced to allow more information per page.
- The choice between Portrait and Landscape may make a difference as to how many pages the report comprises.
- Using a smaller or a different (narrower) font may help. However, make sure the report is comfortably legible.
- Use the Fit to One Page function in the Print menu (doesn’t always give good results)
- In limited cases, you may print on both sides of the paper.
- Most importantly, many reports and other types of communications may remain in electronic form and need not be printed. The most common format across organization is the PDF (Adobe Acrobat) format. A report in PDF format may be produced directly by the software in this format, or can be converted through other software.

SUMMARY REPORTS

The scheduler must relate the schedule information to the project manager not only as computer-generated colorful charts but in clear language as well. For example, after a periodic update, the scheduler will likely produce standard Primavera or MS Project reports, including bar charts, cost tables, and so forth. Along with the reports, a document (written in plain text) summarizing the situation should be included. This summary report should contain the following information:

- The overall situation of the project: the total float for the critical path and the updated expected completion date.
- The preceding information as compared with that in the last update: Did we gain or lose any days?

- The new critical path, if it changed: what is delaying the project?
- Cost information (if applicable): cost this period, cost to date, cost to complete, cost variance, cost at completion, and forecast cost variance.
- Any other information that may help the project manager identify or anticipate trouble spots or make up for any lost time. Also, any suggestion to resolve troubled situations.
- No unnecessary details, such as routine progress per activity or a slight delay in activities that have sufficient float.

The summary report should not exceed one page or two pages. It should be written in the form of a memorandum as a simple word-processed document.

PAPER OR ELECTRONIC REPORTS?

Computers have become an essential part of our lives and businesses, including project management. Many documents are now sent electronically. Electronic signatures are even legally accepted in many situations. Nevertheless, some documents still must be printed on paper. Either way, the contractor, the design professional, the construction management consultant, and the owner must be able to store, manage, and retrieve information efficiently. The software industry has developed several software packages for this purpose, such as Primavera Contract Manager, Meridian's Prolog Manager, and Timberline's Project Management. This software helps organize the "paper-work": transmittals, submittals, purchase orders, payment requisitions, telephone logs, RFIs (requests for information), **requests for proposals (RFPs)**, proposals, change orders, memos, invoices, notices, general correspondence, meeting minutes, daily reports, and any other document that relates to the project management. Such software also helps speed up the communications, including the review and approval processes. There are also many document management software programs that go beyond the objective and capabilities of these mentioned earlier. Such software packages are becoming more and more powerful:

- They are continuously being expanded and more modules are being added to them to circumvent all facets of project management.
- They can be integrated with other programs (CAD, BIM, estimating, accounting, scheduling, etc.).
- They include many standard forms, including some third-party forms.
- They allow the user to tap into the software through their SDKs (software development kits) and to customize certain aspects or to export data.
- They allow project team members to go on the Web (Internet and intranet) and view and respond to documents from anywhere.
- They can be linked to external devices such as palmtops (PDAs), tablets, and BlackBerrys.

Users of electronic media should follow certain precautions, such as the following eight:

1. Back up your documents periodically. If you are on a local server and are using the shared drive, be sure to back up your documents regularly. Keeping a backup copy in a place away from the company's building is also a good idea. Doing so is a precaution against fires, floods, hurricanes, theft, and other events that can destroy the records. Having all the information in one local location only, such as the scheduler's notebook computer, is dangerous and unwise.
2. Programs such as Primavera P3 and P6 either have no undo function (P3) or limited "undo" (P6). There is no "save as" function. Whatever you do will likely be permanent and cannot be reversed. For this reason, if you want to experiment with some "what-if" scenarios, make a copy of the schedule and leave the original intact. Once you finish experimenting, move, delete, or archive the file so it does not get mixed up with other files.
3. When the e-mail system is used for communication, print important e-mail messages or transfer them from the inbox to a secured folder or box that is out of the e-mail system. Most e-mail systems automatically "clean up" the inbox periodically (e.g., every 6 or 12 months).
4. For projects that require periodic updating, always make a copy of the schedule before updating. The names of the schedules must follow a pattern that represents the company's policy. The old Primavera P3 allowed only four characters for a file name. One good practice was to use two alpha characters to identify the project and two numerical characters to indicate the number of the update (starting with the baseline, 00). Primavera P6 and MS Project do not have this limitation and allow almost as many characters as the user desires. However, the scheduler must still choose a pattern for naming project schedule files and be consistent with it. All versions of a project schedule should be stored in an organized and systematic way. An example follows:

When limited to four characters (P3):

```
C:\Schedules\Tampa\OfficeBuilding\OB00  
..... \OB01  
..... \OB02  
.....  
C:\Schedules\Orlando\SmithBuilding\SB00  
..... \SB01  
..... \SB02  
.....
```

When not limited to four characters (P6 or MS Project):

C:\Schedules\Tampa\ShoppingCenter\TpaOfficeBldg00
..... \TpaOfficeBldg01
..... \TpaOfficeBldg02
.....
C:\Schedules\Orlando\CityGarage\OrlandoCityGarage00
..... \OrlandoCityGarage01
..... \OrlandoCityGarage02
.....

5. When making a copy of the schedule (or any project-related file) on a CD or DVD, label or identify the disk with the project name, version, and date. Don't store any unlabeled CD's/DVD's loaded with data.
6. Some users of simple programs such as word processors and spreadsheets "insert" the date format rather than typing the date itself. For example, MS Word has an Update Automatically option that can be turned on or off. Serious problems may result if this option is unintentionally turned on. The document may have originally been created on OCT 15, 2008, but the project manager needs a copy of the document on DEC 16, 2008. The date that would appear on the document would be DEC 16, 2008, not the original date, OCT 15, 2008. Note that other software options many users do not usually pay attention to, may also result in unintended consequences.
7. It has been said that your hard drive is like your garage: no matter how large, it will soon be full of junk. For this reason, completed projects should be archived. Thanks to new technology, what formerly occupied several file cabinets can now be stored on a single CD or DVD. Because of the fragility of CDs and other electronic media, however, making duplicate CDs or other electronic media and storing them in different locations may be wise. Make sure the CDs are labeled properly. Having another copy stored on an Internet website is also a good idea.
8. Only professionals should be in charge of company technology. Computer viruses and hackers often cause serious damage. An overlooked or a careless action by an employee may cause the computer system in a company to shut down for a period or may erase important files, which may result in huge losses and inconvenience. For this reason, large companies usually dedicate a department to taking care of information technology (IT) and safeguarding electronic correspondence.

E-REPORTS

Reports can be e-mailed, but the sender must make sure the receiver has the proper software with which to open them. Many computer programs offer the Save As option with several format options. Some of the format that have become popular are the

HTML and PDF format, which allows any user to view the report. Several Primavera products call this option the *Publish* function. When the e-report has multiple files, the sender may want to “zip” them into one compressed, self-extracting file. The receiver may want to create a temporary folder in which to download the Zip file, and then extract it there. Large attachments should not be sent unless the receiver approves such an action. Large files can be uploaded to an FTP site, and then the FTP address should be sent, along with the user name and password, to the receiver, who can later download them. When sending several documents/reports, the sender should include a table of contents with a brief description of each report and then identify each report.

COMMUNICATIONS IN THE INTERNATIONAL ENVIRONMENT

Technology has rendered the world smaller. Not only can project participants (owner, architect, structural engineer, mechanical engineer, general contractor, etc.) be located in different regions or countries, but also many companies now have a diversified workforce. Thus, making a mistake as a result of lack of knowledge about a local culture and work environment is easy, and possibly embarrassing and costly.

Many books and articles have been written and many seminars have been conducted on this subject. We cover only some scheduling-related issues:

1. In most countries, the date is written in the day/month/year format rather than in the customary U.S. date format of month/day/year. A date such as 11/8/2010 can cause a crisis if it is meant as the 11th day of August but is interpreted as the 8th day of November. For international projects, writing the name of the month, rather than its number, is recommended. The previous date can then be written as 11 August 2010. Alternatively, the month may be abbreviated by three letters, such as 11 AUG 2010.
2. Most of the Western world starts the workweek on Monday and takes Saturday and Sunday off as nonworkdays (weekend). This is not necessarily the case in other parts of the world such as the Middle and Far East. The weekend could be Thursday and Friday or Friday and Saturday. Thus, software defaults must be checked and adjusted accordingly.
3. Holidays differ from one country to another. They may have to be inserted as nonworkdays in the schedule. Even Christmas is not observed on December 25th in all Christian countries. Some (Orthodox) celebrate it on a different date, January 7.
4. In the daily work schedule, the number of workdays (5 or 6), start time, finish time, lunch break, “siesta time,” and other breaks may also differ. In some countries with extreme hot summer, government regulation forbids outdoor work during certain hours of the day. Thus, productivity, and hence activity durations, may have to be recalculated.
5. Weather can have a significant impact on the schedule. The project management team must be fully aware of local weather, including seasonal floods, hurricanes, sandstorms, rain, and so forth.

6. The labor market and customs also differ from one place to another. In some countries, most of the skilled labor needed in construction projects is imported. In such countries, it is not unusual to see workers from different backgrounds (ethnicities, religions, cultures) working together. In some cases, workers on the same project do not speak a common language and communications become a challenge to management.
7. Availability and methods of acquisition and delivery of materials and equipment may differ significantly. In some countries, rigid or slow customs procedures may cause major delays.
8. Permits and government procedures for approval may also differ and may require special consideration.
9. Contracts also differ. Even though there are some internationally known and used forms (e.g. FIDIC), but certain provisions and practices differ. For example, in some countries a percentage (10–20%) of the total contract is paid to the contractor upfront, and then recovered gradually by deducting the same percentage out of progress payments. Retainage (also called retention) rules may also differ. Types, definitions, provisions, and cost of bonds and insurance also differ from one region or country to another.
10. Communication among different cultures, even those using the same language, may result in misunderstandings. For example, in the U.K. scheduling is referred to as “programming” with the schedule called “programme.” The same word may have two meanings to two people. There is a big discussion on what is conceptual design, preliminary design, schematic design, and design development.
Body language and hand gestures may have different—and possibly obscene—meanings in different cultures. In fact, a person may unintentionally insult another person because of a misunderstanding or a language or cultural difference.
11. Currency exchanges may create a nightmare for management. In some international contracts, the budget may be set in U.S. dollars but the materials and labor are paid in local currency. The exchange rate may differ from day to day. It is not uncommon for the same contract to include two currencies at the same time. The management team must deal with such situations carefully.

CHAPTER 9 EXERCISES

1. List the characteristics of good communications. Briefly explain each.
2. Why do you think communication is an important issue? Can you mention a situation in which the lack of good communication resulted in negative consequences?
3. What is the *lazy designer syndrome*?

4. You are a new scheduler for a medium-size project. You joined the company after the project started. The project manager asks you to prepare a report that tells him “everything about the schedule.” Does this statement provide sufficient instructions for you to create the report? If not, list the questions you will ask the project manager so that you will know exactly what you need to print out.
5. You were hired by a company that does not have a formal policy for managing schedule files. Schedules are currently on the project managers’ laptops (created with SureTrak Project Manager software). What precautions do you recommend to ensure the uniformity and security of the schedules?
6. Mention and briefly describe the various types of presentations.
7. What are the major differences between reports and presentations?
8. Indicate which type of presentation is required for each of the following situations.
 - a. The owner of a large project has a short list of three contractors. They all seem qualified but the owner wants each contractor to present the way he or she will build the project so the best contractor can be chosen.
 - b. Primavera and Meridian are competing on a bid to provide project management software to a local government. Each provider will be given a 2-hour time slot in which to show the advantages of his or her software. Following this, the government will make its choice.
 - c. The government in exercise b chose the software. Now, it hires a consultant to teach the use of the software to its employees.
 - d. A large company changes its medical insurance provider. As a result, many terms of the insurance have changed. Linda, a human resources manager, will give a presentation explaining the new terms and procedures of the new medical insurance.
 - e. A construction company is in financial trouble. A new president was appointed by the board of trustees. He lays out a recovery plan for the company. He will present this plan to the employees.
 - f. Before the new president presents his plan in exercise e, he requires each project manager to give a presentation on the status of his or her projects to the upper management members.
 - g. A large company is hiring a chief estimator. There are three top candidates. As part of the interview process, each candidate must give a presentation simulating the estimation of a real project.
9. List some tips for giving a successful presentation.
10. “The report must focus on certain issues.” Discuss this statement and mention some helpful tips.

11. In addition to the main data in the report, what type of information should a report contain?
12. Why is it important to review a report before and after printing it?
13. Provide some tips on saving paper when you are printing reports.
14. You are the scheduler for a shopping center project. You just finished an update on many activities occurring in the project. You printed the updated bar chart and cost tables, but you missed something important before submitting the report to the project manager. What was it? What kind of information must you include?
15. Your company is trying to “go electronic.” It just bought new computers and a new server. You are given the task of writing a set of instructions for all project managers and their personnel on the procedures for storing and managing the projects. Outline your plan.
16. In the previous exercise, since you are the only “computer guru” in the company, you are also given responsibility for the company’s information technology. Outline your plan to back up and secure the company’s files.
17. Mention some tips for a project manager who will be taking over a new project in the Middle East. Bear in mind, this is the manager’s first trip overseas.
18. Can you mention any situation in which not understanding a particular language or culture resulted in an embarrassment or a loss to a company? This experience does not need to be personal. You may use any real story.

Chapter **10**

Scheduling as Part of the Project Management Effort



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INTRODUCTION

Construction project management comprises several components that are often interrelated. Typically, one person (the project manager, or PM for short) is responsible for running and managing the overall operations. Under the PM is the project management team, which may consist of a large number of professionals (assistant PM, project superintendent, project engineer, scheduler, estimator, quality manager, safety manager, procurement manager, document control manager, contract administrator, accountant, clerk, secretary, etc.) for large projects. Small projects typically have a smaller team, and some of the team members may be playing more than one role and/or working on multiple projects.

The management team typically includes field and office personnel. It may include team members who are dedicated exclusively to a particular project and others who are assigned to the project part time (they work on other projects as well) or serve on the project for only a temporary period. For example, a project scheduler may be dedicated to one large project even if he or she works in the main office. For smaller projects, the scheduler may distribute his or her time among assignments for the different projects.

Managing projects requires several skills. We must distinguish between managerial skills and technical skills. In some cases, a person who is top notch in his or her technical field may fail completely as a manager. Managerial skills are essential for a PM. An interesting statement is found in *Commentary on AIA Document A201-2007* (The American Institute of Architects 1999, p. 14, <http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aias076835.pdf>): “A superintendent cannot build a project alone, but an incompetent superintendent can single-handedly ruin one.” This statement applies even more so to the PM. It is outside the scope of this book to discuss the characteristics of a good project manager. As far as technical expertise, construction is a diverse industry. Within each type of construction are many specialties, such as demolition, excavation, concrete, masonry, carpentry, structural steel, finishes, electrical, HVAC (heating, ventilation, and air-conditioning), plumbing, and many others. Within each specialty might be numerous subspecialties. Rarely, if ever, is a person an expert in all fields. A typical PM may be an expert in one or a few fields, but he or she must be familiar with all of them to manage the project competently.¹ Each technical area is usually headed by a foreman, who must be an expert in that particular field.

Scheduling is one of the important pieces of the “project pie.” It is a technical field concerned with time calculation and management. Scheduling interrelates with other components of the overall project management. In this chapter, we briefly discuss some of these interrelationships.

SCHEDULING AND ESTIMATING

Scheduling and estimating are closely related, and their relationship is probably one of the most important relationships in project management. They both make prediction

¹ PM's expertise is generally described as “inch deep, mile wide”

on future consumption: money for estimating and time for scheduling. They both keep updating and adjusting their estimate during the execution of the project, making every attempt to get the project completed within the estimate amount: money and time. These two areas intersect in many ways, such as the following eight:

1. The estimator needs to know how long the project will last in order to estimate certain costs, particularly overhead (management team, field office, utilities, etc.).
2. Estimating and scheduling departments collaborate to provide information to the procurement department. The estimating department tells what resources are needed and how much, and the scheduling department tells when they will be needed. This facilitates the procurement of labor, materials, and equipment.²
3. The scheduler sometimes estimates the durations of activities with help from the estimating department, since estimators usually keep track of crews' productivities.
4. Many schedules are cost-loaded. The cost must be imported (manually or electronically) from the cost estimate.
5. Earned value management, discussed in chapter 7 as part of project control, is an integrated approach to project cost and schedule control.
6. **Progress payments** depend on the schedule of values (prepared by the estimator) and the percent complete (prepared by the scheduler³).
7. Resource allocation and resource leveling are cost-related, although they are scheduling issues.
8. Schedule compression always involves a balance between cost and time.

Both cost estimating and scheduling require breaking down the project into little elements (activities, tasks, items, etc.) that are managed and controlled easily (usually homogeneous; measured with one unit). However, the cost estimator and the scheduler may think differently in this breakdown. The cost estimator usually divides the project into items according to their nature with no regard to the location or chronology. So, 2-by-4 wood studs, can be combined in one item even though they may be installed in different locations and with different timing. The scheduler's attitude toward the project breakdown is focused on the timing and location of the work item, not its homogeneity. For example, many schedulers combine the formwork, rebar, and concrete placement for a reinforced concrete item (e.g., suspended slab) as "FRP Suspended Slab" even though formwork is measured by area (or contact

²The project schedule might have an impact not only on the procurement schedule but also on the estimate because the timing may affect the cost of labor, materials, and equipment.

³Percent complete is initially reported by the field crews (foremen) but collected and formalized by the scheduler.

area, to be precise), reinforcement is measured by weight, and concrete mix and placement is measured by volume. There might be also concrete finishing with them, which is measured by area.

Many construction and software professionals have suggested one project breakdown for both cost estimating and scheduling, and some of them have claimed success. Still, this matter is far from being settled.

Other interrelationships exist between estimating and scheduling, as is shown in the following sections.

Evolution of a Cost Estimate and a Schedule for a Project

When a contractor considers a project for bidding or negotiation, he or she needs to know the cost and the timeframe.⁴ Owners usually specify the required finish date of a project in the bid documents and the contract. However, the contractor must calculate his or her own estimate of the project's duration to ensure that he or she can meet the owner's stipulated finish date. If the contractor's schedule does not meet the owner's date, the contractor must either accelerate (crash/compress) the project to fit it within the given time interval or obtain the owner's approval to extend the time limit on the project.

Depending on the size and type of the project, as well as the contractual arrangement, the contractor may start with a rough estimate of the schedule (not necessarily a critical path method, or CPM, schedule, but an educated estimate of the time required to build the project). The contractor may use his or her previous experience and a "gut feeling" to estimate the duration of the major components of the project and build an initial schedule. After the contractor lays out an initial rough schedule, he or she uses the duration to estimate the indirect cost items (overhead), such as the following:

- Project staff (PM, project superintendent, project engineer, receptionist or secretary, clerk, etc.)
- Office trailer
- Cars and trucks assigned to the project team
- Office equipment (copying machine, fax machine, computers, etc.)
- Temporary utilities (electricity, water, drinking water and ice, telephones, cell phones, gas, portable toilets, etc.)
- Other indirect project-related expenses

The cost of most, if not all, of these items is linearly proportional to time, although not all of them last for the entire duration of the project. This is why the estimator needs to know the duration of the project to assess the indirect expenses. The

⁴ *Timeframe* does not mean only the duration. It includes the time span during which the project will occur. For example, a project scheduled to occur during a winter season in Chicago will probably cost more than if it were built in the summer.

contractor also uses the timeframe of the proposed project to study the impact on other work underway or planned and the resources required.

Schedules, like cost estimates, are created on the basis of available information. Reality (what will actually happen) is never fully known in advance. Thus, every cost estimate or schedule includes some assumptions and guessed information. A difference exists, though, between a situation in which 90% of the information is known and 10% is assumed, and a situation in which 20% of the information is known and 80% is assumed. Estimators use one major criterion to differentiate, in principle, between approximate estimates and detailed estimates. Detailed estimates are obtained by performing quantity takeoffs from the design drawings and using the specifications. These detailed quantities are then multiplied by unit prices set by the estimator. Indirect expenses are added to the calculated direct expenses to yield the grand total.

In contrast, approximate estimates are based on comparing the project under consideration with previous similar projects (applying unit cost such as \$140/SF), then making adjustments according to the size, quality, location, timing, and so forth. No work breakdown or quantity takeoff is used in approximate estimates. The common factor between the two methodologies is that we start with the known information, which is supposed to be the majority for detailed estimates, then complement it with assumptions for the unknown. With detailed estimates, we can look at the estimate and identify the cost of one particular item, such as a window, paint, or even a single footing. With approximate estimates, such identification is generally not possible.

In scheduling, no such clear distinction exists between a “rough schedule” and a “detailed schedule,” but the process is similar to that for cost estimating. We start with the known information and complement it with assumptions. One frequent practice of designers is to show a construction activity as one bar without details. Once a contractor is chosen, he or she will submit a detailed construction schedule that should fit within the time frame of that single bar. This detailed schedule is then integrated into the original schedule created by the designer and replaces the single construction activity.

Summary schedules may also be used for quickness, rather than a lack of detailed information. This approach is not generally used, and such schedules may not be used for field implementation or project control. This approach is also similar to using approximate cost estimates when the contractor needs to give the potential client a ballpark cost estimate of the project without spending much time studying the design drawings and specifications.

When the design is finalized, performing detailed cost estimating and scheduling makes sense. This practice is used in the traditional delivery method, in which the project is completely designed, and then a contractor is selected through the process of bidding or negotiation. In other delivery methods, a contractor may be selected⁵

⁵ In some contractual arrangements, there is no prime or general contractor. Instead, subcontractors may contract directly with the owner (e.g., CM Agency which is CM not-at-risk) or with the construction management professional (e.g., CM at-risk).

before the design is completed or even started, such as in design-build (D/B) or pure agency construction management (Pure CM or CM Agency) delivery methods. In this case, the design may come in stages, called **design development (DD)**. Each stage specifies a completed percentage of the design. For example, if the design is called *DD30*, it is about 30% complete. In this case, when the contractor estimates the cost and duration of the project, he or she must use the available design information, and then supplement it with assumptions. Doing so is exactly like solving a 100-piece puzzle with 30 given pieces and the rest imagined. Later, the designer provides a more detailed design (e.g., DD60, DD90, etc.). The design is still incomplete but contains more information than in the previous stage. The contractor refines the cost estimate and schedule by replacing some assumptions with new design information. If the project schedule changes, the cost estimate may be affected. If the scope changes, both the cost estimate and the schedule may change. This process continues until the final design is issued. The final design⁶ will be the base for the contractor's final cost estimate and schedule.

Estimate-Generated Schedules

Some cost-estimating software packages can export information such as project breakdown to scheduling programs or to a plain spreadsheet. In most of these cases, the result is a list of activities along with their durations but without any logical links (relationships). Before we discuss the **estimate-generated schedule**, let us briefly discuss how information is generated in cost-estimating programs. In short, with regard to labor and equipment costs, two methods for building the cost-estimate database items are used:

1. Provide the labor and equipment cost per unit. For example, if we are placing concrete for columns, using a pump, the cost is \$25.18 per CY (cubic yard) for labor and \$8.88 per CY for equipment. Although there is a basis for how we derived these numbers, the database does not contain this basis or any details about how we generated these numbers.
2. For the same item, suppose that we are using Crew C-20,⁷ and this crew can place 90 CY per day. The crew cost is usually listed as part of the resource information in the database and not for each item. In our case, Crew C-20 comprises the following:

⁶In the traditional delivery method, the final design is called the *construction document* and becomes part of the contract.

⁷This example was taken from *R. S. Means Building Construction Cost Data* (R. S. Means 2010).

Resource	Quantity	Cost/Hour Each (\$)	Total Cost Per Day (\$)
Labor foreman	1	35.10	280.80
Laborer	5	33.10	1324.00
Cement finisher	1	39.70	317.60
Equipment operator	1	42.95	343.60
Total Laborers	8		2266.00
Gas engine vibrator	2	3.80	60.80
Concrete pump	1	92.35	738.80
Total Equipment	—		799.60
Total Crew C-20	—		3065.60

If we check the numbers,

$$\text{Cost/CY} = \text{Total daily cost}/\text{Total daily production},$$

so

$$\text{Labor cost/CY} = \$2,266/90 = \$25.18/\text{CY}$$

and

$$\text{Equipment cost/CY} = \$799.60/90 = \$8.88/\text{CY}$$

which are identical to the numbers obtained with the first method.

The second method has two advantages over the first:

1. If the labor or equipment rates change, you can make limited changes to the labor or equipment rate tables, assuming that you are using a computer. Such changes should automatically adjust the prices of all items using these labor or equipment rates. In the first method, you must manually change every database item that uses the changed resources.
2. When you are deriving a schedule from the estimate, the first method does not indicate productivity and, thus, cannot provide the activity duration. The second method can provide the activity duration if you simply divide the total quantity by the daily production rate. For instance, in the preceding example, if we must place 166 CY of concrete, the duration would be $166/90 \approx 2$ days. The PM may choose to use multiple crews or to adjust the productivity as a result of favorable or unfavorable conditions. Regardless, one source of productivity will feed both the estimate and the schedule.

Materials costs do not affect the productivity level, the durations, or the schedule. One important note regarding materials is how estimators apply the waste factor. A waste factor (usually 3–10%) must be added to the estimate of the materials; however, good estimators differentiate between “takeoff quantity” which does not include waste allowance and “order quantity,” which does include such allowance. The

problem with adding the waste allowance to the takeoff quantity is that it will apply to labor and equipment, while it shouldn't. This erroneously affects both labor productivity and cost. For example, you are taking off the number of studs for framing a building and you calculated a total of 536 studs (2 by 4, 9' 4" long⁸) are needed, that is, 3,335 board-feet. You like to order 600 studs (2 by 4, 10' 0" long), that is, 4,000 board-feet. The total cost should be:

$$\begin{aligned}\text{Total cost} = & \text{takeoff quantity} * [\text{unit price for labor and equipment} \\ & + \text{unit price for materials} * (1 + \text{waste factor \%})]\end{aligned}$$

The scheduler must be extremely careful about using estimate-generated information for three reasons. First, activities in such a schedule are defined by the estimator, not the scheduler. Second, the durations in such schedules are based on the productivity level built into the estimate items. In reality, the productivity level may need to be adjusted because of many factors, such as project size and complexity; crew size; skill level; weather conditions; site conditions; equipment size, type, and condition; overtime or the lack thereof; and management competency and experience. Formulas and adjustment tables and curves have been developed to allow productivity-level adjustments for individual factors such as weather and overtime (Oglesby, Parker, and Howell 1989).⁹ Some authors have even suggested one formula that incorporates these factors for the productivity adjustment (Neil 1982). Third, and finally, in some activities, two or more crews may be working simultaneously (a common occurrence in large projects), which will reduce the duration accordingly.

After the scheduler has adjusted the productivity rate, the logic (relationships and lags) must be built. The importance of such a step cannot be overemphasized.

Cost-Loaded Schedules

A **cost-loaded schedule** is a schedule in which each activity is assigned a monetarily-amount budget. Similarly to the two methods described previously for building the cost-estimate database items, two methods are used to assign a budget to activities in scheduling programs:

1. Assign a lump-sum amount without providing details about how this number is sliced or which resources use it. You may still be required to supply a cost account code in some software packages to help track the cost.
2. Assign a number of units of required resources (e.g., one foreman, one equipment operator, two common laborers, and one hydraulic excavator) to the activity. The schedule must contain a “resource dictionary,” in which

⁸For rough carpentry such as framing, the waste percentage is usually higher than for other items because waste allowance not only covers broken, defective, and missing pieces but also waste resulting from cutting. For example, in the studs case above, the true length may be 9' 4" (9 feet + 4 inches) but studs are sold only in increment of 2 feet, so the estimator has to order studs 10 feet long.

⁹See also the discussion on overtime in chapter 8.

every resource is defined and priced. The program calculates the required resource quantities for the activity by multiplying the number of resources required by the activity by the duration of the activity. For example, if the activity requires 3 laborers and has a 4-day duration, the resource assignment is $3 * 4 = 12$ labor-days, or $3 * 4 * 8 = 96$ man-hours. The program then calculates the budget for the activity by multiplying the resource assignment by the resource unit prices in the resource dictionary. The second method has several advantages discussed in chapter 6.

ESTIMATING AND ACCOUNTING

Cost accounting is defined as “the systematic recording and analysis of the costs of materials, labor, and overhead incident to production” (Merriam-Webster 2004). Cost accounting basically is concerned with checks and balances: matching actual spending with estimated or budgeted amounts. The actual cost of every work item must not exceed the estimated (budgeted) amount. In some cases, particularly in public agencies, accounting also involves different categories of money sources (funds). For example, a transportation project in a city may be funded by a combination of federal funds, state funds, local funds, grants, and special taxes or fees. Each fund has its limits and restrictions. Many grant funds have stipulations, such as the type of project, geographic location, type of expense, equal or greater matching funds from the owner agency, or type of subcontractor (e.g., minority, small business). The accountant must make sure the expenses met these stipulations.

As discussed in chapter 8, construction project costs are classified into direct and indirect expenses. Direct expenses include labor, materials, equipment, subcontracts, and others. Indirect expenses include job overhead, general overhead, profit, and contingency fees. When actual expenses are incurred, the accountant must link each expense to a specific work item. The expense must be categorized (labor, materials, equipment, overhead) and subcategorized (common labor, carpenter, concrete, crane, etc.). The accountant must make sure actual expenses do not exceed the estimated cost.

The contractor’s accounting system maintains a list of vendors, suppliers, and subcontractors. At any time, the contractor should be able to track any material ordered from any particular supplier, including the following information:

- Total quantity ordered
- When it was ordered
- Delivery status. If received, when and who signed for it.
- Total cost, how much paid, the balance, and the due date for the balance
- Any problems with the materials and the action taken

The general contractor’s accounting system should also include records of subcontractor’s monthly payments: how much was requested, approved, authorized, paid, and retained.

The payroll (for hourly workers) is done regularly (weekly or biweekly). Workers' hours (regular and overtime) are also posted against specific work items. Accountants add burden expenses and benefits, then subtract the appropriate amounts from the payroll, such as federal and state withholding tax, FICA (Federal Insurance Contributions Act) fees, FICA medical fees, unemployment insurance contributions, union dues, medical insurance contributions, and so forth.

The general contractor collects subcontractors' pay requests and incorporates them into his or her **request for payment** and submits it to the owner. A pay request goes through the usual steps: verification and approval by the owner, processing, and issuance of the payment (minus any retainage and/or penalties¹⁰). Owners also require lien releases¹¹ from the general contractor and his subcontractors and vendors before releasing the payment. Accountants must also keep track of each subcontractor and vendor: total contract, payments to date, retainage to date, and balance.

Every expense must be approved by an authorized person before it is accepted into the accounting system. Checks must also be signed by an authorized person.

SCHEDULING AND ACCOUNTING

Scheduling is related to accounting in basically one way. When the project is updated (statused), information is obtained on new work progress. The cost of this new work progress is then processed as described previously. If the schedule is cost loaded, it provides periodic information:

- Which activities have started (along with the start dates)
- The percent complete of such activities
- Which activities are completed (along with the finish dates)
- Total budget, cost this period, cost to complete, **cost at completion**, and cost variance,
- Any other activity-related financial information

This information must be reviewed and approved by the PM and is then forwarded to the accounting department.

If the project is not cost-loaded, the same procedure must take place through the accounting system. In this case, the percent complete for each activity must be entered for the pay period. The accounting system uses the schedule of values and calculates

¹⁰In certain locations in the world, contracts allow the contractor to receive an advance payment when signing the contract. It is usually around 10–20% of the contract value and it is recovered gradually by deducting the same percentage from progress payments.

¹¹A lien release is a written agreement by a lien holder (general contractor, subcontractors, vendors) releasing the debtor (owner) from further obligation. Without a lien release, it is possible that the owner pays his general contractor but the general contractor does not pay a subcontractor, then the subcontractor places a mechanics lien against the building (i.e., the owner).

cost this period, cost to complete, cost at completion, and cost variance. After schedule approval, cost this period becomes the basis for monthly progress payments, as described previously.

SCHEDULING AND CHANGE ORDERS

Accounting, estimating, and scheduling departments also handle change orders (COs),¹² each from its own perspective. In construction, COs are almost inevitable. However, well-planned and well-managed projects may have few or no CO's. Change orders may be initiated by the contractor or the owner (and are discussed in more detail in chapter 13). In all cases, the contractor estimates the cost of the CO and the impact on the schedule, if any. The owner approves, rejects, or negotiates the contractor's request. Once the owner approves such a request, he or she issues the CO.

The contractor must then implement the CO in the estimating, scheduling, accounting, and other management/tracking systems. Managing COs may present a challenge to the contractor's staff. Change Orders may—and usually do—affect existing items. For example, two additional floors in a mid-rise office building may require the engineer to redesign the columns, the foundation, the main HVAC unit, the type of elevators, and possibly other items. A deletion of a swimming pool will alter the amount of excavation and landscaping. If the contractor encounters “differing site conditions,” his or her work plan may have to be delayed or altered.

What is important to scheduling and project control is implementing the changes in the baseline schedule (and estimate) so that measuring against the baseline will still be a fair and objective. The original baseline should not be erased. Rather, it must be kept with the project records because it could be used in case of a later dispute.

PAPERLESS PROJECT MANAGEMENT

The construction industry, as well as other industries, is increasingly managing information electronically. As a result, the traditional use of paper has been minimized.

Any project usually starts with preliminary (or concept) then detailed design (architectural, civil, structural, mechanical, electrical, etc.). Many designers work with drafting or design software, such as AutoCAD (Autodesk, Inc., San Rafael, California) or MicroStation (Bentley Systems, Inc., Exton, Pennsylvania). When the design is finalized and approved, it is issued as “construction drawings” (usually on paper) and officially submitted to the contractor, along with the specifications.¹³ The contractor calculates quantity takeoffs from these drawings then prices the job. Contractors do takeoffs by using manual, electronic tools such as digitizer boards, directly from CAD

¹² Also called variation orders, VOs.

¹³ In some nontraditional contracts, the contractor may be involved in the project before the design is complete. In such cases, he/she may receive incomplete design documents (e.g., DD30, DD60) or complete design documents only for a portion of the project.

drawings, or by using BIM¹⁴ modeling. These quantities are carried over to the estimating spreadsheet or program, manually or electronically.

Project management software programs, such as Primavera Contract Manager (formerly known as Expedition), Meridian's Prolog Manager, and Timberline's Project Management, keep records of all project administration and communication documents. In an ideal situation, they link to the schedule, the cost estimate, the accounting software, and other programs. In addition, you can host all this information on an exclusive Web site (Internet or intranet) where project participants obtain access to the project, review documents, and correspond. The Web site administrator can control who sees what. This capability can tremendously expedite communications, such as design review, submittals, RFIs, payment requests, and so forth, among project participants. Several leading companies in the construction software industry are trying to develop an "total project management suite" in which all project management and administration components are available and communicating flawlessly.

PROCUREMENT MANAGEMENT

Procurement is the process of acquiring materials, equipment, and services from external sources for use in a project. Procurement is a process that usually starts long before the start of the construction process and ends with project completion or **project closeout**. The procurement team must work in close coordination with both the estimating and scheduling teams, all under the project management team. Depending on the company's functional hierarchy, the procurement manager or department may or may not be under the project manager. In most large companies, the PM is the highest authority within the project management team. Under this person there are a construction manager, a procurement manager, a quality manager, a safety manager, and so forth.

In management, project organization may be a *pure project organization* (in which the team becomes autonomous, almost like an independent company), a *functional or departmental organization* (in which everyone works under his or her functional department in the main office), or a *matrix organization* (a combination of the preceding two types of organizations that leans more toward a pure project organization, more toward a functional organization, or somewhere between)¹⁵.

The two objectives of procurement, from the general contractor's viewpoint, are as follows:

1. *To hire the subcontractors who will actually erect and assemble the project:* Doing so can be accomplished through bidding or negotiation. Such hiring is also subject to the contractual agreement between the general contractor and the

¹⁴ Building Information Modeling, known as BIM.

¹⁵ *Project Management: A Managerial Approach* by Jack R. Meredith and Samuel J. Mantel Jr. (2008).

owner. The general contractor must know when each subcontractor's role starts in the project. For this reason, the general contractor focuses on subcontracts on the critical path. Some subcontractors may not be hired until after the project starts. Again, such hiring is subject to the agreement between the owner and the general contractor.

2. *To purchase the materials called for in the contract:* This task may not be easy. First, the procurement team must have a list of all needed materials, along with their specifications, quantities, and dates of installation. Custom and special orders as well as long-lead items must be given special attention. Often, if an ordered material does not exactly match its description in the specifications, confusion will arise on the job site and decisions have to be made on what to do. Second, the procurement team must find the best prices for the ordered materials. Finally, the procurement team must also balance between having a conservative attitude of buying the materials early and storing them (the inventory buffer theory) and having a risky attitude of ordering the materials for installation when needed (the just-in-time theory). (Both theories are discussed in chapter 6.)

The purchasing cycle involves the procurement, estimating, scheduling, and accounting, quality assurance, and perhaps other departments. The estimating department provides a list of the types and quantities of materials needed for a certain activity. The scheduling department predicts the date the activity is to start. The procurement team then makes sure the materials are ordered and are available on time. It also verifies the cost of these materials against the cost estimate, then provides the actual cost to the accounting department. The contractor's project management team is responsible for receiving the materials and unloading, accepting, sorting, and storing them. The quality assurance department of both the contractor's and the owner's organizations may become involved to ensure that the materials comply with the specifications.

The purchase of some materials, such as ready-mix concrete, must be carefully coordinated. This type of concrete must be installed immediately upon delivery and cannot be stored. Some materials may be flammable, explosive, poisonous, or dangerous in any other way. Some materials may be fragile and need extra care in handling and storing. Other materials may be expensive and must be secured before and after installation. The procurement department must take care of all the requirements of such types of materials.

A clear distinction must be made here between procurement department and human resources department in hiring people. The latter one is responsible for hiring staff employees such as managers, engineers, administrators, and so forth.

MANAGEMENT OF SUBMITTALS

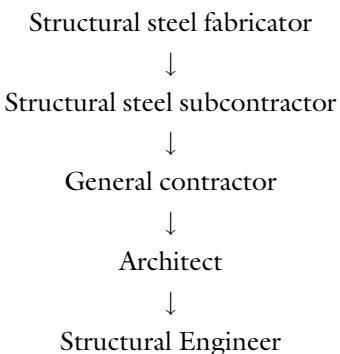
A **submittal** is a sample, manufacturer's data, a shop drawing, or another item submitted to the owner or the design professional by the contractor for approval

or another action, usually a contractual requirement. Submittals are an important part of the schedule. In many cases, placement of a posttensioned cable, reinforcement, structural steel detail, or framing cannot proceed until the shop drawing is approved. In the case of samples, such as types and colors of carpet or paint, the procedure includes the submittal of the samples and the owner's selection or acceptance of one or more of them.

In the case of shop drawings, the cycle consists of four steps:

1. Preparation of the shop drawings by the subcontractor or supplier
2. Submittal of the drawings to the contractor, then forwarding them to the A/E or the party responsible for reviewing them
3. Review of the drawings by the appropriate party (engineer or architect).
Typically, the drawings are accepted as is, rejected, or accepted with changes.
If they are rejected, the subcontractor or supplier must redo and resubmit them.
4. After approval, fabrication of the work by the subcontractor or supplier.

The formal chain of command should be specified in the contract. It usually restricts correspondence between parties who have a contractual agreement. For example,



The direction of these arrows is reversed when the drawings are sent back after the review. This chain may be shortened, to speed up the process, by sending the drawings from the fabricator or subcontractor directly to the structural engineer. Such an arrangement requires the approval of the main contracting parties. Most likely, it also requires copying all parties between in both directions. Electronic correspondence helps expedite this process.

The submittal procedure in the contract must be precise in terms of time limits. Ambiguous expressions such as "the owner will review submittals within a reasonable period of time so as not to delay work progress" and "as soon as possible" must be avoided. Document/contract management software tracks shop drawings and other

submittals and documents. They show the party that is holding the process (ball in court) and send alerts before deadlines.

Another important point, from a scheduling point of view, is the possibility of rejection.¹⁶ If the shop drawing cycle is on a critical or a near-critical path, the contractor must be careful in handling the submittals. He or she should try to determine the results of the review as soon as possible so that he or she can plan for the next step. Allowing a contingency time in the schedule for the possibility of rejection is a good idea.

THE MASTER SCHEDULE AND SUBSCHEDULES

In a typical construction project, many parties are involved: the general contractor, the owner, the architect or engineer (which could be several entities), subcontractors, government agencies, vendors, and so forth. There are two approaches to scheduling in this situation:

1. *Build a master schedule that includes several subschedules:* Each subschedule represents the activities belonging to one party involved in the project. The external relationships will show only in the master schedule. In this approach, when scheduling (performing the CPM calculations for) a subschedule, the scheduler must be sure to consider the external relationships because the software may ignore them. For instance, consider the three activities shown in Figure 10.1. Assume the relationship between activity GC230 and activity SDF1270 is external. If you schedule the SDF schedule alone, you may get early dates for activity SDF1270 as (35, 40) instead of (51, 56).

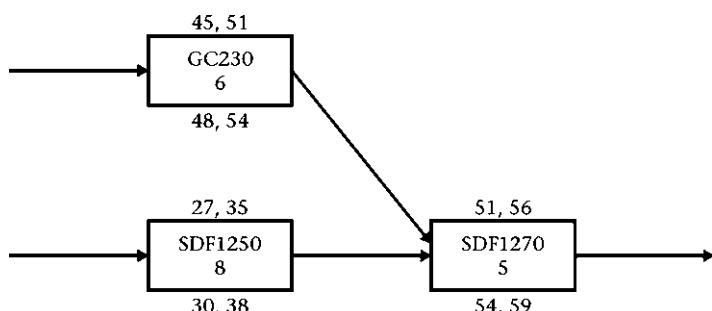


Figure 10.1 Subnet of a master schedule with two activities belonging to one subschedule and one activity belonging to a different subschedule

¹⁶If the objections of the reviewer are minor, the actions maybe “Accepted as noted,” which indicates a need for corrections and/or changes in the submittals but allows the work to continue while corrections and changes are being made.

This solution was ideal under the old Primavera P3, where the user could not open more than one project at a time but could open a one master schedule with several subschedules under it. In the enterprise version of Primavera (which started with P3e and is currently P6), the user can open almost as many projects as he/she wants; simultaneously. The user in P6 also can link activities in different projects with the option to consider or ignore external relationships when scheduling. The user in P6 can also take advantage of the EBS (Enterprise Breakdown Structure) by placing the subschedules at one level below the master schedule.

2. *Include all activities in one schedule and assign a Responsibility code for each contracting party:* The scheduler can later apply a filter to show activities belonging to only one party. This way, the “external relationships” are always there, even if they do not show.

It is important to include external relationships for proper project management. For example, an owner’s furnished kitchen equipment for a commercial project may have to be delivered after the structure has been erected and after mechanical and electrical rough-ins, but before doors and windows are installed and before mechanical and electrical finishing. Such operations will involve coordination among several entities.

In many situations, the master schedule is not the creation of one party (the general contractor or the project management consultant, PMC). Contracting parties, such as subcontractors, create their own schedules (using the same or compatible software) and submit them to the general contractor (or PMC). The general contractor (or PMC) then assembles these subschedules, along with his or hers, in one master schedule, using one of the two approaches just mentioned.

MULTIPROJECT MANAGEMENT

In large corporations or government agencies, tens or hundreds of projects may have to be managed simultaneously. Typically, there are two levels of project management:

1. *Management at the individual project level (micromanagement):* The PM should be managing or monitoring all activities and all project details. The project is the focus of the PM. Depending on the size and complexity of the project, the management team can be composed of one part-time person to several people.

For such a PM, the basic unit of control is the activity, with related information, such as duration, logic (predecessors, successors, lags), constraints, calendar, resources, budget, cost, notes, and so forth. The information may be rolled over to a WBS (work breakdown structure) level or other codes within the project (e.g. floor, area, phase, segment, mile marker). The highest level of roll-up is the project itself, where only one unit shows, with the total duration, total budget, and so forth.

In some owner's organizations such as governmental agencies (counties, municipalities, etc.) and developers, every project has two managers: the owner's PM and the contractor's PM. The first one monitors the project and makes sure that the contractor is performing according to the terms of the contract. He or she also authorizes payments to the contractor. The contractor's PM is the "real" construction manager. He or she is responsible for the day-to-day construction operations in the project. It is also possible, and likely, that a professional project management consultant (PMC) agency is involved representing the owner. In this case, it will be micromanaging the project representing the owner's interest.

2. *Management at the corporate or enterprise level (macromanagement)*: The corporate manager will look at all projects, with each project represented as one basic integral unit (usually represented by a single bar in a bar chart). The corporate manager (could be program or portfolio manager) may not get involved in the details of individual projects (although he or she usually can, and will do so in certain cases). The basic unit in this case is the project. Projects can be grouped by organizational breakdown structure, such as department, section, program, and so forth.

Primavera P6, for example, is a product designed for the "enterprise," with a multiproject management capability.¹⁷ It offers three breakdown structures:

- a. The *EBS (enterprise breakdown structure)* is a breakdown for the corporation (enterprise). Typically, this structure includes the departments under the organization. Each department can be broken down further into sections and so on, where projects reside.
- b. The *OBS (organizational breakdown structure)* is a breakdown of the functional responsibility. Typically, you tie the EBS to the OBS to define people along with their departments (who does what).
- c. The *WBS (work breakdown structure)* is a typical **project breakdown structure (PBS)**. Unlike the EBS and the OBS, the WBS is at the project level and can differ from one project to another.

TIME CONTINGENCY AND MANAGEMENT OPTIONS

When a scheduler or PM creates a schedule, he or she must include a time contingency representing the expected nonworkdays. This time contingency includes two types of nonworkdays:

¹⁷ As mentioned in chapter 7, Microsoft has developed solutions, such as Microsoft Office EPM (Enterprise Premier Solution), in which the solution is customized by selecting certain Microsoft or partner components to fit the client's needs.

1. *Known dates such as holidays and planned shutdown days:* The scheduler must enter these days in the calendar of the computer program. The computer program will not allow any work on an activity on such days (provided the activity uses that calendar).
2. *Unknown dates:* A scheduler should typically expect some occurrences that will prevent work from taking place, such as severe or unusual weather conditions or accidents. For example, for a 1-year project, the scheduler allocates 18 nonworkdays. This 18-day **schedule contingency** can be considered total float for the entire project, in addition to the calculated total float. It can be handled in one of the following two ways, or a combination of both can be used:
 - a. *Allow the crews to control this float:* In this case, the durations of all activities are stretched by a percentage that makes the entire schedule extend by these 18 days. As an alternative, the PM may assign these 18 days to certain activities according to his or her discretion.
 - b. *Give management control of these days and allow them to “be spent” as needed:* Management must be careful not to use such time contingency days to compensate for poor performance or low productivity. The challenge in this approach is how to implement such days in the baseline schedule. There are two ways to do so:
 - i. *Distribute these days evenly along the duration of the schedule:* In this case, the scheduling program treats these days the same as holidays and scheduled nonworkdays. This approach may cause some problems in tracking the project when a certain day is shown on the schedule as a nonworkday when it is not. The advantage of this method is that the schedule is most realistic in the occurrence distribution of nonworkdays, although the specific date may be incorrect. As a remedy, the scheduler can adjust dates for nonworkdays during the update.
 - ii. *Put the entire 18 days at the end of the project:* This method makes the actual schedule look worse than it is. As the project progresses, nonworkdays occur, but they are not reflected in the schedule, so the schedule looks behind till the end. At this point, the 18 contingency days start, and the negative float (up to 18 days) disappears.

One approach used in some organizations, particularly municipal governments, is to have two different completion dates:

1. An internal completion date: this is the date when the project manager is responsible before his/her management for completing the project
2. An external completion date: this is the date when the management is responsible before the client (owner/board of commissioners or trustees) for completing the project

The first date is, obviously, the earlier one. The difference between the two dates is “management float” or “time contingency.” The management uses that as a bank and authorizes the PM to use days out of it only for a valid excuse. It is not a good idea for the management to exaggerate this time contingency. One possible problem with such exaggeration is in the timing of funding. This may be a particular problem for public agencies (municipalities and local governments). Budget departments may distribute the cost of the project over its fluffed duration, then it takes less time than officially reported. This early execution¹⁸ of the project may mean earlier demand for money than anticipated (even though the total is unchanged) and the agency may have the money committed for next, not current, fiscal year.

Besides using the nonworkdays, the contractor may create *hidden float*. Hidden float can be created either by inflating the duration of an activity or by manipulating the logic. For example, assume that the durations and logic in Figure 10.2a are correct, but the contractor wants to show that the project takes 25 days instead of 20. He or she can “fluff” the durations, as shown in Figure 10.2b, or add an unnecessary link to extend the critical path, and thus extend the duration of the project, as shown in Figure 10.2c.

The author strongly opposes the tactic used in Figure 10.2c. Phony logic should never be allowed in the schedule. Fluffing the duration is a controversial subject and also discouraged. The danger of using a fluffed duration in project control and performance measurement is that it may skew the performance observations and conclusions, and subsequently future estimates.

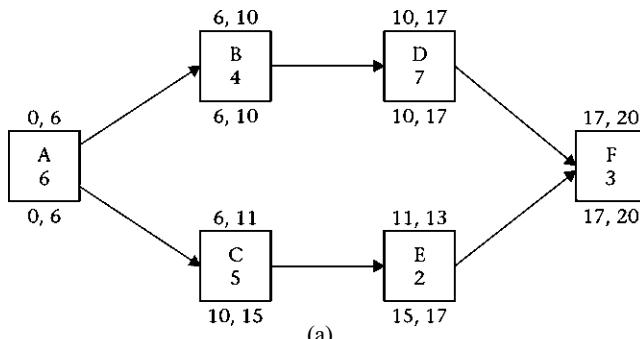


Figure 10.2 (a) Real durations

¹⁸Not really early but compared to the “fluffed” schedule.

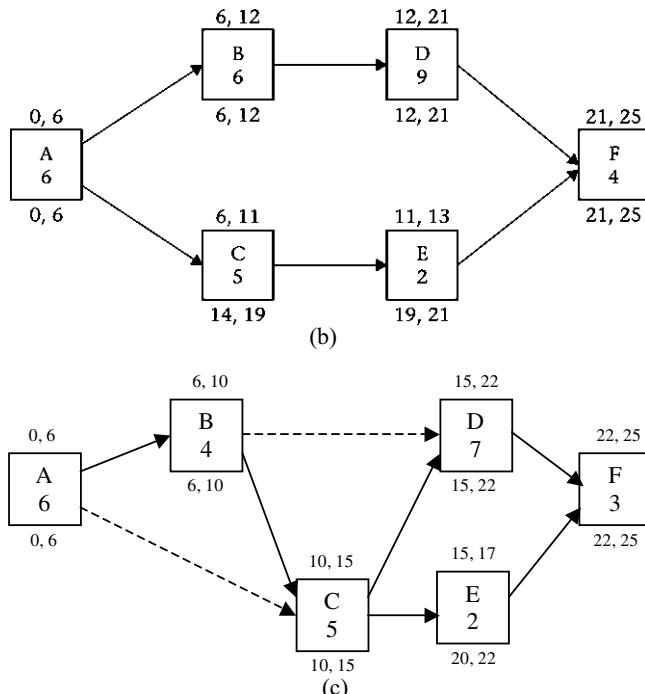


Figure 10.2 (continued) (b) “fluffed” durations; (c) manipulated logic

CHAPTER 10 EXERCISES

1. Discuss three ways in which cost estimating and scheduling interrelate.
2. Discuss the evolution of a cost estimate. How does this relate to the creation of the schedule?
3. What is an *estimate-generated schedule*? What precautions must the scheduler take before using such a schedule?
4. What is a *cost-loaded schedule*?
5. What are the two methods of loading cost into a schedule? Which method is more powerful? Why?
6. How does accounting relate to scheduling? Discuss briefly.
7. How do change orders affect a schedule? What should the scheduler do for objective project control when changes occur?
8. What is the “total project management suite” computer program?
9. Define *procurement*. What are the main objectives of procurement?
10. How does procurement relate to scheduling?

11. Explain the cycle of submittal management.
12. What can the scheduler do to account for potential delay during the submittal cycle?
13. When you take on a large project made up of several smaller projects, how can you handle this situation in the schedule?
14. When using the “master project” and “subprojects” approach, what pitfalls may happen in the schedule? How do you deal with them?
15. In a highway project, both the contractor and the government schedulers must keep track of the schedule. However, their roles differ significantly. Explain.
16. The scheduler must include a time contingency in the schedule. How many ways can you implement such a contingency? What are the pros and cons of each method?
17. After you prepare a schedule for a shopping mall, the architect issues a design change in which an escalator is added inside one of the areas that will be occupied by a major store in the mall. The subcontractor in charge of the escalator submits his schedule, showing that the work can be completed in 6 weeks. First, mention the work packages that will be affected (e.g., concrete, electrical, etc.). Second, do you believe that the master schedule will affect the escalator schedule, the escalator schedule will affect the master schedule, or both? Explain the potential interdependencies between the escalator work and other subcontractors’ work. Why do you believe that the escalator work will take more than 6 weeks?

Chapter **11**

Other Scheduling Methods



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INTRODUCTION

Although the critical path method (CPM) is the predominant method used for scheduling construction projects, other methods may be used for particular types of projects or in other industries. In this chapter, three of these methods are discussed. (Note: Some of the information discussed in this chapter requires basic knowledge of statistics.)

PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT)

Definition

The **program evaluation and review technique (PERT)** is an event-oriented network analysis technique used to estimate project duration when individual activity duration estimates are highly uncertain. PERT applies the CPM to a weighted-average duration estimate. PERT is considered a probabilistic, or stochastic, method.

Background

In the 1950s, the U.S. Navy had a budget overrun and a schedule delay of as much as 50% in the Polaris missile system project. The main problem was the lack of any relevant historical data. The project team—the U.S. Navy (the owner), Lockheed Aircraft Corporation (the prime contractor), and Booz Allen Hamilton (the management consultant team)—launched a joint research effort to develop a tool to assist in the planning of the Polaris project. The objective was to devise a method that predicts the completion date of a project with a certain likelihood using the theory of probability. In 1958, this tool was developed under the name *program evaluation and review technique* and later became known by its acronym, PERT.

The PERT system was adopted in its early days by the Department of Defense (DoD) under the name *program evaluation procedure (PEP)*. After that, PERT was modified several times and carried different names: PERT I, PERT II, PERT III, PERT/TIME, and PERT/COST. In June 1962, the DoD and the National Aeronautics and Space Administration (NASA) adopted a uniform approach of planning and controlling procedures for major weapon systems (Popescu and Charoenngam 1995).

Concept of PERT

Like the regular (deterministic) CPM, PERT uses logic networks to calculate the completion date of a project or the date of any other event in the schedule. In PERT, a probability (likelihood) is associated with any event date. This probability depends on uncertainty in the durations of the activities that lead to the desired event (e.g., project completion). PERT realizes that actual durations vary from those assigned, so it attempts to compensate for this variation with a “time range” during which activity durations may realistically occur. This topic is discussed in more detail after the details of PERT are covered.

How PERT Works

PERT uses a probabilistic approach, which requires a duration frequency distribution for each activity. In most cases, such distributions are unknown or unavailable. Because of this, PERT requires the user to set three durations that constitute the practical range of the duration for each activity. For example, Assembling and Erecting the Falsework for an Elevated Slab will most likely require 5 days. If all goes well, without interruption or snags, the duration may be cut to 4 days. However, in the practically worst-case scenario, this activity may take 8 days. These three durations give a “distribution” for the activity, and we can produce the statistical mean and variance for the duration of the activity.

When we need to compute the probability that a certain event, such as Substantial Completion of a building, will occur by a certain date, we need to take into account all preceding events, starting at the beginning of the project and including the continuous chain of activities till Substantial Completion. Using the **central limit theorem**, PERT treats the means of the durations of these activities as a **normal distribution**, no matter what distributions these durations followed. PERT then uses simple statistics to calculate the mean and variance (or standard deviation) of the time required to complete the chain of events leading to Substantial Completion. It calculates the probability that Substantial Completion will occur by a particular date, or, conversely, it calculates the date that the Substantial Completion event will happen with a certain level of confidence (probability).

PERT Calculations

As mentioned previously, the path (chain of activities or events) leading to the examined event (e.g., Substantial Completion) must be chosen. For each activity on that path, three durations must be estimated:

- T_o : Optimistic Duration
- T_m : Most Likely Duration
- T_p : Pessimistic Duration

The preceding values are estimated by the scheduler or project manager, who uses his or her experience and good judgment to do so. The optimistic duration is the amount of time the activity will take if everything goes smoothly and efficiently. The pessimistic duration is the duration under the worst-case scenario. Both values must be within the realistic, although perhaps unlikely, realm of expectations.

The mean weighted value for these three durations is called the **expected duration** (T_e). It is calculated as follows:

$$T_e = \frac{T_o + 4T_m + T_p}{6} \quad (11.1)$$

The weights assigned to these times (coefficients of T_o , T_m , and T_p) may be adjusted, but the denominator must equal the sum of all weights. The weights in equation 11.1

represent a population of durations made up of 16.7% (one-sixth) optimistic (T_o); 66.7% (four-sixths) most likely (T_m); and 16.7% (one-sixth) pessimistic (T_p).

Several symbols are used in other textbooks to represent the mean (arithmetic average), such as μ and X .

The standard deviation for the expected duration (σ_e) is

$$\sigma_e = \frac{T_p - T_o}{6} \quad (11.2)$$

and the variance (V_e) is

$$V_e = \sigma_e^2 \quad (11.3)$$

Now, add the expected duration for all activities on the studied path (T_E),

$$T_E = \sum_{i=1}^n (T_e)_i \quad (11.4)$$

The variance (V_E) and standard deviation (σ_E) for the entire path are calculated as

$$V_E = \sum_{i=1}^n (\sigma_e^2)_i \quad (11.5)$$

and

$$\sigma_E = \sqrt{V_E} \quad (11.6)$$

With the information just calculated for the examined path, we can calculate the probability that an event will occur on or by a certain date (T_S) by using the normal distribution formulas:

$$Z = \frac{T_S - T_E}{\sigma_E} \quad (11.7)$$

where Z (called the **Z function**) represents the number of standard deviations (σ_E) away from the mean (T_E).

Plugging the Z value just calculated into the Z table (Table 11.1), we can find the probability.

PERT can also predict the date by which a certain event will be completed, with a certain level of confidence (i.e., probability). This date is calculated by using the set probability value (level of confidence) to find the corresponding Z value in the Z table. Rewriting equation 11.7, we get

$$T_S = \sigma_E \cdot Z + T_E \quad (11.8)$$

These calculations are clarified further in the following examples.

Table 11.1 Z Table: Cumulative Probability of the Standard Normal Distribution

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

Graphic Explanation

The **probability density function** of a normal distribution is represented by a bell-shaped curve. The area under the curve represents the **probability universe**, where all possibilities are covered, which is 1.00, or 100%. The probability that an event will occur by a certain date (i.e., on or before that date) is the area under the curve to left of that date. See Figure 11.1.

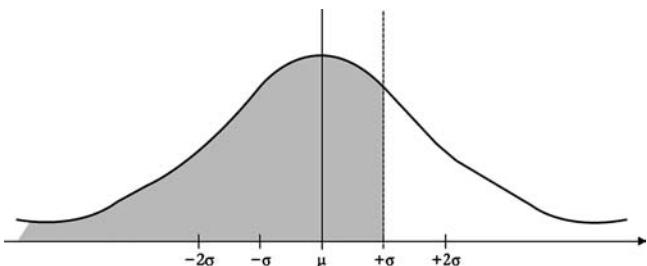


Figure 11.1 Probability density function curve (shaded area indicates the probability that an event will occur by a certain date)

Example 11.1

In a CPM network, the critical path includes five activities. Their durations are tabulated next.

Activity	Duration (Days)		
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
A	2	4	7
B	5	8	14
C	4	6	8
D	2	2	2
E	7	10	21

Compute the following nine values:

1. The probability that the project will finish by the end of day 32
2. The probability that the project will finish by the end of day 34
3. The probability that the project will finish before day 30
4. The probability that the project will finish on the 32nd day
5. The probability that the project will finish no later than the 35th day
6. The probability that the project will finish at least 2 days early
7. The probability that the project will finish at least 2 days late
8. The probability that the project will finish on the 32nd day ± 1 day
9. The completion date with at least a 90% confidence level

Solution

Before computing any of the nine values, we need to calculate the expected duration (T_E) and the standard deviation (σ_E) of the path ABCDE. We start by performing the calculations for the individual activities. For every activity, we calculate the expected duration (T_e) and standard deviation (σ_e) by using equations 11.1 and 11.2. After this, we calculate the variance (V_e) by using equation 11.3. We tabulate the results as shown next.

Activity	Duration			Expected Duration (T_e)	Standard Deviation (σ_e)	Variance $V_e = \sigma_e^2$
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)			
A	2	4	7	4.167	0.833	0.694
B	5	8	14	8.500	1.500	2.250
C	4	6	8	6.000	0.667	0.444
D	2	2	2	2.000	0	0
E	7	10	21	11.333	2.333	5.444
				$T_E = 32$		$V_E = 8.833$

The next step is to do the calculations for the entire path. We simply add the expected durations and variances, as explained in equations 11.4 and 11.5, to obtain T_E and V_E .

Next, take the square root of V_E (use equation 11.6) to find the standard deviation (σ_E) of the path:

$$T_E = 32 \text{ days}$$

$$V_E = 8.833 \text{ days}$$

and

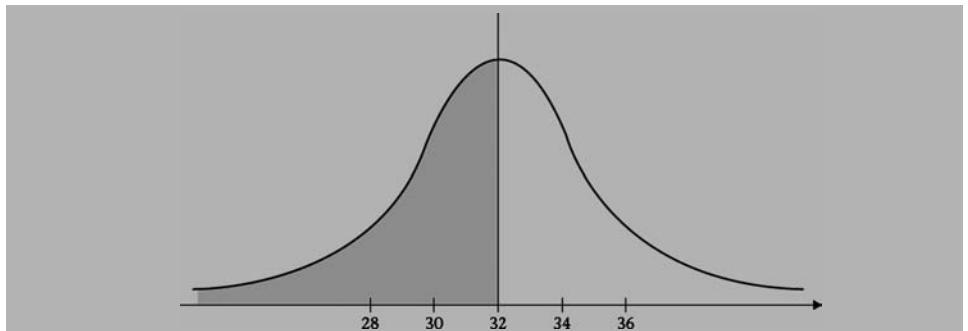
$$\sigma_E = \sqrt{8.833} = 2.972 \text{ days}$$

Note that $\sigma_E \neq \sum_{i=1}^n (\sigma_E)_i$

1. The probability that the project will finish by the end of day 32. Using equation 11.7, we find that $Z = (32 - 32)/2.972 = 0$. From the Z table (Table 11.1), we find that

$$\Pr(T_S \leq 32) = 0.5 = 50\%$$

See Figure 11.2.

**Figure 11.2 Solution to example 11.1, part 1**

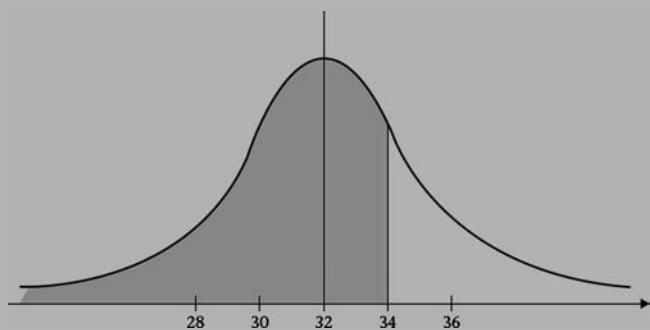
2. The probability that the project will finish by the end of day 34.

$$Z = (34 - 32)/2.972 = 0.67$$

From Table 11.1, we find that

$$\Pr(T_S \leq 34) = 0.749 = 74.9\%$$

See Figure 11.3.

**Figure 11.3 Solution to example 11.1, part 2**

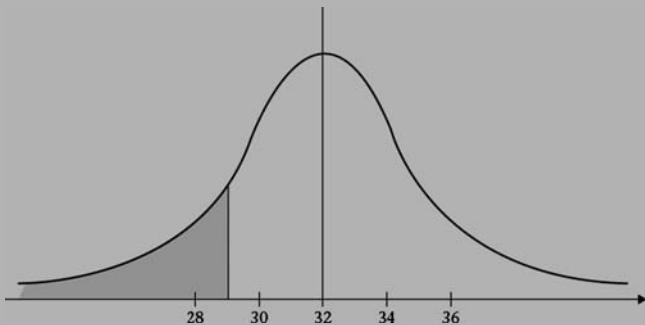
3. The probability that the project will finish before day 30. This probability is the same as the probability of finishing by the end of day 29:

$$Z = (29 - 32)/2.972 = -1.01$$

When $Z < 0$, take the probability that corresponds to the positive value of Z , then subtract it from 1.0 (100%):

$$\Pr(T_S \leq 29) = 1 - 0.844 = 0.156 = 15.6\%$$

See Figure 11.4.

**Figure 11.4 Solution to example 11.1, part 3**

4. The probability that the project will finish on the 32nd day.

$$\Pr(T_S = 32) = \Pr(T_S \leq 32) - \Pr(T_S \leq 31)$$

We already calculated $\Pr(T_S \leq 32) = 0.5 = 50\%$ (part 1). For $\Pr(T_S \leq 31)$,

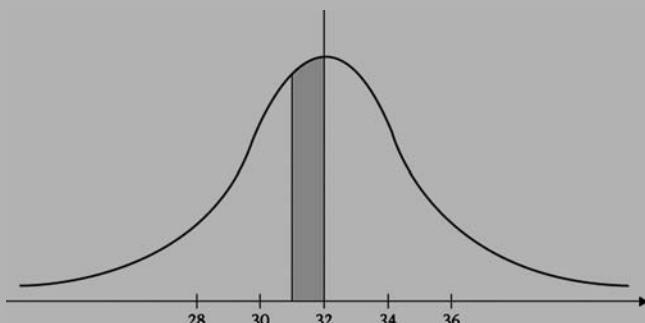
$$Z = (31 - 32)/2.972 = -0.34$$

$$\Pr(T_S \leq 31) = 1 - 0.633 = 0.367 = 36.7\%$$

and

$$\Pr(T_S = 32) = \Pr(T_S \leq 32) - \Pr(T_S \leq 31) = 50\% - 36.7\% = 13.3\%$$

See Figure 11.5.

**Figure 11.5 Solution to example 11.1, part 4**

5. The probability the project will finish no later than the 35th day. This probability is the same as the probability that the project will finish by the

end of day 35:

$$Z = (35 - 32)/2.972 = 1.01$$

and

$$\Pr(T_S \leq 35) = 0.844 = 84.4\%$$

See Figure 11.6.

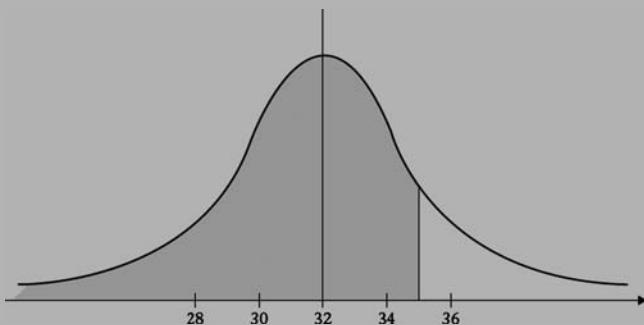


Figure 11.6 Solution to example 11.1, part 5

6. The probability that the project will finish at least 2 days early. This probability is the same as the probability of finishing on the 30th day or earlier, or the same as the probability that the project will finish by the end of day 30:

$$Z = (30 - 32)/2.972 = -0.67$$

and

$$\Pr(T_S \leq 30) = 1 - 0.749 = 0.251 = 25.1\%$$

See Figure 11.7.

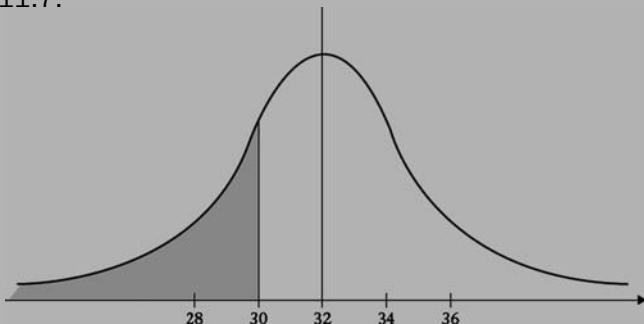


Figure 11.7 Solution to example 11.1, part 6

7. The probability that the project will finish at least 2 days late. This probability is the same as the probability of finishing by the 34th day or later, or the same as the probability that the project will finish after day 33:

$$\Pr(T_S > 33) = 1 - \Pr(T_S \leq 33)$$

For $\Pr(T_S \leq 33)$,

$$Z = (33 - 32)/2.972 = 0.34$$

and

$$\Pr(T_S \leq 33) = 0.633 = 63.3\%$$

Thus,

$$\Pr(T_S > 33) = 1 - 0.633 = 0.367 = 36.7\%$$

See Figure 11.8.

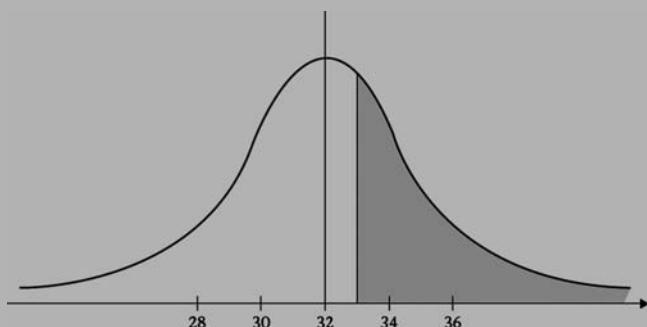


Figure 11.8 Solution to example 11.1, part 7

Note that if the instruction had said “the probability that the project will finish *more than* [rather than *at least*] 2 days late,” it would have meant $\Pr(T_S > 34)$.

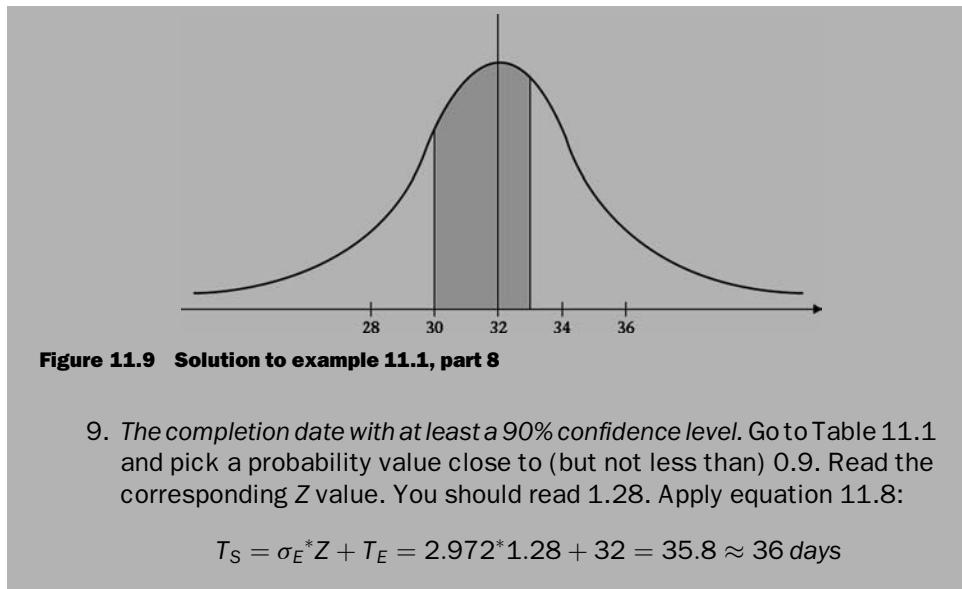
8. The probability that the project will finish on the 32nd day ± 1 day. This means finishing on day 31, 32, or 33.

$$\Pr(T_S = 31, 32, 33) = \Pr(30 < T_S \leq 33) - \Pr(T_S \geq 33) - \Pr(T_S \leq 30)$$

and

$$\Pr(T_S = 31, 32, 33) = 0.633 - 0.251 = 0.382 = 38.2\%$$

See Figure 11.9.



Difference between “Most Likely” and “Expected” Durations

From a linguistic viewpoint, *most likely* and *expected* may be thought of as similar. However, statistically they are different. The most likely duration is simply the duration that we believe has more likelihood of happening than any other duration. In our case, it is a user-defined amount; that is, we provide it along with other durations (optimistic and pessimistic) in the equation so that we can calculate the expected duration and the standard deviation. It does not represent the arithmetic mean or the median.

The expected duration is the amount of time we expect the project or path duration to take, considering the different durations (optimistic and pessimistic), their values, and their weights. It is a computed amount. For example, consider a case in which 6, 8, and 10 are the optimistic, most likely, and pessimistic durations, respectively. The expected duration will be equal to 8. In this case, it is equal to the most likely duration because the optimistic and pessimistic durations “deviate” by the same amount from the most likely duration (6 to 8 and 10 to 8). Now, suppose that the pessimistic duration is 13 days, whereas the optimistic and most likely durations are still the same. The expected duration is calculated as 8.5 days, by using equation 11.1. The expected duration value increased as a result of the increase in the skewness of the pessimistic duration. Even though the probability of the occurrence of the pessimistic duration (or the weight) is still the same in both examples (one-sixth), the consequences worsened in the second case.

Is the Longest Path Still the Most Critical?

A typical network project has tens or hundreds (perhaps thousands) of paths. Typically, we define the critical path as the longest path from the start till the end of the network

(see the definition of *critical path* in chapter 4). In addition to the duration, another factor must be considered in the criticality of the path in PERT. This factor is the “uncertainty” of the duration of the path, measured by the standard deviation. Let us look at the following example for an illustration.

Example 11.2

Draw the network for the following project.

Activity	IPA	Duration (Days)		
		Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
A	—	4	5	6
B	A	10	12	14
C	A	7	9	16
D	B	14	17	22
E	B,C	10	15	30
F	C	4	7	13
G	D	12	20	40
H	D, E	10	12	15
I	F, H	8	9	10

Compare the three paths: ABDHI, ABDG, and ABEHI. Calculate the Expected Duration and Standard Deviation for each path. Considering all three paths, what is the duration of the project with at least 95% confidence?

Solution

With regular CPM calculations (using Most Likely durations), the critical path is ABDHI with 55 days followed by paths ABDG and ABEHI at 54 and 53 days; respectively (Figure 11.10). Now, let's do PERT calculations:

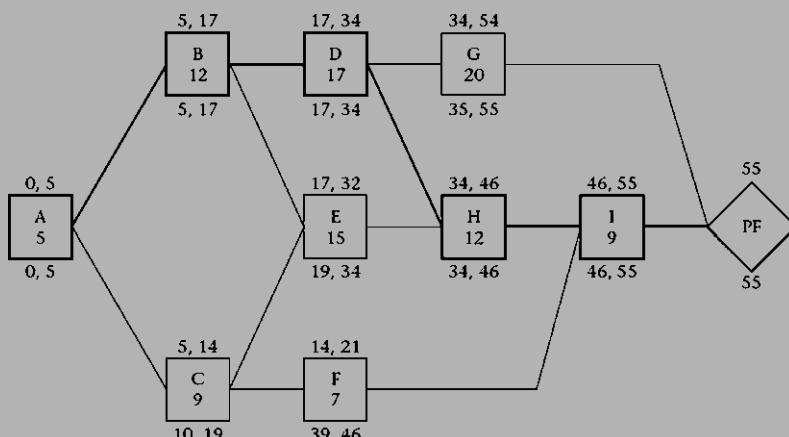


Figure 11.10 CPM network solution to example 11.2

Activity	Duration					
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)	Expected Duration (T_e)	Standard Deviation (σ_e)	Variance ($V_e = \sigma_e^2$)
A	4	5	6	5.00	0.33	0.11
B	10	12	14	12.00	0.67	0.44
C	13	9	16	9.83	1.50	2.25
D	20	17	22	17.33	1.33	1.78
E	10	15	30	16.67	3.33	11.11
F	4	7	13	7.50	1.50	2.25
G	12	20	40	22.00	4.67	21.78
H	10	12	15	12.17	0.83	0.69
I	8	9	10	9.00	0.33	0.11

With regard to path ABDHI,

$$T_E = 5.00 + 12.00 + 17.33 + 12.17 + 9.00 = \boxed{55.50 \text{ days}}$$

$$V_E = 0.11 + 0.44 + 1.78 + 0.69 + 0.11 = 3.14$$

and

$$\sigma_E = \sqrt{3.14} = 1.77 \text{ days}$$

To find the duration with a minimum level of confidence of 95%, find the Z values associated with probability of 0.95. From the table, this Z value is 1.645, and

$$T_S = \sigma_E \cdot Z + T_E = 1.77 \cdot 1.645 + 55.50 = \boxed{58.41 \text{ days}}$$

Applying the same calculations to path ABDG, we find

$$T_E = 5.00 + 12.00 + 17.33 + 22.00 = \boxed{56.33 \text{ days}}$$

$$V_E = 0.11 + 0.44 + 1.78 + 21.78 = 24.11$$

$$\sigma_E = \sqrt{24.11} = 4.91 \text{ days}$$

and

$$T_S = \sigma_E \cdot Z + T_E = 4.91 \cdot 1.645 + 56.33 = \boxed{64.41 \text{ days}}$$

Applying the same calculations again to path ABEHI, we find

$$T_E = 5.00 + 12.00 + 16.67 + 12.17 + 9.00 = \boxed{54.83 \text{ days}}$$

$$V_E = 0.11 + 0.44 + 11.11 + 0.69 + 0.11 = 12.47$$

$$\sigma_E = \sqrt{12.47} = 3.53 \text{ days}$$

and

$$T_S = \sigma_E \cdot Z + T_E = 3.53 \cdot 1.645 + 54.83 = \boxed{60.64 \text{ days}}$$

Let us discuss the results: When we look at the most likely durations (as single-value, or deterministic, durations), path ABDHI is the longest, at 55 days. When we look at the expected durations, path ABDG is the longest, at 56.33 (say, 57) days. When we consider the standard deviation and the 95% required confidence level, the same path, ABDG, is longest (by a larger margin), at 64.41 (say, 65) days. Note also that in this case, path ABEHI is second in importance (at 60.64 days), after path ABDG and before path ABDHI. In other words, the path considered longest by the deterministic CPM calculations was superseded by two other paths considered by PERT to be more critical.

Note: The preceding calculations were done using an Excel spreadsheet. The answers were rounded for simplicity.

Example 11.2 illustrates the importance of considering near-critical paths, especially those with high uncertainty (a large standard deviation). Simulations may be used to determine which path is the most critical.

Using PERT to Calculate the Date of an Event with a Certain Level of Confidence

The main focus in PERT is the event, not the activity.¹ You can use the same probabilistic approach with any event (e.g., delivery of a custom item, the building is watertight, substantial completion). In this case, you consider the path from the start of the project (or data date, if project has already started) until, and including, the event under consideration.

Example 11.3

Calculate the date of completion of activity F in example 11.2 with 90% confidence.

Solution

From the calculation table in example 11.2, we take the path ACF:
(continued)

¹ The terms *event* and *activity* were introduced in chapter 3. An activity has a start date, a duration, and a finish date. An event has just one date (start or finish) with no duration. An event can be the start or finish of an activity.

(continued)

Activity	Duration					
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)	Expected Duration (T_e)	Standard Deviation (σ_e)	Variance ($V_e = \sigma_e^2$)
A	4	5	6	5.00	0.33	0.11
C	13	9	16	9.83	1.50	2.25
F	4	7	13	7.50	1.50	2.25
				$T_E = 22.33$		$V_E = 4.61$

$\sigma_E = \sqrt{4.61} = 2.15$ days The Z value associated with a probability of 95% is 1.645, and

$$T_S = \sigma_E \cdot Z + T_E = 2.15 \cdot 1.645 + 22.33 = 25.87 \text{ days}$$

Note: The preceding calculations were done using an Excel spreadsheet. The answers were rounded for simplicity.

Determining the Probability of a Certain Project Finish Date (Multiple Paths Considered)

In statistics and probability, the probability that two *independent* events will happen simultaneously is equal to the product of the two probabilities:

$$\Pr(A \cap B) = \Pr(A) \cdot \Pr(B) \quad (11.9)$$

Equation 11.9 holds only if events A and B are independent. If they are dependent, the probability that both events will happen at the same time will depend on the correlation between the two events and cannot be defined in one simple equation. For example, in the network of Figure 11.10, paths BDG and CFI may be, but not necessarily, independent. We cannot be sure until we know everything about them. Even though they are not linked with a logical relationship, they could be dependent, for example, if activities on both paths are performed by the same crew or use materials delivered in the same shipment.

Theoretically, if we need to calculate the probability that the project in Figure 11.10 will finish by a certain date, we need to consider all paths. In our small example, we have five paths: ABDG, ABEHI, ABDHI, ACEHI, and ACFI. Since they all share at least one activity, A, they have dependencies. Calculating the probability that the project will finish by a certain date requires not only complicated calculations but also correlation factors between activities that may be difficult to obtain or estimate. In real-life projects, we may have tens, hundreds, or even thousands of paths in a CPM network. For practical reasons, we focus on one path at a time, as we did in the last example.

PERT and the Construction Industry

Even though PERT can be a good tool for predicting event dates, it is rarely, if ever, used in the construction industry. There are four reasons for this:

1. The main area of effective application for PERT is experimental projects or those with a great deal of uncertainty with regard to durations. In construction projects, even if the project design is new, the basic elements of the construction operations are usually well known. Project managers usually feel comfortable with the estimated durations they provide. A good project manager's estimates may be slightly over or under for the duration of individual activities, but the overall duration of the project should be fairly accurate.
2. As shown previously, PERT focuses on a single path. The scheduler must study different paths and analyze them for the highest uncertainty (least likelihood) of meeting a specific finish date. This process may be complicated and time-consuming.
3. Project managers may have a problem providing three durations (optimistic, most probable, and pessimistic) for each activity. During a discussion with the author, one project manager sarcastically said "We can barely come up with one duration per activity, and you want me to provide you with *three* durations?"
4. Many project managers adopt the practice of adjusting and correcting the durations (and possibly the logic) while updating the schedule. Even though we are required to do such adjusting and correcting while updating, this practice must not be an excuse for poorly prepared schedules. The project manager should always remember that the project schedule could be a legal and binding document, as part of the contract. In such a case, it may be used in court later to prove or disprove a delay claim.

PERT and Computer Project-Scheduling Software²

Several computer software programs perform **Monte Carlo simulations**, generating random numbers that follow the distribution of individual activities (optimistic, most likely, and pessimistic, along with their weights). The program generates results for each run. It is typical to do 100 runs or more. The more runs we do, the more confidence we will have in the results. Some products run Monte Carlo simulations in a "generic" environment. Crystal Ball (Decisioneering, Inc., Denver, Colorado) performs risk analysis by using Monte Carlo simulations in MS Excel. Other products tie in with specific scheduling software. For example, Pertmaster³ runs risk analysis by integrating

² There is more discussion on PERT (three-point estimate) and its applications in risk management in chapter 14.

³ Originally Pertmaster Professional Risk, created by Pertmaster Ltd., London, UK, then acquired by Primavera Systems, Inc., and renamed Primavera Pertmaster. With the recent acquisition of Primavera by Oracle, Primavera Pertmaster was again renamed Oracle Risk Analysis.

with Primavera scheduling products. You can assign an uncertainty to activity durations, costs, and resources, then determine the probability of completing the project on time and within budget. Risk (ProjectGear, Inc., Tacoma, Washington) and @Risk (Palisade Corp., Newfield, New York) are compatible with MS Project for calculating risk and probabilities based on PERT calculations. Regardless of the product you use, you must ensure that it integrates with the scheduling program you are using.

Some software companies call precedence network diagrams *PERT*. In most cases, the displayed diagram is nothing but a precedence network applying the deterministic CPM calculations. Because of this, many people in the construction industry began to use the term *PERT* simply, and erroneously, to indicate a CPM logic diagram, as compared with a bar chart. The author has even observed this terminology error in some owners' specifications calling for "PERT reports" to be submitted. The author strongly recommends refraining from this use of the term *PERT*.

GRAPHICAL EVALUATION AND REVIEW TECHNIQUE (GERT)

The **graphical evaluation and review technique (GERT)** is a network analysis technique that allows for conditional and probabilistic treatment of logical relationships (that is, some activities may not be performed) (Project Management Institute 2000). GERT is similar to PERT but considers both deterministic and probabilistic branching. It incorporates both in the network analysis. GERT allows additional branching features not provided by CPM or PERT.

In deterministic branching, as shown in Figure 11.11a, we consider all activities leaving the node. In other words, activities A, B, and C in Figure 11.11a, will all take place. In probabilistic branching, as shown in Figure 11.11b, we consider one branch at any given time. For example, in Figure 11.11b, we consider either A or B. However, the sum of the probabilities for each branch leaving a probabilistic branching must equal 100% (Fair 1994).

Furthermore, GERT allows looping, something both CPM and PERT do not allow. For example, Figure 11.12 shows three possible outcomes following activity A: activity B (with 30% probability), activity C (with 50% probability), *or* activity D (repeat of activity A, with 20% probability). We can think of activity A as Shop Drawing Submittal, activity B as Accepted As Is, activity C as Accepted with Changes, and activity D as Rejected; Resubmit.

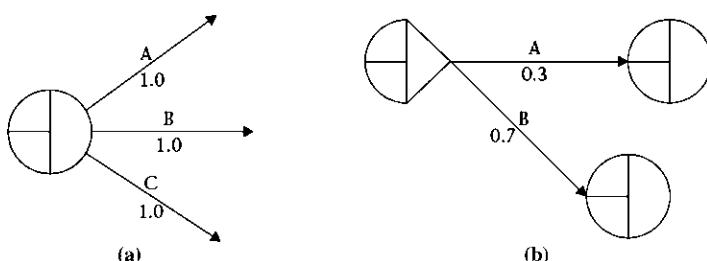


Figure 11.11 (a) Deterministic and (b) probabilistic branching

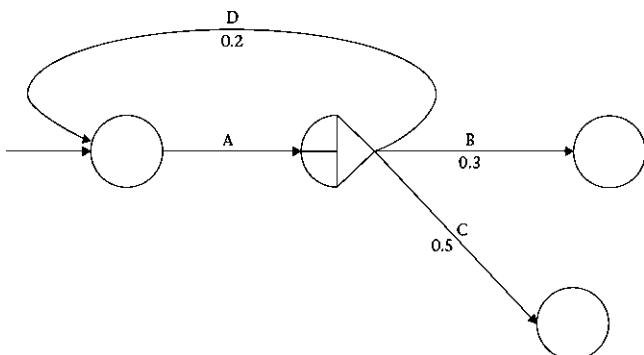


Figure 11.12 Three possible outcomes following activity A

GERT has not gained popularity in the construction industry. In fact, it did not gain any interest beyond some academic research.

LINEAR SCHEDULING METHOD (LSM)⁴

Construction projects differ in type, size, and nature. Scheduling methods also differ in efficacy depending on the type of project they are serving. Bar charts are generally good for small, simple projects.⁵ CPM networks are used for medium-size to large projects that consist of large numbers of small activities. Some construction projects consist of a few activities (usually with large quantities) that must be done in the same order or sequence, such as heavy construction projects such as roads, earthwork, or utility piping. Let us consider a project to lay down 5,000 linear feet (LF) of an underground utility pipe. The basic activities are Excavation, Prepare Subbase, Lay Pipe, Backfill, and Compact. If we are to use CPM networks for this project, we can take one of the following two approaches:

1. Create a project with only five large activities. Connect these activities with start-to-start (with lags) and finish-to-finish relationships.
2. Divide each major activity into a number of activities (e.g., 50 subactivities) in which each represents a distance of 100 LF and connect them with finish-to-start relationships with no lags.

⁴ There are very similar, almost identical, methods to LSM such as Line of Balance (LOB) and Vertical Production Method (VPM). Also, the method is known in some parts of Europe as Time Couplings Method, TCM.

⁵ Practically, bar (Gantt) Charts are obsolete as a scheduling method. However, it is very live and popular as a reporting method for projects scheduled using CPM networks and calculations. In this case, bar charts are effectively used in large projects, focusing on a small group of activities or presenting the schedule in a form of summary activities. Refer to the discussion in chapters 3 and 9.

Steps Required to Build a Schedule by Using the LSM

Three simple steps (similar to the first three steps in the CPM discussed in chapter 4) are necessary to build a schedule by using the LSM:

1. Determine the work activities. As mentioned previously, we expect only a few activities in LSM schedules.
2. Estimate activity production rates. Such estimation is similar to determining durations. We still estimate durations, but we are more concerned with production rates.
3. Develop an activity sequence, similar to determining logical relationships. All relationships are start to start (with lags) with finish to finish.

Before applying the LSM, we must make sure it is the most appropriate method.

How the LSM Works

In the LSM, since the x -axis represents time and the y -axis represents distance, the slope represents the “speed,” or rate, of production (Figure 11.13). When we have two or more activities, the production rate will differ from one to another. The horizontal distance between two lines represents the float of the earlier activity. In the LSM, we call it the *time buffer*. The vertical distance represents the distance separating the two operations. We call it the *distance buffer*. See Figure 11.14.

Lines are not allowed to intersect because an intersection literally means that the successor has gotten ahead of the predecessor, which is impossible (see Figure 11.15).

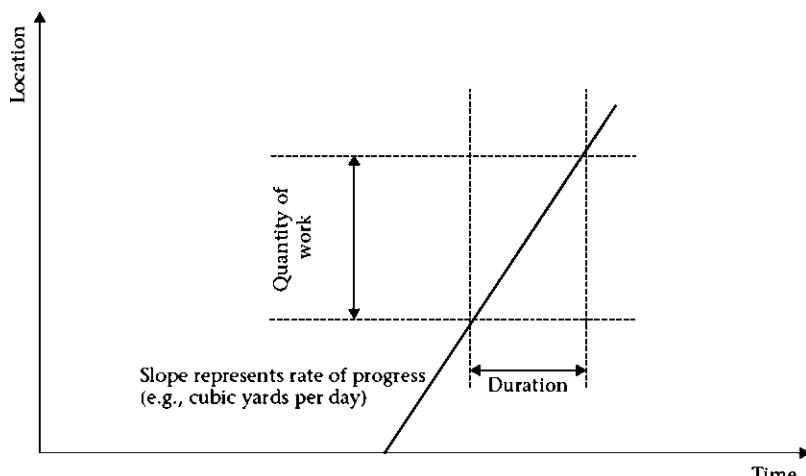


Figure 11.13 The linear scheduling method (LSM)

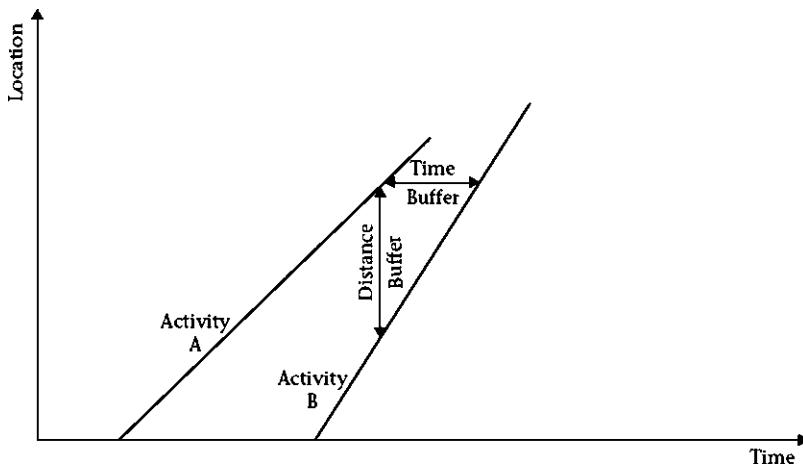


Figure 11.14 Time and distance buffers in the LSM

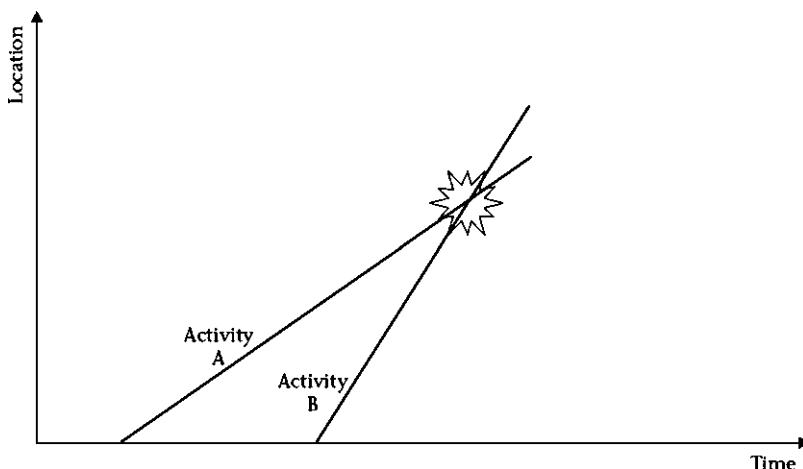


Figure 11.15 A successor's getting ahead of its predecessor: an illegal relationship

Consider, for example, a carpentry crew installing and taping drywall for a total of 10,000 square feet (SF). The production rate for the crew is 500 SF per day for installation and taping. The painting crew is directly behind at a production rate of 800 SF per day. Assume that the painting crew starts on day 2 (1 day after the carpentry crew started), then, at the end of day 3, the carpentry crew would have finished $500 \cdot 3 = 1,500$ SF, but the painting crew would have finished $800 \cdot 2 = 1,600$ SF, which is impossible. There are four solutions for this problem:

1. Speed up the rate of the carpentry crew
2. Slow the rate of the painting crew
3. Make the painting crew start later (calculate the time buffer)
4. Make the painting crew work in intervals: once they catch up with the carpentry team, they stop for a period, resume, and so on

Solution 1 would increase the slope of activity A. Solution 2 would decrease the slope of activity B. Solution 3 would increase the time buffer. All three solutions aim at preventing the intersection of the two lines. Solution 4 would be represented in an LSM diagram as shown in Figure 11.16. The horizontal lines (slope = 0) represent an interruption or stoppage time (no production). If the productivity of the crew changes, the slope changes too. Therefore, alternatively, instead of completely halting activity B during intervals, we can reduce the crew size to slow the rate until there is a safe time buffer (a combination of solutions 2 and 4; see Figure 11.17).

The time buffer is necessary only if the rate of the successor is faster than the rate of the predecessor. If the rate of the successor is slower than that of the predecessor, the time buffer can start at zero. Naturally, the successor (activity B) will finish after the predecessor (activity A). See Figure 11.18.

To calculate the time buffer (Figure 11.19), we start from the end: Allow activities A and B to finish simultaneously. Then,

$$\text{Duration A} = \text{Duration B} + \text{Time buffer}$$

or

$$\text{Time buffer} = \text{Duration A} - \text{Duration B} \quad (11.10)$$

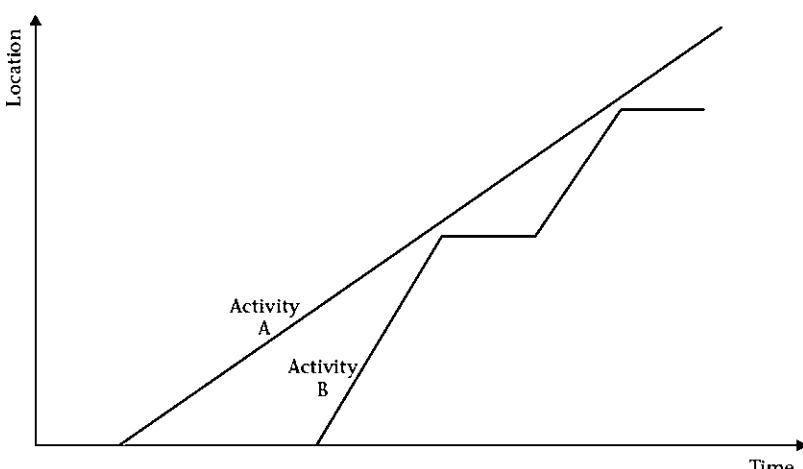


Figure 11.16 Solution 4 for avoiding an intersection in the LSM

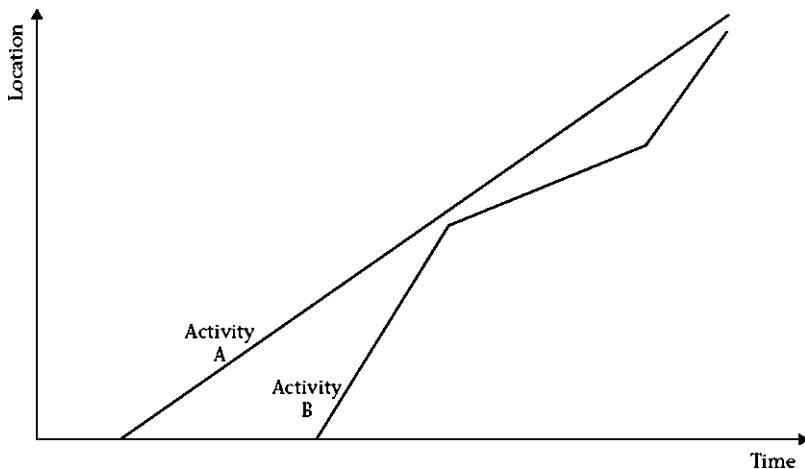


Figure 11.17 Combination of solutions 2 and 4 for avoiding an intersection in the LSM

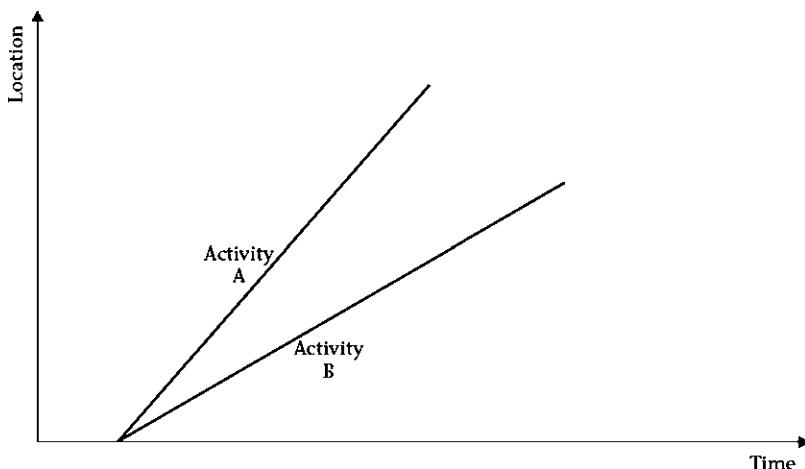


Figure 11.18 Rate of successor slower than rate of predecessor in the LSM

With multiple activities, you must consider two activities at a time. Starting from the beginning, do the following:

1. Compare the durations of activities 1 and 2. If activity 2 has a shorter duration, determine the time buffer from equation 11.10. If activity 2 has a longer duration, there is no need for a time buffer (practically, we need a minimum buffer because a predecessor and a successor cannot start at exactly the same time).
2. Repeat step 1 for activities 2 and 3 and so on.

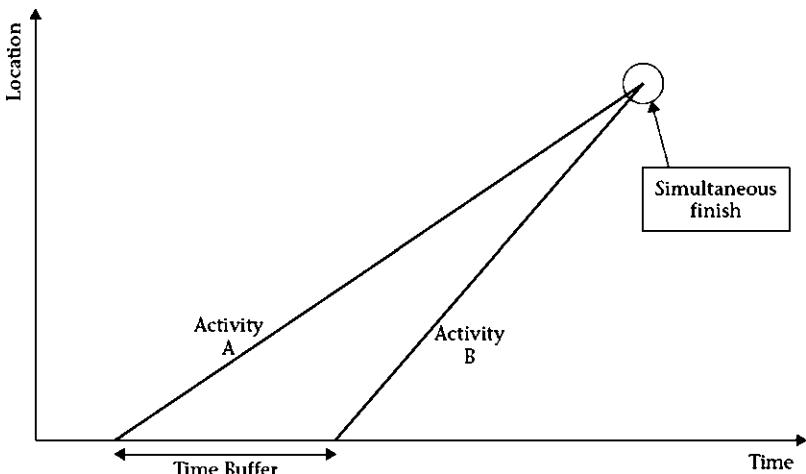


Figure 11.19 Time buffer calculation in the LSM

Example 11.4

A project consists of five activities:

- Excavating a trench
- Laying a subbase of gravel
- Laying a concrete pipe
- Backfilling
- Compacting

Assume that the length of the pipe is 1,000 LF and that the productivity rates for the five activities are 100, 125, 75, 200, and 150 LF per day, respectively. Draw the project diagram, using the LSM. Leave a *minimum* 1-day time buffer.

Solution

First, determine the durations by dividing the total quantity, 1,000 LF, by the production rate for each activity. The following durations result: 10, 8, 14, 5, and 7 days for activities A through E, respectively.

If we start activity A on (end of) day 0, it will finish on day 10. Activity B lasts only 8 days and we must leave at least a 1-day time buffer so that we can finish this activity on day 11. Subtracting its duration of 8 days, we find the starting point: day 3. Activity C lasts 14 days, so we lag it by 1 day and start it on day 4. It will finish on day 18. Activity D can finish no earlier than

day 19. It will start on day 14. Finally, activity E can start on day 15 and finish on day 22. See Figure 11.20.

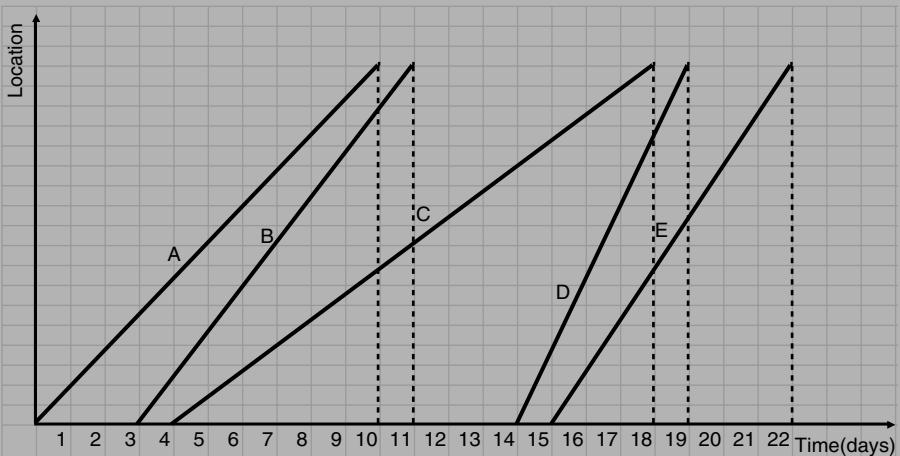


Figure 11.20 Solution to example 11.4

LSM Computer Software Programs

The LSM method has not found a wide acceptance in the construction industry despite its analytical advantages. One drawback appeared to be the lack of major software packages offering LSM capabilities. However, the method is believed to be making a comeback as a growing number of programs are becoming available, commercially as well as academically, that employ this versatile method. Examples include:

- Vico ControlTM (formerly Graphisoft[®] Control/DYNAPROjectTM at Helsinki University of Technology) by Vico Software in Finland
- TILOS by Asta Development in Germany
- Spider Project PM System by Spider Management Technologies in Russia
- PlaNet by Artemis International Solutions in Finland
- LinearPlus Time Chainage Charts by PCF that is part of QEI Exec Project Management Software and was developed for the Channel Tunnel

And the earlier programs include Q. Scheduling by Misronet Construction Information Services, TimeChg 2000 by Peter Clarke, and TransCon Xposition by TransCon Consulting in Richmond, Virginia, now Milestone Consultants.

Researchers at several universities have created prototype software, including UNaLSS (University of Naples Linear Scheduling Software) in 2005 in Italy, PULSS (Purdue University Linear Scheduling Software) in 2001, FLSP (Florida Linear Scheduling Program) in 1999 at the University of Florida, and LCPM (Linear Construction Project Manager) in 1998 at Texas A&M University (Dell'Acqua et al. 2005), as well as PSM (Productivity Scheduling Method) in 2008 at Catholic University of America, LBMS (Location-Based Management System) in 2006 at Swinburne University of Technology in Australia, POLO (Planning & Optimization for Linear Operations) in 1995 at Purdue University, and various other older computer implementations.

LSM has been used in the form of diagrams that were drawn in computer-aided design (CAD) software, for example, for a pipeline project. Finally, any spreadsheet software, for example, Microsoft Excel as well as scientific computing environments, e.g. MATLAB®, can be set manually up to perform calculations and draw linear schedule diagrams that can be updated during project execution.

Graphical Path Method (GPM)⁶

The Graphical Path Method (GPM) was developed by Dr. Gui Ponce de Leon, as an alternative to database-driven CPM models. Rooted in robust mathematics, yet graphical in nature, this interactive tool facilitates hands-on, real-time scheduling. In other words, GPM lets users plan and schedule simultaneously, allowing them to carry out resource leveling, schedule optimization and time/cost trade-offs as the schedule is being built. The goal of GPM is to transform conventional planning and scheduling into an engaging, planning-dominated experience for project stakeholders. This method posits a number of new concepts; *float*, *drift*, *gap*, *buffer*, *proportional link offsets*, and *forensic* are briefly introduced in this summary.

In GPM, planning proceeds by drawing a graph of logically related, dated objects (*activities*, *milestones*, and *benchmarks*) into a project network model. At the core of this model is LDM (Logic Diagramming Method), a blend of both PDM (Precedence Diagramming Method) and ADM (Arrow Diagramming Method). In a way, LDM resembles a time-scaled version of ADM that allows for PDM overlapping logic. With LDM, logic ties have multiple arrowheads. Start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF) logic is accepted through *embedded nodes*, placed in between or directly on an activity's start or finish nodes. Driving relationships are modeled by a common node (FS only) or, owing to the time scale, a *vertical link*. Noncontrolling links include a horizontal leg. Figure 11.21 shows an LDM schedule for sample project.

From links and object dates, GPM continually calculates *gaps* for all links and *floats* for dated objects. Gaps are calculated from the dates of the two connected activities; floats are algorithmically calculated from gaps. An activity that may slip and/or extend to later dates without causing an overrun of project completion (or deadline) has float,

⁶This section was mainly written by the method developer, Dr. Gui Ponce de Leon

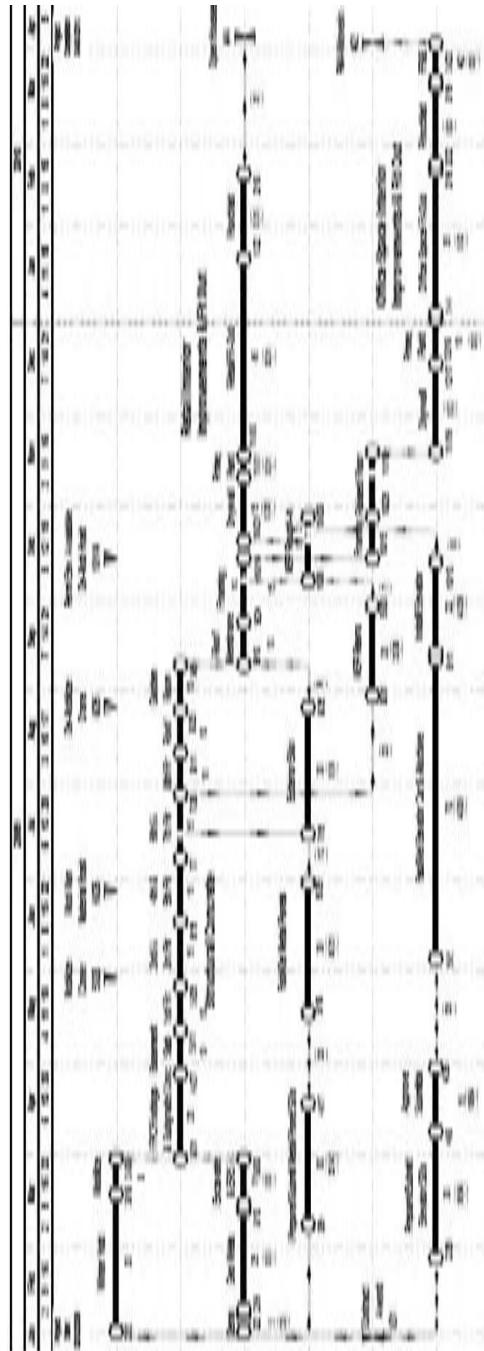


Figure 11.21 Logic Diagramming Method (LDM Notation)

and is a *floater*. An activity that may backslide and/or extend to earlier dates without causing an earlier project start (or release) has preceding float, or *drift*, and is a *drifter*. An activity that has neither float nor drift is *critical*. For every object, float plus drift is a constant equal to CPM total float. In other words:

- Float measures days an activity may slip from and/or extend beyond its planned dates without necessarily overrunning the project completion date or, if applicable, an interim required completion date.
- Drift measures days an activity may backslide from planned dates and/or extend to earlier planned dates without forcing an earlier project start, or if applicable, an earlier stipulated release date.
- For two related activities, gap measures days the predecessor may slip and/or extend before it delays the successor; gap (in this case drift-gap) also measures the number of days the successor may backslide and/or start on an earlier date before it forces the predecessor back.
- Buffer (equivalent of CPM free float) measures the minimum of the gaps on logic ties to the activity's successors. It is a GPM-perfected free float concept as it homogenizes all relationship types to a single formula.

Unique to GPM is that it continuously updates durations, dates, floats, resource profiles, and all schedule data on a real-time basis; as such, it eliminates the black-box mystery behind many CPM applications. Additionally, GPM is not “early date biased,” it allows activities with float to be scheduled anywhere within the float range, focusing on planned dates instead of early dates.

GPM also introduces the concepts of *proportional link offsets* and *forensic float*. Proportional link offsets allow the amount of overlap in a SS, FF, or SF relationship to be contingent upon the duration of the host activity. In many situations, this better reflects the reality in the field than a more traditional, constant overlap does. In addition, GPM has the ability to calculate floats *left of the data date*, that is, for completed activities. *Forensic float* can be crucial to accurately identifying as-built critical paths and facilitates retrospective delay analysis.

Currently, the only GPM software application is NetPoint®. NetPoint is mathematically based and intuitive to learn and use, making it ideal for scheduling practitioners and non-scheduling-trained stakeholders alike. This tool allows project managers, superintendents, subcontractors, and other stakeholders to collaboratively, in one session, build a schedule by graphically positioning activities on a planning surface and using a variety of simple and intuitive logic ties to convey relationships. Development of NetPoint started in 2004 and was commercially released in the fall of 2009. An example of a simple NetPoint schedule is shown in the Figure 11.22. The histogram at the bottom represents resource profiles in color-coded bars, both in daily and cumulative formats.

As a collaboration tool, the NetPoint application provides planning, scheduling, resource management and other project control capabilities similar to what Primavera

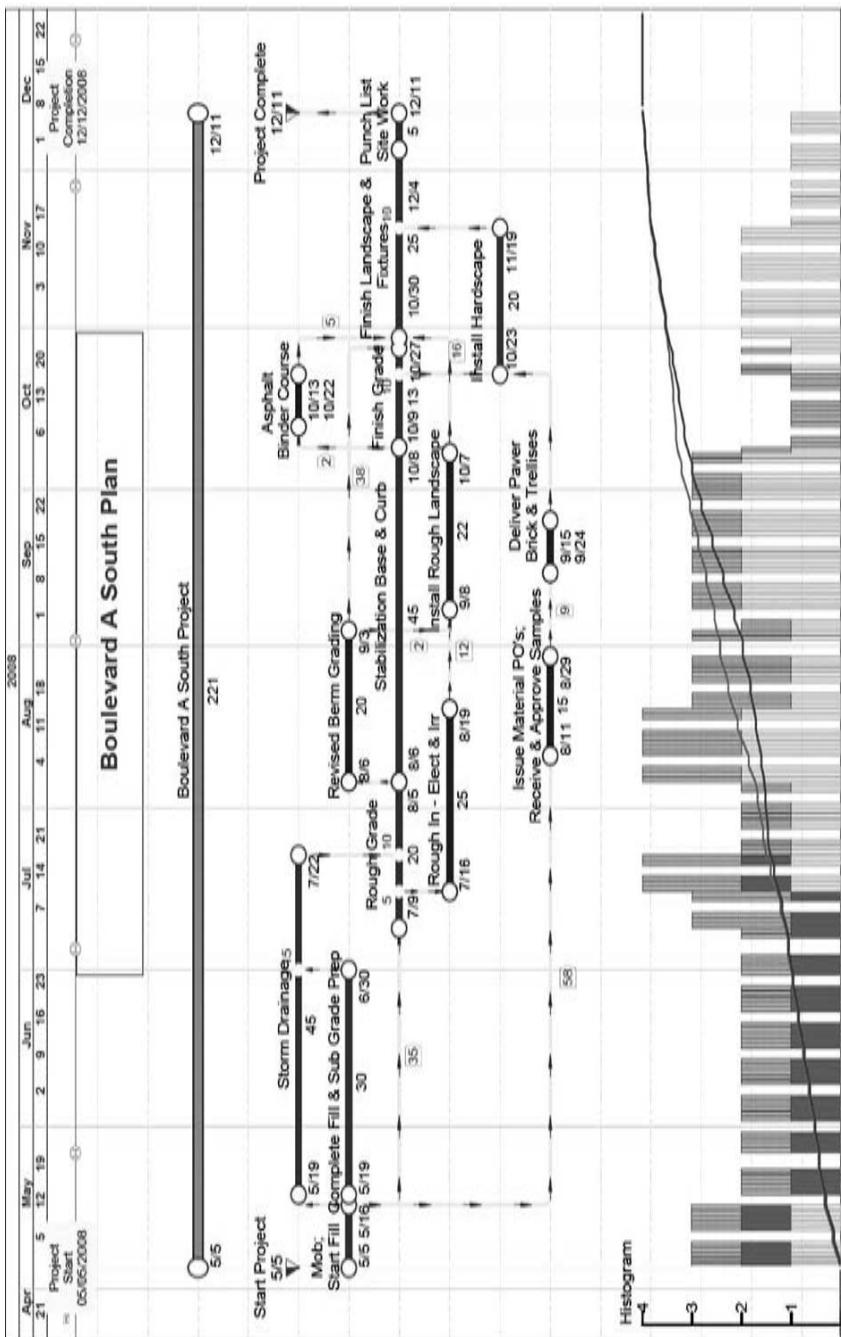


Figure 11.22 NetPoint Schedule with Resources

Project Management and Microsoft Project offer; however, looking within the software architecture, there exist major differences and enhancements that underscore how GPM provides a planning-centric, real-time, collaborative, and intuitive planning environment. Unlike CPM applications anchored in database-driven scheduling engines controlled by keyboard and mouse, NetPoint, as an interactive and object-base system, allows hand-directed planning and scheduling using touch or a stylus.

Relationship Diagramming Method (RDM)⁷

In 2004, The Relationship Diagramming Method, RDM, was introduced by Dr. Fredric Plotnick to address issues resulting from ambiguities of logic in software implementations of Precedence Diagramming Method, PDM. Engineering News Record (ENR) magazine highlighted a number of these issues in a 2003 cover story that cited Dr. Plotnick, a scheduling and legal expert.

RDM started from a premise that ADM (Arrow Diagramming Method) and PDM improve upon the Gantt chart by recording (and use for further calculation) some of the data that the project manager and team considered in preparation of a plan and schedule. However, the quantity of data that could be stored in early computers was limited, and, thus, many assumptions relating to the logic were not recorded. The general solution to the problem was therefore to obtain, record, and then use information relating to these assumptions.

The RDM format begins by allowing the recording of this additional information, and then augments the calculations and resultant data output. While the primary focus of additional recorded data relates to the restraints between activities, including noting the reason why such are provided in both a code format and freeform description, there are five areas of additional information that may be recorded and used for further calculation in the full implementation of RDM. These five classes of information include:

EVENTS: RDM restores the concept of a discrete event at the start and finish of an activity, similar to that of the original ADM format, but adds to such the concept of events *within* an activity whenever the logic restraint between activities relates to completion of some portion of one activity before the start of another, or completion of one activity before starting the final portion of another. Events may also be free standing from an activity as true milestones and as such do not have a “start” date and “finish” date, but rather an “occur” date. A freeform description or “title” may be assigned to an activity, as may be event codes analogous to activity codes supported by many software products.

DURATION: RDM records and utilizes several of the assumptions relating to activity durations. These include the calendar and several other assumptions which are either recorded for all durations via a system setting in some software implementations, or ignored by others which provide only one option. While in most cases, this data will not affect the calculated output for an initial CPM, such may impact calculated output

⁷ This section was mainly written by the idea's developer, Dr. Fredrick Plotnick.

for an update, especially if the progress of the past period is not as was initially planned. The first consideration is to recognize that durations between activities (known as *lag* in the PDM format) are just as important as the durations of activities, and that the duration calendar and other duration codes may be recorded for each such duration. Duration codes include:

P/C/K (Progressed/Clocked/ClockCheck): Durations may indicate work to be performed which must then be monitored during the course of subsequent updates, or merely represent a period of time that will continue without further monitoring once commenced. Curing of concrete is one such example. While actual labor may be required (such as to provide periodic spraying with water) the completion of the activity may be calculated without further monitoring of progress. The ClockCheck option is designed for a special situation where monitoring of progress is not required (or in many cases possible) but completion may and should be noted before scheduling of successor activities. Approval of a shop drawing is an example; once the drawing is submitted, the software will automatically count down the duration of the approval period but will stop at one day for manual verification that the approval has been sent by the engineer to the contractor.

C/I/S (Continuous/Interruptible/Stretched): Where an activity is subject to a restraint to its start and also to its finish (such as by separate SS and FF restraints) the early finish may be later than early start plus duration. Many software products will assume that a project manager will not deploy resources until they may be used continuously and without interruption, and, therefore, the software will recalculate the early start as being equal to the early finish minus the stipulated duration. Where this is done, and is not understood by the user of the software, issues will occur when such activity is connected to yet another by a SS (start-to-start) restraint, which will be based upon the new, delayed early start. While this mode of calculation may be shut off by a system setting in some software, the choice really should be on an activity by activity basis. A third option is to recalculate the duration as being EF – ES, and adjusting resource usage by DUR_{old}/DUR_{new}.

M/R/P (Modified/Retained/ProgressOverride Logic): Where an activity has been performed out-of-sequence, there have (in some software products) been two options on how to calculate the schedule of started-but-not-finished and subsequent activities. The first option is named *Retained Logic*. Here, the original logic is used to schedule the remaining work on the started activity. Therefore continued work on the started activity may not occur until after all predecessors of this activity have been completed. The second, named *progress override*, is to assume that if an activity has started out of sequence, it will most likely continue through the completion and that subsequent activities may also then continue without regard to the uncompleted predecessors of the out-of-sequence activity. Current software offerings either lock into one of these

two calculation models or provide a system option for all activities. RDM provides the choice of option for each activity, and also provides a third option (which is the default setting.) This third option is called *modified logic*, which schedules continuation of the started-but-not-finished activity on the data date but creates a FF, finish-to-finish, restraint on the finish of the activity from the finish of all predecessors to that activity (similarly to the retained logic option.)

Calendar—Shift/Hourly—RDM recognizes that a shift is a discrete time unit and not merely (any) 8 hours. An activity of original duration of 10 days reported 35% complete will calculate a remaining duration of 7 days and not $6\frac{1}{2}$ days. Similarly an activity with 5 days duration, but on a two shifts per day calendar, will then push a successor activity on a one shift per day calendar to start at the beginning of the third day.

RESTRAINT TYPES: RDM recognizes several additional restraint types to the standard PDM choices of FS, SS, FF, and SF (finish-to-start, start-to-start, finish-to-finish, and start-to-finish.) These include a PS and FR (progressed-to-start and finish-to-remainder) restraint, as well as several other specialty restraints beyond the discussion of RDM in this text. RDM recognizes a distinction between a restraint measuring time elapsed from the calculated or reported start of an activity to the start of another, and a restraint from a point (event) within an activity representing some portion completed to the start of another. The first is the traditional SS restraint, but the latter is a new PS or progressed-to-start restraint. Similarly, RDM recognizes a distinction between a restraint from the finish of one activity to the finish of another, possibly with a specified period of delay, and a restraint from the finish of one activity to permitting the continuation and completion of effort on a second activity. The first is the traditional FF, the latter the new FR or finish-to-remainder restraint.

RESTRAINT REASON/WHY: RDM records (or in some instances may calculates) the reason why a restraint has been placed between two activities. The primary reasons are either P (for physical) or R (for resource.) Since one of the attributes of a good CPM is that each activity (other than first and last) must have both a physical predecessor to its start and physical successor to its finish (to avoid issues where a crew shows up to erect a roof and the walls have not yet been erected,) this information may be used to provide a better software diagnostic to assure adherence to this rule. The “why” of the code is typically “gravity” or “contract requirement” for physical restraints, and a listed resource or activity code (such as subcontractor) for the resource restraints. The codes may be augmented by a freeform description or title assigned to *the restraint*, similar to that provided to activities. A special form of the physical reason/why is coded as J (for just-in-time) and is used in calculation of a second backward pass for determination of the latest dates of predecessors to support the early start of the immediate successor to the J restraint. Other special forms are used in automated leveling routines and are beyond the scope of discussion of RDM in this text.

RESTRAINT RELATIONSHIP: RDM calculates and records the various relationships between the two activities (or events) at the start and finish of a restraint. This calculation may be performed on all activity (or event) codes (including resource

codes) and registers when such change. This, in turn, may be used to create custom reports to highlight when there is a handoff between crafts or subcontractors (calling for greater supervision by the project manager,) or when a crew moves from one location to another (calling for a manual or automated check for a *lag* duration to account for moving of forms and equipment.) Comparison of the two sets of activity codes may result in equal, not equal, greater than, lesser than, one (or both) code fields blank, or other noted relationships. (An increasing or decreasing crew size would be one example for differential comparison.)

The implementation of RDM in commercial software is in its infancy. Primavera Pertmaster⁸ is currently the only product that implements this concept. More information can be obtained at www.RDCPM.com

CHAPTER 11 EXERCISES

1. What do the acronyms PERT, GERT, and LSM stand for?
2. What is the main concept of PERT?
3. How does the PERT method work?
4. What are the main differences between CPM and PERT?
5. In a CPM network, the critical path has five activities. Their durations are tabulated next.

Activity	Duration (Days)		
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
A	2	5	9
B	3	4	8
C	4	6	9
D	5	10	20
E	3	5	9

Compute the following:

- a. The probability that the project will finish by the end of day 32
- b. The probability that the project will finish by the end of day 34
- c. The probability that the project will finish before day 30
- d. The probability that the project will finish on the 32nd day
- e. The probability that the project will finish no later than the 35th day

⁸ Primavera Pertmaster has been renamed Oracle as Risk Analysis in the recent acquisition to Primavera by Oracle.

- f. The probability that the project will finish at least 2 days early
 - g. The probability that the project will finish at least 2 days late
 - h. The probability that the project will finish on the 32nd day ± 1 day
 - i. The completion date with at least a 90% confidence level
6. In a CPM network, the critical path has five activities. Their durations are tabulated next.

Activity	Duration (Days)		
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
A	4	6	9
D	6	10	15
G	7	11	15
H	10	20	36
M	8	10	14
O	4	5	8

Compute the following:

- a. The probability that the project will finish by the end of day 64
 - b. The probability that the project will finish by the end of day 65
 - c. The probability that the project will finish before day 60
 - d. The probability that the project will finish on the 62nd day
 - e. The probability that the project will finish at least 6 days early
 - f. The probability that the project will finish no more than 4 days late
 - g. The completion date with at least a 95% confidence level
7. In a CPM network, the critical path has six activities. Their durations are tabulated next.

Activity	Duration (Days)		
	Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
B	2	3	5
D	4	8	13
F	5	6	8
K	3	3	3
N	7	10	15
S	3	5	8

Compute the following:

- a. The probability that the project will finish by the end of day 36
 - b. The probability that the project will finish by the end of day 39
 - c. The probability that the project will finish before day 38
 - d. The probability that the project will finish on the 35th day
 - e. The probability that the project will finish at least 3 days early
 - f. The probability that the project will finish more than 4 days late
 - g. The completion date with at least a 90% confidence level
8. Draw the network for the following project. Perform the CPM calculations on the basis of the most likely durations. Pick the longest three paths. Calculate the expected duration and the standard deviation for each path. Considering all three paths, what is the duration of the project with at least a 90% confidence level?

Activity	IPA	Duration (Days)		
		Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)
A	—	4	6	11
B	—	3	4	6
C	—	6	9	15
D	A, B	3	4	11
E	B	5	7	10
F	D	4	5	8
G	D, E	7	10	16
H	C, F, G	6	8	10
I	C, G	3	3	5
J	H, I	2	2	2

9. What is the risk of using PERT and focusing on the critical path only?
10. What types of projects are best for the PERT application?
11. Is PERT popular in the construction industry? Why?
12. What is the main difference between PERT and GERT?
13. What types of projects are best for the LSM application?
14. What are the steps for preparing an LSM schedule?
15. Define *time buffer* and *distance buffer*. Use words and graphs to explain your answer.

16. Draw an LSM schedule for a 5-mile stretch of a road project. Consider the following activities:

Activity	Daily production (LF)
A. Excavation	500
B. Subbase	300
C. Base	240
D. Paving	1,000
E. Striping and Signage	1,500

17. Draw an LSM schedule for a 2-mile road-resurfacing project. Consider the following activities:

Activity	Daily production (LF)
A. Milling	2,000
B. Structural Course	1,000
C. Friction Course	800
D. Striping and Signage	1,200

Chapter **12**

Dynamic Minimum Lag Relationship¹



Mirage JW Marriott Hotel - Cairo, Egypt

¹ This is a new concept in CPM scheduling, introduced by the author and presented in both the PMI-College of Scheduling Fifth Annual Conference in Chicago, April 2008, and the PMI Global Congress in Colorado, October 2008.

INTRODUCTION

When the critical path method (CPM) was introduced in the late 1950s as a tool for scheduling projects, activity on arrow (AOA) networks were used for depicting the logic and performing the calculations. There was only one type of logic relationship: finish-to-start (FS). Shortly later, activity on node (AON) networks were introduced but also with FS relationship only; however, they were capable of incorporating lags. In the early 1960s Stanford Professor John Fondahl introduced precedence diagrams with four types of relationships: finish-to-start (FS), start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF). Precedence diagrams revolutionized project scheduling because they accommodated overlapping activities for the first time in CPM networks without the need to split them.

The Dynamic Minimum Lag (DML) is a new type of relationship in CPM networks. Unlike the SS and FF relationships, the DML relationship is dynamic, not stationary at the start or finish points of the predecessor or successor activities. It moves along the work progress in the successor activity in parallel to work progress, not allowing the successor to get ahead of (or undesirably close to) the predecessor, see Figure 12.1. It maintains a minimum lag between the successor and the predecessor during the entire course of work progress.

WHY DML?

Traditionally in precedence networks, overlapping activities are connected with an SS, an FF, or—in most cases—a combination SS + FF relationship. If productivity is assumed to be linear in both the predecessor and the successor, *and if* actual work progress conformed to the estimated productivities and durations, then the DML relationship will act the same as the SS and/or FF relationship.

However, we all know that things rarely if ever go as planned. There are many situations where the successor can—theoretically—get ahead of the predecessor or be within less than the specified lag:

Definition: The Dynamic Minimum Lag (DML) is a new type of logical relationships in critical path method (CPM) scheduling. The DML relationship is dynamic; moving along with the predecessor and successor activities, in parallel to work progress, to ensure that the minimum lag is maintained at all times, not just at the start or finish.

Assumption: The DML assumes that the predecessor activity can take any type of linear or nonlinear distribution. The successor activity, however, is assumed linear.



Figure 12.1 The Dynamic Minimum Lag (DML) relationship

² Refer to Linear Scheduling Method, LSM, in chapter 11.

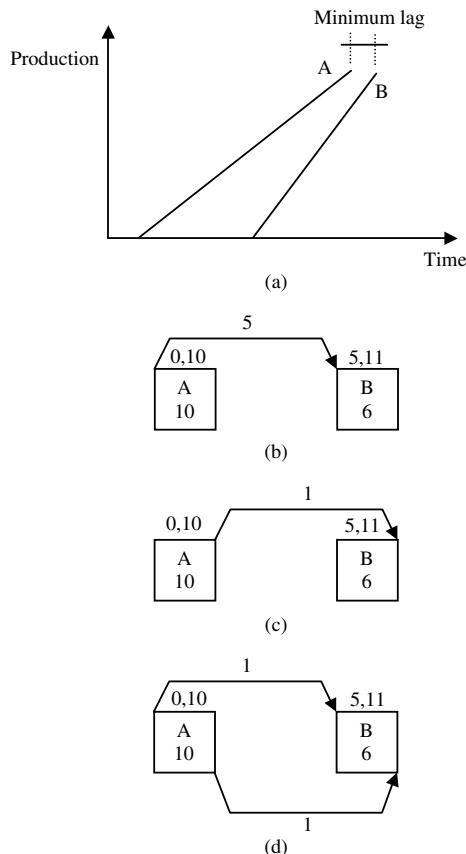


Figure 12.2 Two overlapping activities represented in LSM graph and three different PDM networks (SS, FF, and SS + FF), all leading to the same dates. Activities are assumed to be contiguous.

SIMILARITY OF DML CONCEPT WITH LINEAR SCHEDULING METHOD (LSM)

The DML relationship is similar to LSM method² in maintaining a distance or time buffer (see Figure 12.2a), but they are not the same. There are two main differences:

1. LSM is a different scheduling method from CPM and cannot be implemented in network scheduling or use CPM calculations. DML is just a logical relationship that is fully compatible with CPM calculations and network scheduling.
2. DML works with linear and nonlinear productivities for the predecessor (the successor is assumed linear), while the LSM (as the name implies) works strictly for linear activities.

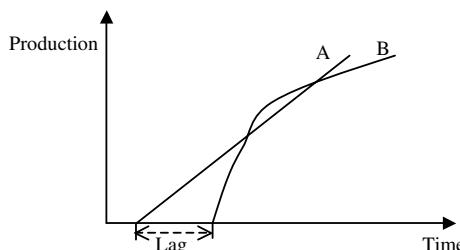
HOW DOES THE DML WORK?

We start with the percent complete (PC) of both predecessor and successor activities:

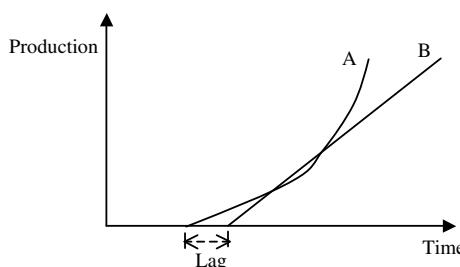
$$PC_A > PC_B$$

The successor is still assumed to be linear, while the predecessor can follow any productivity distribution (cases in Figures 12.3b and 12.3c can be implemented by DML relationship, but the case in Figure 12.3a cannot). If we assign a minimum lag, L, then:

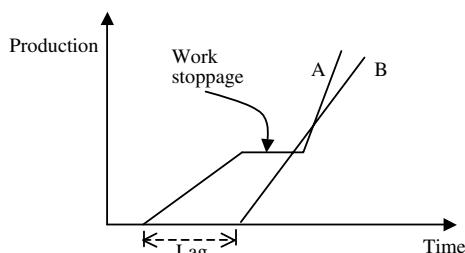
$$PC_A \geq PC_B + L(\text{days}) \quad (12.1)$$



a. Activity B has nonlinear (parabolic) productivity



b. Activity A has nonlinear (hyperbolic) productivity



c. Activities A and B have linear productivities
but activity A has a work stoppage

Figure 12.3 Cases where the successor (activity B) has gotten ahead of the predecessor (activity A) at some point although there was no violation of the traditional SS and FF relationships

However, the equation above is not homogeneous; percent complete is unitless, while the lag has a time unit (day). In order to correct the equation, we need to analyze the percent complete to its basic components:

$$PC = \frac{AD}{ACD} = \frac{AD}{(AD + RD)} \quad (12.2)$$

Where:

AD: Actual duration

ACD: At completion duration

RD: Remaining duration

Substituting equation (12.2) for Activity B in equation (12.1):

$$PC_A \geq \frac{AD_B + L}{AD_B + RD_B} \quad (12.3)$$

All of the four variables in equation 12.3 are usually assigned by the user; however, the lag (*L*) is set when creating the schedule. The predecessor's percent complete, *PC_A*, is assumed to be given (reported/estimated by the field team). This leaves us with the successor's durations, *AD_B* and *RD_B*; if one is given by the user (known), the other one is calculated by the equation:

$$\begin{aligned} PC_A \cdot (AD_B + RD_B) &\geq AD_B + L \\ RD_B &\geq \frac{AD_B(1 - PC_A) + L}{PC_A} \end{aligned} \quad (12.4)$$

Since this is an “inequality,” *RD_B* has to be equal to or greater than the right-hand side. So, in a software program case, the program calculates the minimum value for *RD_B* but the user can override it with a larger, not a smaller, number.

It is also possible—although not recommended—to allow the user to give the *RD_B*. In this case, equation 12.3 will solve for *AD_B*, that is, limit its value:

$$AD_B \leq \frac{PC_A \cdot RD_B - L}{1 - PC_A} \quad (12.5)$$

Similarly, the software program calculates the maximum value for *RD_B*, but the user can override it with a smaller number.

When using the DML relationship, the software program should use equation 12.4 as the default, that is, *AD_B* is given and *RD_B* is calculated. The software program may give the user the option to reverse the rule.

DML RELATIONSHIP IN THE CPM CALCULATIONS

When creating a schedule for a project, obviously all activities are 0% complete before the start of the project. The DML equation 12.4 can not be applied, since it will involve division by zero. For this reason, the calculations (manually or by the software program)

will implicitly include both SS and FF relationships. The SS relationship applies till the predecessor starts so the denominator in equation 12.4 becomes greater than zero and the DML relationship is now active. Practically the DML equation does not differentiate itself from the SS relationship till the successor starts. The FF relationship may be needed only to compare results to RD_B , calculated by DML equation, where the greater value governs as will be demonstrated in the Examples 12.1 and 12.2.

However, when the user assigns a DML relationship, there should be no need to add SS and FF relationships, as these two relationships should be automatically built in with the DML relationship, that is, in the mathematical background. More clearly: The difference between the DML relationship and the current SS + FF combination relationship is that the latter guards against the successor activity violating the lag with the predecessor activity when it starts and when it ends. The DML relationships does that but, in addition, guards against the violation of the lag during the entire duration of the successor activity.

DML relationship also works (with the same equations above) with interruptible (noncontiguous) activities. However, the user has to be careful in defining actual duration, AD , and at completion duration, ACD , so they will not include unproductive time (see note 4 of “Important observation on example 12.1”).

Rounding Numbers: Since most schedulers use the “day” as the unit of time, software programs need to round up RD_B to the nearest larger day (or unit of time) in equation 12.4 and truncate AD_B to the nearest smaller day (or unit of time) in equation 12.5.

Note of Caution: Percent complete may be interpreted differently by different people in different situations.³ Software programs have numerous types of activity percent complete. For DML calculations, percent complete is strictly defined in equation 12.2 above.

CAN THE LAG IN THE DML RELATIONSHIP BE A PERCENTAGE?

It depends on how we define the percentage: If the SS + 20% relationship shown in Figure 12.4 means a constant lag of 20% of the original duration of activity A, that is, $20\% * 8 = 2$ days, then it becomes just like a fixed time duration (unless the original duration of activity A changes during updates to be replaced by the At Completion Duration). In this case, the implementation in the DML relationship is possible using the same methodology and equations explained earlier.

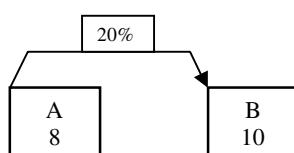


Figure 12.4 SS Relationship with a percent lag

³ Check discussion on Percent Complete in chapter 7.

However, if the lag in Figure 12.4 means 20% of the remaining duration of activity A, then this lag gets smaller and smaller as work progresses till it becomes zero towards the end, that is, simultaneous finish. This understanding of the percent-lag negates the premise of DML (of maintaining a minimum lag) and is not compatible with the DML equations.

Example 12.1

Assume the following two activities:

Activity Title	Original Duration (days)
Roof Sheathing	20
Install Shingles	16

We need to maintain at least a one-day lag between the two activities at all times. Activities are contiguous. Assume activity B (Shingles) to be linear.

Project Update and Solution

1. Using traditional CPM relationships, we calculate the regular early and late dates for both activities at day 0, that is, before any work occurs:

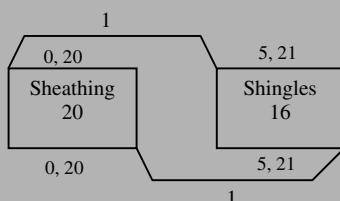


Figure 12.5 Activity A (Sheathing) as the predecessor and Activity B (Shingles) as the successor

2. By day 10 (end of day 10): Assume only 40% of activity A (Sheathing) is completed:

Activity A: Started on time: end of day 0, that is, beginning of day 1

Actual duration = 10 days

Remaining duration = 10 days (productivity will pick up in the last 10 days)

At completion duration = 20 days

Activity B: Started end of day 3, that is, two days earlier than scheduled.

Actual duration = 7 days

Remaining duration = 11 days (Assuming the end of activity A + 1 day)

Using DML Equation:

$$RD_B \geq \frac{AD_B(1 - PC_A) + L}{PC_A}$$

$$RD_B \geq [7(1 - 0.40) + 1]/0.40 = 13 \text{ days}$$

Finish date for Activity B \geq day 23 not day 21 as calculated by the FF relationship.

3. Day 15: Assume only 70% of activity A (Sheathing) is completed:

Activity A:

Actual duration = 15 days

Remaining duration = 5 days

At completion duration = 20 days

Activity B:

Actual duration = 12 days

Remaining duration = 6 days (Assuming the end of activity A + 1 day)

Using DML Equation:

$$RD_B \geq \frac{AD_B(1 - PC_A) + L}{PC_A}$$

$$RD_B \geq [12(1 - 0.70) + 1]/0.70 = 6.6 \text{ say 7 days}$$

Finish date for Activity B = day 22, not day 21 as calculated by the FF relationship.

4. Assume there was work stoppage between day 10 and day 15:

Activity A is still 40% complete:

Activity A:

Actual duration = 15 days (including stoppage)

Remaining duration = 12 days (estimated)

At completion duration = 27 days

Activity B:

Actual duration = 12 days

Remaining duration = 13 days (Assuming the end of activity A + 1 day)

Using DML Equation:

$$RD_B \geq \frac{AD_B(1 - PC_A) + L}{PC_A}$$

$$RD_B = [12(1 - 0.40) + 1]/0.40 = 20.5 \text{ say } 21 \text{ days}$$

Finish date for Activity B = day 36.

Discussion on Example 12.1

1. The DML equation is independent of the estimate of Activity A's remaining duration. It is rather dependent on its percent complete. For example, in part 4 above, the scheduler may not have updated the remaining duration of Activity A, so it shows only 5 days. The DML equation still gives the same answer for RD_B , that is, 21 days. This is particularly important in the event when production in an activity differs from reality and the scheduler fails to adjust/update the remaining duration.
2. The DML equation is dependent, however, on the actual duration of Activity B. For example, if Activity B in the previous example had started at end of day 5, not 3, its remaining duration, according to the DML equation, would be different:

In part 2, after 10 days: $RD_B \geq [5(1 - 0.40) + 1]/0.40 = 10$ (versus 13 days)

In part 3, after 15 days: $RD_B \geq [10(1 - 0.70) + 1]/0.70 = 5.7$ (versus 6.6 days)

The explanation for this observation is simply in the assumption of linearity of Activity B: If it took a number of days to reach the current situation (AD), it will take a proportional number of days to complete the activity (RD). With a smaller AD and constant percent complete, we are assuming a higher productivity. Thus, the remaining duration will be less.

3. Remember the assumption of linearity for the successor. If, however, this assumption does not hold, as in the case where the production rate is known to increase later, the scheduler may not use the DML relationship.

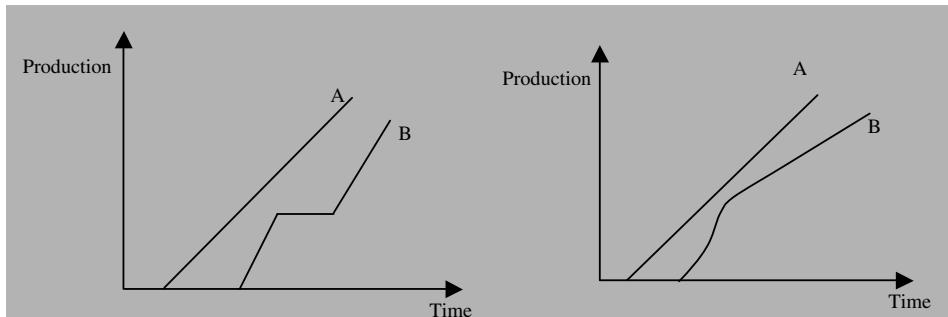


Figure 12.6 Cases where the DML relationship does not work because the successor's production is nonlinear or linear with changing production rates

4. The result of part 4 in Example 12.1 seems too high. It is, because the value used for AD_B includes unproductive time (days 11 through 15). This is generally a problem that software programs need to address in calculating production rates (Quantity/Duration) and true percent complete. For example, the production rate for Activity A till end of day 15 should be:

Performed work (Quantity)/Productive duration (i.e., 10 not 15 days)

Another point to be taken in consideration: Did the work stop in Activity B during all or part of the stoppage of Activity A? If yes, then what is the true actual duration for Activity B? If we assume that Activity B stopped when Activity A did, then $AD_B = 7$ days and RD_B is calculated same as in part 2 earlier, that is, 13 days.

This is an important point, in general, for calculating actual duration, AD , and at completion duration, ACD . These two variables are part of the calculation of production rates and percent complete, two very important parameters in project management, not only in scheduling but for estimating and finance as well.

Example 12.2

In the previous example, let's take a different and opposite case: The production in the predecessor activity (Sheathing) was faster than estimated.

Project Update and Solution

Using traditional CPM relationships:

1. Day 10 (end of day 10): Assume 70% of activity A (Sheathing) is completed:

Activity A: Started on time: end of day 0, that is, beginning of day 1
 Actual duration = 10 days
 Remaining duration = 10 days (no update was done)
 At completion duration = 20 days

Activity B (Shingles): Started end of day 3, that is, two days earlier than scheduled.
 Actual duration = 7 days
 Remaining duration = 11 days (Assuming the end of activity A + 1 day)

Using DML Equation:

$$RD_B \geq \frac{AD_B(1 - PC_A) + L}{PC_A}$$

$$RD_B = [7(1 - 0.70) + 1]/0.70 = 4.43, \text{ say } 5, \text{ days}$$

This result sounds like a violation of the FF relationship with Activity A, which puts the remaining duration of Activity B at 11 days. In reality, the remaining duration of Activity A will be, most likely, a lot less than 10 days. Assuming linear production: If Activity A reached 70% completion in 10 days, it can reach 100% in $10 * (100\% / 70\%) = 14.29$ days, that is, the remaining duration = 4.29 days, which is slightly less than the 4.43 days calculated by the DML equation as the minimum for RD_B . Practically, RD_A and RD_B can be 4 and 5 or 5 and 6 days, respectively.

2. Repeat step 1 assuming that Activity B started as scheduled, that is, at the end of day 5.

Activity B (Shingles):

Actual duration = 5 days

Remaining duration = 11 days (Assuming the end of activity A + 1 day)

Using DML Equation:

$$RD_B \geq [5(1 - 0.70) + 1]/0.70 = 3.6, \text{ say } 4, \text{ days}$$

Same previous argument applies: RD_A and RD_B will most likely be 4 and 5 days, respectively.

CONCLUSION

The DML relationship is a new and potentially useful concept in project scheduling. It should be used mainly for the situation involving overlapping activities when the predecessor has to stay ahead of the successor by a certain margin from start to finish. For example in building construction, this relationship can be used for the series of four activities: framing, drywall, pasting and taping, and wall painting. In infrastructure construction, it can be used for trench excavating, subbase, laying pipe, backfilling, and compaction operations. There are numerous applications in all types of projects.

The DML relationship eliminates the need for the SS + FF combination relationship and most of the cases where a single SS or FF relationship is used.⁴ However, there will be a few cases where a single SS or FF relationship is still used. For example, in the case of a developer who is planning to build an apartment complex on a large piece of land.

In this case, the developer needs to “Clear and Grub” a certain portion of the land where the building will be erected. There is no connection between the finish “Clear and Grub” and “Excavate.” The scheduler in this case has to make sure that the minimum required percentage of “Clear and Grub” is completed before the excavation can start. A safer way to depict that logic is demonstrated in Figure 12.8.

An example of FF relationship dependency that does not require a DML relationship is the situation in Figure 12.9. The Landscape activity’s start is independent of Parking Lot activity, but you need to finish the Parking Lot before you can finish the Landscape.

The DML relationship is a new concept. It may, and most likely will, need more research and fine-tuning before it is applied commercially.

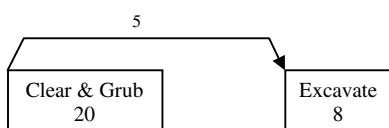


Figure 12.7 A case where DML relationship cannot be used in lieu of SS relationship

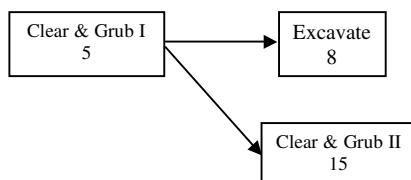


Figure 12.8 A better alternative to depict the logic of the network in Figure 12.7

⁴ As explained earlier, the SS and FF relationships’ calculations will be included with the DML calculations but will not appear to the user because they will be in the background. In other words, the user will only assign a DML relationship, not a combo.

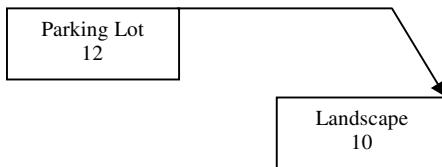


Figure 12.9 A case where DML relationship cannot be used in lieu of FF relationship

CHAPTER 12 EXERCISES

1. What is the main idea of the DML? What makes it different from the logical relationships of the precedence diagramming method, PDM?
2. Give two examples of construction work (combination of 2 to 4 activities, each) that DML would be suitable for.
3. What are the limitations of the DML?
4. For the following two activities:

Activity Title	Original Duration (days)
A. Trench Excavation	18
B. Laying Pipe	13

we need to maintain at least one day lag between the two activities at all times. Activities are contiguous. Assume activity B (Pipe) to be linear. What is the minimum RD_B according to DML equation in these stages? What is the RD_B you should consider, taking into consideration both the DML and the FF relationships?

- a. After 5 days, activity A is 25% complete. Activity B started two days early, that is, $AD_B = 1$ day
- b. After 8 days, activity A is only 30% complete. Activity B's $AD_B = 4$ days. Assume that activity A will finish on time.
- c. After 10 days, activity A is still 40% complete. Activity B's $AD_B = 6$ days. Assume that activity A will finish on time.
- d. After 13 days, activity A is 70% complete. Activity B's $AD_B = 9$ days. Assume that activity A will finish on time.
5. What is the challenge in taking the lag in the DML relationship as a percentage of the predecessor's duration?
6. Give an example of an SS relationship that should not be replaced by a DML relationship.
7. Give an example of an FF relationship that should not be replaced by a DML relationship.

Chapter **13**

Construction Delay and Other Claims¹



Khalifa Sports Hall - Qatar

¹This chapter was written with contributions from Attorney Barry B. Bramble, Regional Director, Trett Consulting, Houston, Texas.

Preface: Construction delays and their resolution is a complicated subject. Many attorneys retain consulting engineers, schedulers, and other experts to assist them in understanding the technical issues that arise in construction-related cases as well as to provide expert witness testimony. Some attorneys have gone back to school to obtain college degrees in engineering and construction in order to acquire technical knowledge in addition to their legal knowledge.² Many books, seminars, and organizations have been dedicated to this subject. This chapter is merely a touch on the subject with some “common-sense” concepts and general outlines. The author strongly commends that readers refer to books and specialized sources for in-depth study.

Introduction: In the simplest definition,³ a delay is the action or condition that results in finishing the project later than stipulated in the contract. A delay can also pertain to starting or finishing a specific activity later than planned. On the other hand, a claim is a request from one contract party (usually the contractor) to another party for additional compensation, an extension of time, or both. If we put the two terms together, a delay claim simply means a claim related to a delay.

As is well known, construction projects involve many risks because things rarely, if ever, go as planned. As a result, claims have become almost inevitable in construction projects.

Claims can be initiated by any project participant against any other participant. An architect may have a claim against an owner or vice versa. A supplier may have a claim against the contractor or the owner, and so on. Since the contractor is the party that is usually responsible for performing the physical work in the project, and since the contractor does not traditionally have a contracting relationship with the designer (A/E), most claims are initiated by the contractor against the owner.

It is important though to note that a claim is not necessarily a negative thing nor does it automatically indicate a confrontation. Many claims are legitimate and are routinely resolved to the satisfaction of both parties.

Delay claims: A delay claim can be for an extension of contract time, monetary compensation, or both. Delays are also classified into excusable, compensable and nonexcusable (explained later).

A claim for only monetary compensation often forms the basis for a change order (CO). A change order may be initiated upon the request of the owner, contractor, subcontractor, and so on. For example, an owner may wish to change the color of the brick, the type of floor tile, or the light fixtures. Such a change order may be initiated by the owner submitting a change order request of work directive. This could be an owner’s decision or a “what-if” inquiry. In the latter case, the owner sends a request for a change order price or quotation,⁴ along with relevant architectural/engineering details (drawings/specifications) if necessary, to the contractor. The contractor

²Conversely, some engineers and architects go to law schools and become lawyers, utilizing their technical background.

³In the construction management context.

⁴Some contractors called it “Request for Price”, however, it should not be abbreviated as RFP which is an industry acronym for “Request for Proposal.”

evaluates the new changes, including their impact on its work plan, and issues a quote to the owner. The contractor's change order proposal or quote typically includes a cost estimate but may also include an impact on the schedule. In response, the owner accepts, rejects, or negotiates this quotation with the contractor. Once the owner and contractor agree on the price and/or schedule change, the owner issues a change order. The change order signals the owner's acceptance of the cost and other terms already agreed upon with the contractor, and authorizes the contractor to execute the work. A change order can be for an addition, deletion, or substitution to original contract. An example of a deletion change order is an owner deleting a swimming pool from a contract to build a house. In such cases, most contractors issue a partial credit that is smaller than the amount originally estimated in the contract for that item.

For this reason and in order to minimize the number of change orders, owners are strongly recommended to do a thorough job in defining the scope of the project and selecting a competent designer or architect/engineer (A/E). Many projects suffer from the "cost-creep" syndrome⁵ when change orders keep adding to the project budget and put it at levels far beyond what the owner originally planned. From the contractor's perspective, change orders may be a source of headache, but they can be a source of extra income. Many experts contend that if all change orders were taken in consideration prior to designing the project, the total cost to the owner would be a lot less. Some owners, when not sure about certain major items, bid projects with alternates. For our example, the base bid can be the house without a swimming pool with an alternate to add a pool. In this case, the bidder must provide a base bid price and an additional amount for the pool in case the owner decides to add it. If the owner is leaning more toward including the pool, he/she may include the pool in the base bid with an alternate to omit it.

Timing of the changes makes a big difference, too. The later the change is made, the more expensive (and perhaps more time-consuming) it gets. Let's take a simple example: An owner decides to change a few doors from 2 feet 8 inches wide to 3 feet 0 inches wide. Let's consider the following five different scenarios along with the cost associated with each:

Scenario 1: The owner makes the change before design is done. The cost is minimal: (the difference in the door prices).

Scenario 2: The owner makes the change after design is done but before bidding. There may be a minor additional cost associated with the architect redoing some of the drawings and specifications.

Scenario 3: The owner makes the change after signing the construction contract but before doors are delivered and work in that portion has started. The cost may still be small, but this has become a change order. The contractor may try to make some "extra profit" there.

⁵ Directly related to the "scope creep".

Scenario 4: The owner makes the change after the door openings have been framed (in masonry walls) but before the walls were finished. The change includes the cost of widening the door openings, that is, demolition of part of the masonry walls, and installing new doorframes. If the doors have been delivered, there is extra charge for delivery and restocking.

Scenario 5: The owner makes the change after everything is finished. This is a more significant change order that includes widening the door openings, that is, demolition of part of the masonry walls covered by drywall and painted, and installing new doorframes. There will be also cost to redo the masonry walls, drywall, paint, and cleanup. The doors—after painting—may not be returnable to the vendor so their cost will be a waste, added to the total loss.

Scenarios 4 and 5 have a potential to impact the project schedule.

In certain cases, the change order process may be shortened where there exists a certain level of trust between the owner and the contractor, when the owner is constrained due to lack of time, or when the change order has a minimal economic impact. In these cases, the owner may issue a “directive” to the contractor before verifying the price. The contractor performs the work then charges the owner later.

Reasons for claims: Claims usually occur because of the “unexpected” events or developments, regardless of who is at fault. Unlike other industries, no two construction projects are the same. Even when two projects have the same design and are performed by the same company, they may differ in site conditions, climate, regulations, subcontractors, market conditions, and team members. Consequently, it is difficult to anticipate every event that will impact a construction project, even where the projects are substantially similar.

There are several reasons a claim may arise on any construction project. Among the reasons are the following:

1. *Differing site conditions:* A contractor may initiate a claim in the event that the actual site conditions differ from those mentioned in the contract documents. A contractor may encounter underground water that wasn’t mentioned in the contract documents. Types of soil may also be found different from what was mentioned in the geological (soil) report. The contractor may encounter soil contamination or unexploded bombs that wasn’t known or mentioned in the contract. One of the possible reasons for differing site conditions is when the architect/engineer uses old site plans that may not reflect recent activities. The contractor may find a temporary structure that needs to be demolished or a utility pole that needs to be relocated, and it was not shown in the design drawings. It is always a good idea for the owner to provide accurate information about the site and for the contractor to visit the site before mobilization and even before bidding.

The risk of dealing with unknown site conditions are usually addressed in the contract documents in provisions known as the “site inspection” and

“differing site conditions” clauses. These clauses typically impose upon the contractor the duty of site investigation and assumption of responsibility of bearing the cost of conditions that a bidder performing a reasonable pre-bid investigation would encounter. However, the differing site conditions clause allows the contractor to recover for unknown site conditions that differ from the contract documents or are unusual. The owner often bears the cost to deal with matters that fall within the terms of the differing site conditions clause.

2. *Design errors or omissions:* Errors or omissions in design may, and usually do, require the contractor to perform additional work than originally contemplated. Not all design errors or omissions form the basis of a compensable claim. Courts have rejected some contractor claims where an error or omission was patently obvious and a contractor could have discovered it during the bidding or negotiation phase. For example, if floor joist spacing is shown as 16' rather than 16" on center, it should be obvious that it is a typographical error. Also, if the structural drawings did not show any reinforcement on a concrete column or beam section, the contractor should know that such member has to have reinforcement. The contractor, in general, must inquire about obvious design errors prior to submitting it bid. Failing to do so, they proceed at their own risk.⁷
3. *Changes in owner's requirements:* This may constitute a change to the contract and makes a foundation for change orders. As discussed earlier, owners are always encouraged to know exactly what they want within the limit of their budget.⁸
4. *Unusually adverse weather:* Most contracts allow for certain expected weather delays without allowing time extensions to the contract time.⁹ A contractor who was rained out five or six days during the month of July in Tampa, Florida will probably not get a break from the owner because such delay is not unexpected or unusual. A weather condition that is not usual for that geographic area during that time of the year may provide grounds for the

⁶In Imperial units, the ' symbol represents feet and the " symbol represents inches.

⁷*Blinderman Construction Co. v. United States*, 17 Cl. Ct. 860 (1989).

⁸In a project the author was involved in, a city municipality asked an architect if it would be possible to design a parking garage in a certain location with a capacity of 280 cars within a budget of \$2.5 million. The architect confirmed based on a “plain” design with simple finish and no fancy options. The contractor’s estimate for that design was indeed just below the \$2.5 million mark. During the detailed design phase, the city started adding options such as sprinkler system, security system, retail space, planters, pavers, trees and some landscape, an extra half-floor that increased the capacity to about 325 cars, etc. These additions kept increasing the cost till it topped \$4.2 million. The city liked the design, but was shocked to see the contractor’s price tag. It asked the architect “we thought we are getting the parking for about \$2.5 million?” The architect replied “You can’t get the Cadillac for the price of Chevy!” The city had to go back and remove many of the added options but insisted on some. The project was eventually constructed for slightly over the original budget.

⁹See American Institute of Architects document A201-1997, paragraph 4.3.7.2.

contractor for a time extension claim. A hurricane or tornado may be regarded as *force majeure*¹⁰ and provide grounds for time extension even if that area is known for hurricanes or tornados.

5. *Other factors:* Factors that may not be the claimant's fault such as owner's failure to provide project site, late notice to proceed (NTP), labor strikes,¹¹ delay in delivery of owner's furnished equipment, or events that can be classified as *force majeure*, or problems deemed to be the responsibility of the owner.

Note that the factors above may entitle the contractor to monetary compensation, time extension, both, or neither.

Force majeure: The term *force majeure* (also written as *force majure*) came into use around 1883 from the French for “superior force.”¹² In the context of construction projects, this term generally combines three important elements:

1. Superior, overwhelming, or overpowering, that is, cannot be prevented
2. Unexpected or cannot reasonably anticipated or controlled, and
3. Has a destructive or disruptive effect on the construction process

It is usually used for events that satisfy the above criteria in order to excuse the contractor from certain contractual requirement. Examples are earthquakes, hurricanes, tornados, wars, labor strikes, and acts of sabotage or terrorism.

Other contractual terms with similar meaning include *vis major*, which has a Latin origin and means “act of God.” In the author’s opinion, it is more appropriate to use the term *force majeure* rather than “act of God” in this context, because it indicates an event that could not have been prevented within our reasonable effort. Even though the term “act of God” has been construed to mean the same thing as *force majeure*, it may be interpreted differently according to individuals’ religious beliefs or philosophy. In some extreme cases, one may argue that every action happens in this world is an “act of God,” whether or not we have control over it or responsibility for it.

Types of delays: As far as the construction schedule, delay events are classified into the following types:¹³

1. *Excusable delay:* This is a delay that entitles the contractor to additional time for completing the contract work. Excusable delays usually stem from reasons beyond the contractor’s control. These delays are further classified into:

¹⁰This term is discussed in detail later.

¹¹Courts have ruled in some cases when the contractor signs the construction contract at a time when a labor strike is looming, that such strike is not a grounds for time extension.

¹²See Webster Dictionary, Merriam Webster Collegiate Dictionary, Dictionary.com, The American Heritage Dictionary of the English Language, and the International Law Dictionary & Directory.

¹³Bramble and Callahan, Construction Delay Claims, §1.01 [A], [B] and [D] (3rd ed. 2000).

- a. Delays beyond the control, nor the fault, of the owner such as unusual weather conditions, natural disasters (earthquakes, floods, hurricanes, etc.), wars or national crises, or labor strikes. These types of delays will most likely entitle the contractor to a time extension but not monetary compensation (noncompensable delay).¹⁴
 - b. Delays caused by the owner or the designer (architect/engineer.) These types of delay typically allow the contractor to recover the costs and time associated with the delay, and are known as “compensable delays.”
2. *Nonexcusable delay:* By definition, this is a delay that does not entitle the contractor to either time extension or monetary compensation. Typically, a nonexcusable delay is any delay that is either caused by the contractor or not caused by the contractor but should have been anticipated by the contractor under normal conditions. Examples of the first type include slow mobilization, poor workmanship, labor strikes due to unfair labor practices, or accidents in the project site caused by the contractor’s negligence or lack of preparation. Other examples include late delivery of contractor’s furnished materials and equipment, contractor’s cash-flow problems, adverse weather conditions that are expected for that location during that time of the year, or lack of skilled labor.
3. *Concurrent delay:* A combination of two or more independent causes of delay during the same general time period may be considered to be concurrent delays. Often the concurrent delays are excusable and nonexcusable delays. For example, the author was involved in a case where the contractor was performing at a slow rate and falling behind schedule because it didn’t have an adequate work force on the site. At around the middle of the project, the owner issued a major change order. The contractor requested a 120 days of time extension due to this change order. In order to prove his point, he presented two schedules: original (baseline) schedule and “impact schedule.” After analysis, the author found that the change order justified 56 days of delay. The rest, that is, 64 days, were nonexcusable delay. The contractor was trying to hide this nonexcusable delay behind the owner’s change order.

It is important to note that just because the additional work may require time to perform, the contractor is not automatically entitled to an extension of time. He/she may have to demonstrate that the additional work impacts the critical path of the project. The use of CPM schedules and scheduling experts are often necessary to prove or disprove such claim.

Conversely, the contractor—in a case of a change order—may be entitled to extra monetary compensation in lieu of time extension even if he finished by the original finish deadline. Typically, this extra payment covers the contractor’s effort—above and beyond the original work plan—for accelerating the schedule. Such effort may include

¹⁴ In most cases, the contractor’s Builder’s Risk insurance covers such losses.

overtime payments and/or extra labor/equipment. In such cases, when an owner issues a schedule-impacting change order or causes a delay, the contractor may negotiate with the owner for finishing on time in exchange for extra payment.

Scheduling mistakes related to delay claims: Construction projects take months or years to finish with many people and events involved. In many cases, people are replaced in the middle of the project for a myriad of reasons. Participants in the project may forget details of what occurred in the project. The importance of diligently maintaining daily reports, journals, and the like cannot be overemphasized. Many a case or claim has been won or lost on the quality of the record keeping performed on a construction project.

One of the most important documents in delay claims is the as-planned or baseline schedule.¹⁵ It represents the manner (timing, sequence and possible resources) in which the contractor planned to perform the work, and the owner's acceptance to that plan. The 2007 version of the AIA A201 General Conditions document requires the contractor to submit a schedule that complies with the contract completion date. Most contract forms used by public and private owners today also require a schedule prepared by the contractor and accepted or approved by the owner. Such schedule, once adopted as the baseline schedule in the contract, becomes a very important document because it constitutes the yardstick for measuring any variation if it is properly updated and maintained. Because of lack of knowledge or experience, negligence, or other reasons, many contractors commit errors or submit faulty schedules. Following is a list of some of the frequent scheduling mistakes some contractors commit.

1. *Baseline schedules that don't show logic:* Some contractors use spreadsheets or simple bar charts as schedules. Spreadsheets are not scheduling programs, and they are used merely like color ribbons to indicate when the contractor intends to start and finish each activity without showing interdependencies. When an activity is delayed or shifted, there is no mechanism to reflect the impact of this delay or shifting on other activities.
2. *Baseline schedule with dates rather than logic:* Some schedules, even if built using scheduling programs, use "events" rather than "activities." For example, instead of showing "Excavation" as a 20-day activity, the schedule shows two milestones (events): "Start Excavation" and "Finish Excavation." There are several problems with this approach. Some contractors use constraints to "fix" the date of an event. This negates the introduction of logic in the schedule. This approach also deprives the control manager (on both the contractor's and owner's sides) from evaluating the percent complete of that activity.
3. *Overuse of constraints:* When, instead of logic ties, the contractor "schedules" activities by assigning start and finish dates to them, usually by the use of

¹⁵ Defined and discussed earlier in chapter 6.

“Constraints.” Similar to the previous case, activities “get nailed” with such constraints and cannot react to logic and other changes. Often in construction, activities get delayed, omitted, or adjusted; or finish early. Such change can have impact on succeeding activities but won’t show if activities are constrained.¹⁶

4. *Erasing footprints*: A contractor may build/update the schedule as project progresses without keeping a copy of the original or previous updates. This schedule will be an “as-built” schedule. It shows how the project was actually built, not how the contractor intended to build it. This conduct leaves no footprints to track and no baseline to compare progress to.
5. *Unrealistic baseline schedules*: Some contractors don’t realize that a baseline schedule that is approved by the owner may be a legal and binding document. Contractors cannot get relief by complaining of unrealistic duration or logic in the schedule later on during construction, unless a change in work circumstances warrants such relief.
6. *Schedules with logic errors*: Errors may render the schedule useless and cause it to be thrown out by the court in case of a dispute.¹⁷ The schedule must be prepared by a construction professional. Contractors who don’t have scheduling capability, usually hire CPM consultants. It is important to note that the reliability and correctness of the schedule may have nothing to do with the contractor’s field practice. The contractor may deviate from the schedule or planned sequence (network logic) but the schedule is still evaluated based on its own merit.
7. *Skipping periodic updates*: A contractor may be tempted not to update the schedule on a regular basis because “things are going just fine.” In many cases, we find only a baseline schedule and an updated schedule that reflect work progress six months after the start of construction. This leaves a large gap in between the two schedules and makes it difficult to trace back events during that period of time. Courts may not accept schedules to prove delays unless they are regularly updated.¹⁸
8. *Lack of proper documentation*: This can have serious repercussions. When updating, the scheduler should record any unusual events. For example, an excavation activity finished one week after its scheduled finish date. The scheduler should record the reason for this delay. Most scheduling programs provide “notes” or “log” functions at both the activity and the project levels.
9. *Lack of reasonable time contingency*: Contractors must have a reasonable amount of time contingency built in the schedule for delays such as expected

¹⁶ Some computer programs introduce different types of constraints: some are subject to logic and some override logic.

¹⁷ *Fortec Constructors v. United States*, 8 Cl. Ct. 490 (1985).

¹⁸ *Wilner v. United States*, 26 Cl. Ct. 260 (1992).

weather conditions. One of the commonly overlooked scenarios is the possibility of rejection of submittals. A contractor may allocate 10 days for shop drawings review and approval in a tight schedule. In case the drawings are rejected, the drawings have to be corrected and resubmitted for approval again. This will likely cause the process to take more than 10 days and may cause a delay in the schedule. In most cases like this, the contractor has to absorb this delay with no relief from the owner.

10. *No allocation of the “pacing” or limited resources:* There has never been a project that had unlimited resources. Hence a schedule based on CPM’s early dates that assumes unlimited resources is not a realistic or rational schedule. Resource “loading” is only estimating the resource requirements, not scheduling them to smooth the demand in accordance with availability.

Project documentation: Characteristics for good communications were discussed in chapter 9. This includes both oral and written communications. Written communications include both text and graphic reports. The importance of good communication cannot be overemphasized. Most construction companies list “good communications skills” as one of the top criteria for hiring any project management personnel. Communication generally mean conveying information from one party to other party(s) within the same organization or across different organizations. Documentation, on the other hand, generally means saving the information in an organized manner for possible retrieval in the future. What should be in common between communication and documentation is the need for information to be clear, providing the right amount of details, and efficiently stored so it can be easily retrieved.

Project documentation includes both home office and field office documentation. Since many types of information may be documented in the home office or on site, we will list all the information to be documented wherever its location. With the advancement of communication technology, the home office and field office information are more and more integrated to make one comprehensive project database. There are several software packages construction companies are using for this purpose.¹⁹ They are getting better, more powerful, and more capable of integrating with other systems such as drafting, scheduling, estimating, accounting, web publishing, and e-mail communications.

For the purpose of delay claims prevention and resolution, the following information should be documented:

1. Project baseline schedule that was approved by the owner. Both an electronic copy and a printed report (bar chart, predecessors/successors table, etc.) should be kept both in the main office and the field office.

¹⁹The author is familiar with Primavera Contract Manager, Meridian’s ProLog Manager, and Timberline’s Project Management.

2. Periodic updates for the schedule. The scheduler has to name and store these projects in a clear and consistent fashion. It is also a good idea to keep copies of these updates in the main office. Updates should include both the printout (bar chart and/or other reports) as well as an electronic copy of the CPM schedule.
3. Change orders, including the administrative and technical correspondence.
4. Project manager's daily log. Even though the trend is to use electronic logbooks, many project managers still do it the old-fashioned way and use a traditional daily logbook. There are many logbooks that are commercially available.²⁰ Also many companies print their own official logbooks. A typical logbook should include—on a daily basis—information such as:
 - a. Weather conditions such as temperature, humidity, precipitation, wind, lightening, etc.
 - b. Work performed during that day. Record any disruption such as accidents or unforeseen conditions.
 - c. Number of workers on site and the entities (i.e., subcontractors) by whom they are employed. Record number of work hours, especially overtime hours.
 - d. Equipment on site along with their condition (working or not).
 - e. Any material delivered to the site along with inspection record.
 - f. Materials used and materials stored on site.
 - g. Any telephone calls made by the project manager or other field personnel that is relevant to the project.
 - h. Any visitors to the site, what time, and what organization they represented.
 - i. Any accidents that happened on site.
 - j. Any other events that may be related to the project, especially problems that may cause delays.
5. A job diary book, which is an informal daily logbook. It may contain the accounts of the project manager or superintendent without following a certain format. It may also contain personal observations, suggestions, and opinions. Because of their informality and subjectivity, such diaries may not be accepted as direct evidence in the court of law but may be used to refresh someone's memory about a certain event.

²⁰ See *Construction Project Log Book* printed by Prentice Hall Inc., 2000.

6. Submittals such as shop drawings and material samples. In addition to shop drawings and material samples, the record must contain a log showing the dates and actions (accepted, rejected, etc.) taken for any submittal.
7. Record of any transmittals such as requests for information (RFI), requests for clarification (RFC), test lab results, warranties and certificates.
8. Correspondence with the owner, architect/engineer, subcontractors, vendors and suppliers, or other contracting parties. The record must include the topic of the communication, the person with whom the project manager (or his staff) communicated, and the date of the communication.
9. Correspondence with the home office.
10. Meeting minutes, including the typical information in any meeting minutes (subject, date, location of meeting, names of people attending and absent people, etc.)
11. Procurement records, including materials and equipment orders and delivery tickets, equipment maintenance records, any quotations for materials; labor; or other, receipts for any purchases or payments, and any other record that deals with acquisition of labor, materials, or equipment.
12. Government records such as permits, code nonconformance reports, and OSHA forms/citations.
13. Record of payments (owner to general contractor and general contractor to his subs and vendors) along with total amount billed, total amount paid, retainage, and other financial details. General contractor must also keep lien releases signed by its subs (owner would keep lien releases signed by general contractor.)
14. It is a good idea for the resident project manager to keep a camera on hand to take photos for important events. Any picture must have the date printed on its back or front. Digital cameras are very effective where the picture can be downloaded to a computer then attached to a document or to the project management software. Some sites have security cameras and recordings may be kept by the security company or IT department for a limited period of time, since it is impractical to store thousands of hours of recordings. Project manager should permanently store any video clip showing important events that may support a case later on.
15. E-mails, electronic schedules, electronic submittals, project databases, and similar electronic data in its native format.

The cost estimate may belong to a different department but the scheduler/scheduling department must have a copy of the baseline cost estimate as well as all cost estimate updates.

A good documentation system stores the information in a well-organized fashion that is efficient and easy to retrieve. One major challenge to anyone asserting a delay

claim is to retrieve all the information in an accurate manner and then recreate past events in the correct sequence. Keeping good records helps refresh the memory of any party involved, which may help not only in a case of a dispute but also help prevent such a dispute from emerging. A work breakdown structure (WBS) is a convenient format for storing all documentation, as it unifies all of the pertinent data for each constructible feature.

Delay claim resolution: Most contracts contain clauses for claim dispute resolution. The process usually starts with the simplest and quickest procedure then goes into the next level and so on. Since the court system is lengthy, costly, and complicated, other alternative dispute resolution methods have been used. Below are the methods that are usually used in resolving disputed claims:

1. *Negotiation:* This is the most direct method for resolving any type of construction claim. In many cases, the “truth” may not be entirely known or acknowledged and “fairness” is seen differently by the different disputing parties. Negotiation requires certain skills that tend to reduce the gap between the negotiating parties. Although negotiation occurs basically between the disputing parties, independent experts or consultants may be asked to give opinions on certain issues. Negotiation starts with parties at the project management level, but higher-level officers may get involved if the lower-level team fails to reach an agreement. While complete satisfaction may never be reached, the objective of negotiation is to reach a solution that will be acceptable to both parties.
2. *Mediation:* When negotiation does not work, either because of lack of trust or skills, an independent neutral or mediator may get involved to bring the disputing parties together. The mediator can be an individual or a team. The mediator usually starts by explaining the role of a neutral in bringing the parties to an agreement. The mediator must demonstrate neutrality and patience, and must collect all the facts before making any recommendation. Typically, the mediator spends time with each party individually but—if the atmosphere is encouraging—may bring the parties to a meeting. The mediator, like the negotiator, must be skilled in narrowing the gap between the disputing parties and focusing on the positive side of any proposed solution. For example, although the dispute may be on financial issues between a general contractor and their subcontractor, the mediator may sense that the subcontractor is concerned about security and future work. The mediator may then convince the subcontractor to accept a lesser financial settlement in exchange of extended relationship with the general contractor.
3. *Disputes review boards:* Rather than waiting until the end of a project to settle claims, dispute review boards (DRBs) may be used to resolve disputes as they arise on a construction project. An independent neutral panel with construction experience is selected by the owner and contractor when the contract is signed, and the parties agree to call upon the neutral to assist them

in resolving disputes during construction. Since some cases involve large, complicated, and lengthy projects, it may be very difficult for the parties to collect all the information. The DRB technique was created to help this process by involving the neutral from the very early stages of the project. DRB members often visit the construction site periodically to become familiar with the progress of the work and to provide assistance in the early stages of disputes.²¹

Negotiation, mediation and DRB's are nonbinding. This means the solution changes its shape—like a piece of dough—during the process until it reaches a form acceptable to both parties. No party is under obligation until it accepts the proposed solution.

4. *Arbitration:* Arbitration is usually a formal process that is performed by an independent professional arbitrator. It is defined by the American Arbitration Association as a “referral of a dispute to one or more impartial persons for final and binding determination. Private and confidential, it is designed for quick, practical, and economical settlements.”²² Arbitration in construction is usually performed by experts in the construction industry such as architects, engineers, or construction management professionals. Some jurisdictions grant the design professionals quasi-judicial immunity when acting as judge. Although arbitration is usually binding to both parties, arbitrators do not have the enforcement power that judges have. An arbitration award in a binding arbitration can be reduced to an enforceable judgment by a court of law, if necessary.

It should be noted here that in many contracts, arbitration is specified as a binding process if negotiation and mediation fail. As mentioned earlier, unlike judges, arbitrators cannot enforce their judgment. If a party refuses to comply with the arbitrator’s judgment, it may be necessary for the other party to seek a court’s intervention. Most state arbitration statutes specify grounds for reviewing an arbitrator’s award such as a proof of corruption or fraud, evidence of arbitrator’s partiality, or if the arbitrator’s exceeded his/her powers.²³

Unlike litigation, arbitration is voluntary, at least until the parties accept it in the contract or later after the dispute arises. Arbitration does not require the employing of lawyers, although it is not unusual for parties arbitrating important matters to employ lawyers. Not being subject to the complicated procedures and restrictions of the court system gives the arbitrator more freedom and makes the arbitration process faster. The powers given to an arbitrator differ from one state to another. For example, in many states,

²¹ *Construction Project Management* by F. E. Gould and N. E. Joyce, Prentice Hall, 2nd edition, 2003.

²² *Introduction to Construction Dispute Resolution* by F. Peña-Mora, C. E. Sosa, and D. S. McCone, MIT/ Prentice Hall Series on Civil, Environmental, and Systems Engineering, 2003.

²³ *Legal Aspects of Architecture, Engineering and the Construction Process* by Justin Sweet, 5th edition, West Publishing Company.

arbitration does not allow for an effective method of discovery, the process by which attorneys in litigation can obtain evidence from the other party to prepare for the hearing.²⁴

Mediation and arbitration can be combined in a two-stage process: The disputing parties select a mediator and agree that the very same third-party will become the arbitrator if the parties fail to reach a mediated settlement within a specific time frame.²⁵

5. *Litigation:* When none of the previous processes work and parties cannot reach a settlement, the complaining party may sue the other party in a court of the law. The legal process is complex and often involves pre-trial discovery procedures such as interrogatories (written questions to the other party), requests for the production of documents, and pre-trial testimony in depositions. When the matter goes to trial, the facts may be decided by a jury or judge who may be overwhelmed by the technical details involved in a construction delay claim. Construction litigation is usually complicated, lengthy, and expensive. Many plaintiffs spend more money on attorney's fees than they later recover by the court's judgment.

The importance of CPM schedules in delay claims: Resolving a delay claim may be a complicated and challenging task. There might be several concurrent factors involved in impacting the schedule. A concurrent delay means more than one delay contributed to the project delay; however, it does not necessarily mean that the delays occurred at the same time. A concurrent delay may occur during the same period as another delay, but concurrent delay may also include any delay that could have contributed to the overall project delay, whether or not the delay overlaps with another.²⁶ For example, the owner may have caused 1-month delay but the contractor claims that this delay pushed the start of the schedule to the rainy season that caused additional delay. A delay by the A/E in reviewing and approving the shop drawing of one day only may cause the cancellation of placement of concrete to a suspended slab. The contractor may not be able to reschedule the concrete delivery for another week or so. Concurrent delay may also involve two or more factors that happened at the same time, and it may be very difficult for the investigator to isolate the impact of each one. This is particularly important when one of the factors is the fault of the contractor and the other is not. For example, if materials delivery was delayed because of contractor's negligence and severe weather happened concurrently. A contractor may be late due to his own fault, but when a change order comes from the owner, the contractor tries to dodge its delay into the change order time-extension claim. The investigator must try to verify the effect of one factor at a time. This works—theoretically—by isolating other factors, which might practically be very difficult if not impossible. Here comes

²⁴ Same last reference.

²⁵ Same last reference.

²⁶ *Construction Project Scheduling* by Callahan, Quackenbush, and Rowings, McGraw-Hill, 1992.

the importance of CPM schedules. The claimant usually provides at least two CPM schedules: one without the impact of the change and one with the impact, in a bid to prove that the alleged change caused the claimed delay. The investigator, on the other hand, may develop several CPM schedules, each representing one factor isolated from other factors in order to show how much exactly of the alleged delay, if any, is attributed to causes the contractor is claiming.

METHODS OF SCHEDULE ANALYSIS

There are many methods that have been employed to demonstrate the impact of delays upon the project. Most involve sophisticated evaluation of schedules.²⁷

As-built schedule: As the name implies, the as-built schedule should reflect what actually happened in the field. Activities are plotted by their real start and real finish dates disregarding any logic (as-built schedules may not have logic ties). It may also contain real budget and actual resources numbers. Investigators usually develop the as-built schedule from project records such as daily logs, diaries, project correspondence, and the like. It may require a considerable effort to develop the as-built schedule, and there may be some gaps left in the progress information to be filled by the recollection of the project manager and the judgment of the investigator. Again, documentation proves very valuable in retrieving information that helps develop the case for proving/disproving a delay claim.

Updated impact schedule: The U.S. Army Corps of Engineers modified this method by creating an “as-built” schedule or updated schedule from the start of the project only to the point just before the delay occurred. The “original” or baseline schedule is updated with progress information and then compared to the impacted completion date on another schedule on which a delay is included.²⁸

As-planned schedule: The as-planned schedule describes the manner in which the contractor intended to build the project. It is usually the same schedule that is submitted by the contractor to the owner and becomes later the baseline schedule.²⁹ However, in some cases the originally submitted schedule may contain some errors and need to be corrected.³⁰ When no CPM schedule was required or when it was required but not submitted or submitted but not formally approved, it may be necessary to develop a revised or prototype schedule using the best and most credible information available to reflect the original plan and intentions.³¹

²⁷ Bramble and Callahan, *Construction Delay Claims*, chapter 11 (3rd. Ed. 2000); AACEI Recommended Practice No. 29R-03, Forensic Schedule Analysis (June 25, 2007).

²⁸ *Construction Project Scheduling* by Callahan, Quackenbush, and Rowings, McGraw-Hill, 1992.

²⁹ Popescu and Charoennangam.

³⁰ O'Brien and Plotnick, p. 480.

³¹ Wickwire, Driscoll, and Hurlbut, p. 377.

Comparison schedule: The original schedule (usually as-planned) schedule is revised to incorporate any claimed delays. Typically, for a delay claim, the contractor submits two schedules: one without the causative factors (factors allegedly causing the schedule delays) and one with the causative factors (called the “impacted” schedule). By comparing the two schedules, the contractor hopes to prove that the delay is caused by the alleged factors. The contractor may lump more than one factor in the delay claim. The investigator may then build an impacted schedule for each factor.

Accelerated schedule: An accelerated schedule is a schedule submitted usually by the contractor implementing some adjustment to the project baseline schedule in order to complete the project by the contract finish date. By doing that, the contractor attempts to collect the cost associated with the acceleration of the project.³² The owner tries to make sure the contractor utilized all available float before any crashing takes place.

Recovery schedules (as discussed in Chapter 8) are similar to accelerated schedules in the sense that both make adjustments to compress the schedule (or the remainder of it) to ensure completion of the project by the contract finish date. However, the main difference is in the reason for the delay that triggered this compression. Recovery schedules are mainly used when the contractor caused the delay and the owner became concerned and suspicious of the contractor’s completion of the project by the contract finish date. The owner may then demand that the contractor makes adjustments and submit a recovery schedule that demonstrates a timely completion. Accelerated schedules are usually prepared by the contractor in case of a delay that the contractor alleges it is caused by the owner, *force majeure*, or a third party.

Who owns the float? Float may be defined technically as the maximum amount of time an activity can be delayed from its early start date, without delaying the entire project.³³ From a practical point of view, float is regarded as the time contingency associated with a path or chain of activities.³⁴ Some contracts give the owner the right to use the float in case of a delay. In this case, the contractor may not be entitled to time extension or compensation until and unless the float is entirely exhausted. The contractor, on the other hand, has a range of time for each noncritical activity between its early and late dates. The contractor may choose specific dates within this range for efficient resource allocation or other reasons.

Conclusion on Delay and Float

The subject of float is complicated and cannot be covered in this simple discussion. It was mentioned earlier in chapters 4 and 5 that there are several types of float, not just

³² Review the cost of schedule compression in Chapter 8.

³³ This is the definition of total float. See definitions in Chapter 4.

³⁴ *Construction Scheduling: Preparation, Liability, and Claims*, by Wickwire, Driscoll, and Hurlbut, John Wiley Publications, 1991.

Example 13.1

In the construction project represented by the logic network shown in Figure 13.1 (a), the owner issued a work order to the contractor that would delay the start of activity E till day 16 (i.e., its late start date). Would the contractor be entitled to time extension, compensation, both, or neither?

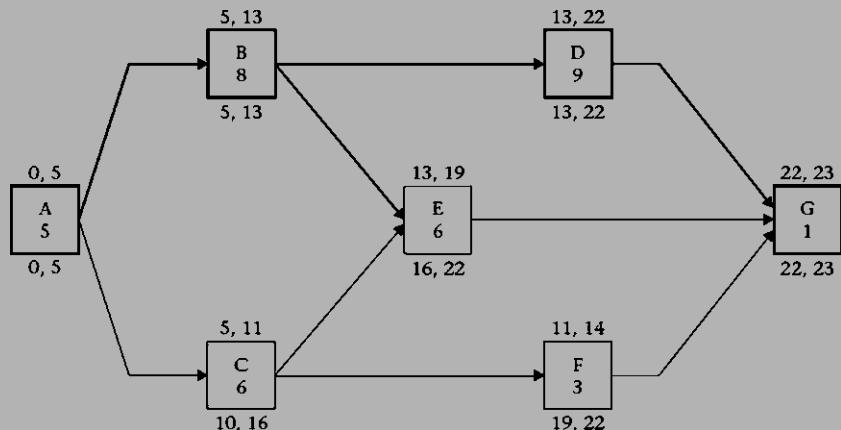


Figure 13.1 CPM network for Example 12.1

Solution

As we see in Figure 13.1, activities C, E, and F have total float equals to 5, 3, and 8 days, respectively. Let's redraw the schedule as a bar chart, showing the amount of float—if any—each activity has. See Figure 13.2.

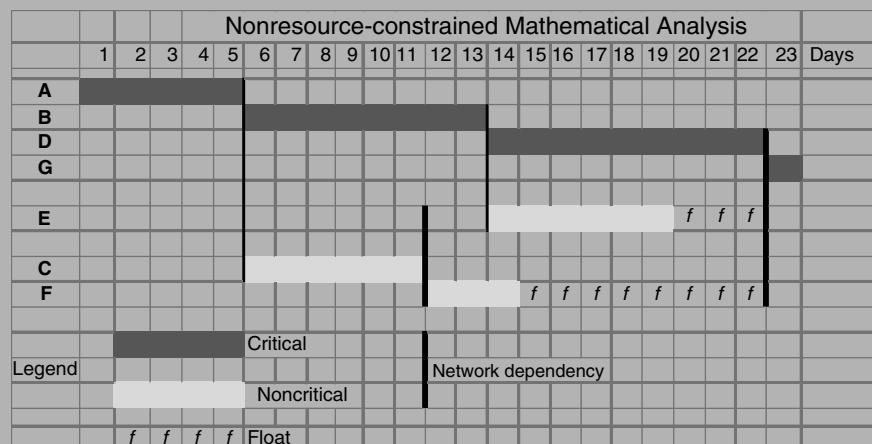


Figure 13.2 Bar chart with sequence dependencies

The contractor may choose not to start noncritical activities on their early dates. Assume these three activities require the same crew. For the most efficient use of the crew, the contractor chooses the plan shown in Figure 13.3. According to this plan, all activities are “critical,” some by logic constraints and others by resource constraints. If we start activity C one or two days earlier than shown in Figure 13.3, we then have to hire the crew for an extra day or two (since activity E can’t be started earlier).

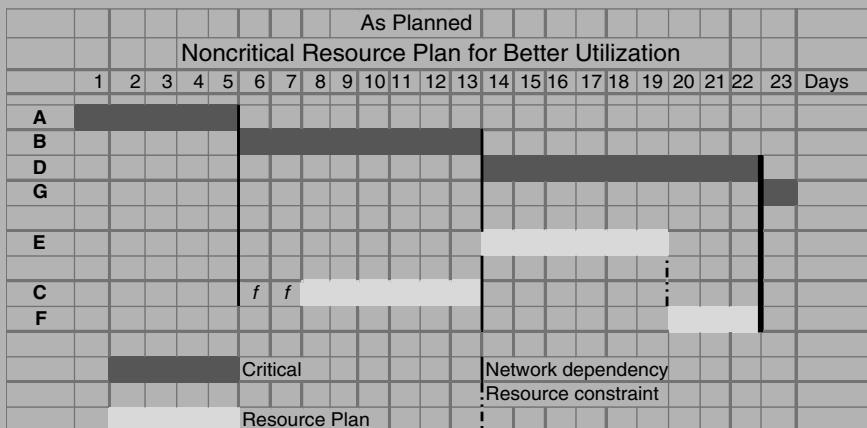


Figure 13.3 Bar chart with resource constraints

Now assume the owner caused a delay of three days in the start of activity E (so it starts on its original late date). The owner can use the argument that activity E had three days of total float, thus the contractor does not qualify for time extension or compensation (see Figure 13.4).

The contractor argues that this delay will force it either to hire a second crew on days 20, 21, and 22 or finish the project three days late. For this reason, the contractor requests additional compensation and/or time extension for 3 days.³⁵ The answer to this argument generally lies in the contract agreement. If the contractor granted the owner ownership of the float, the owner can use the float to absorb any delay. If the contractor has ownership of float, he may be entitled to time extension or compensation if he can prove

³⁵ Additional compensation and/or time extension may be involved because even with three days time extension, the contractor still needs to hire the crew for three extra days (8th through the 25th instead of 8th through the 22nd), unless the crew can do other work during the delay time (i.e., the 14th, 15th, and 16th). The alternative is to hire a second crew and do E and F concurrently (finish them both by the end of the 22nd day).

that the delay disrupted his resource allocation plan, even though it affected a noncritical activity and did not delay the entire project (see Figures 13.5 to 13.7).

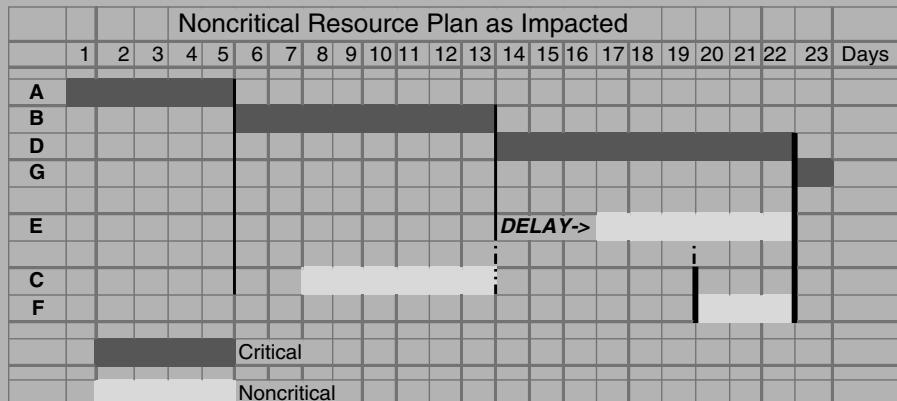


Figure 13.4 Bar chart with impact of owner's delay to activity E. The owner's delay has disrupted the planned use of the noncritical resources. While the contractor would claim three days (14–16) of idle time plus three days 20–22 of and extra crew, a resequencing of the noncritical resource if possible would mitigate the owner's delay

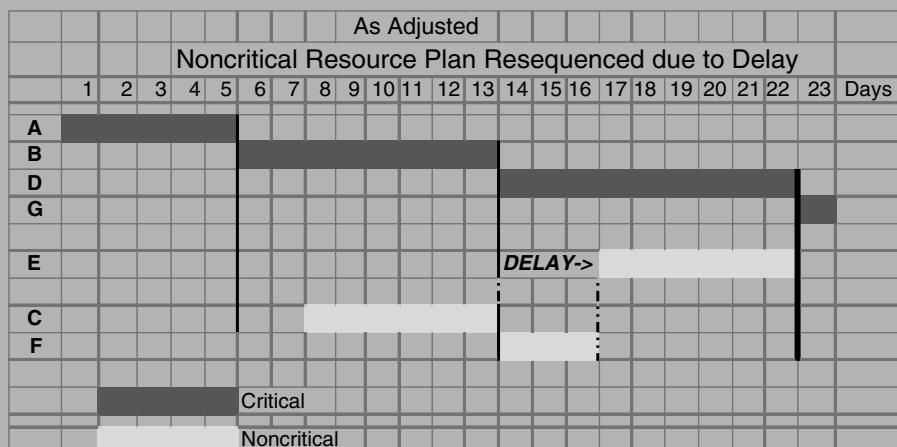


Figure 13.5 With the impact of owner's delay to activity E but mitigated by resequencing activities E & F

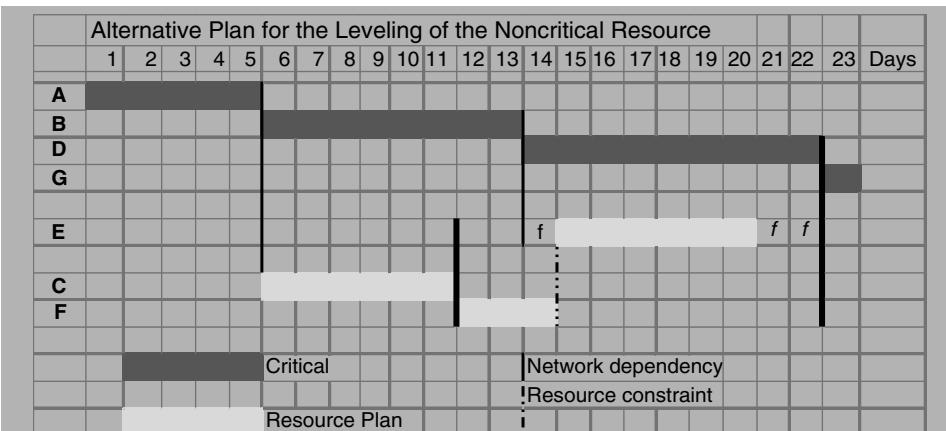


Figure 13.6 Alternate version of Figure 13.3, redrawn with activities C-F-E resource-constrained

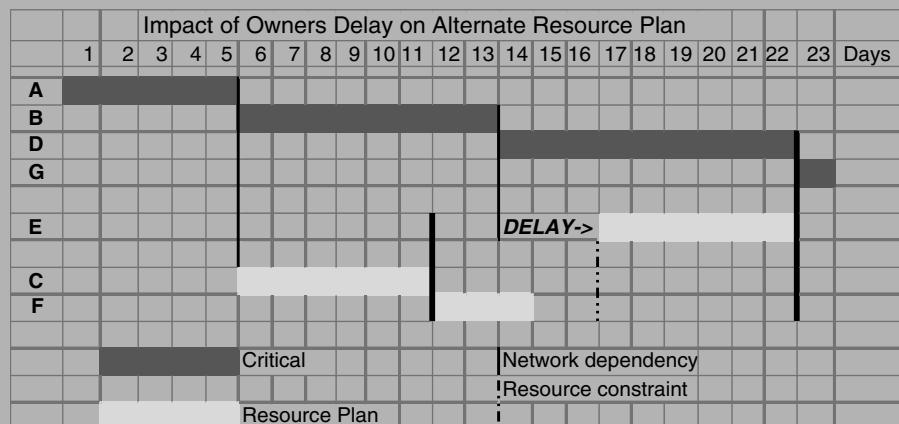


Figure 13.7 The timing of the delay notification becomes important in permitting mitigation options. If the delay is known early enough, the start of activities C & F can be delayed without an early notification and the contractor could claim two days of an idle resource.

total and free float. Types like interfering and independent float³⁶ may not mean anything to field personnel or even project manager. But these terms could be used in a case of dispute to illustrate dependency and distribution of float. Total float as defined earlier is more like a path-shared float, whereby if an activity at the beginning of the path uses that float, the rest of the activities on that path will be impacted. A very simple

³⁶ Review chapter 4 for definition and calculations.

example is the network in Figure 13.1. If activity C uses its 5 days of float, activity E becomes critical and activity F's total float shrinks from 8 to 3 days. Free float represents the portion of total float that would not impact the succeeding activities. But free float is still subject to impact from preceding activities. For example, activity E has $FF = TF = 3$ days but this float will disappear if activity C uses "its" float. The difference between total float and free float is interfering float, Int. F., which is the part of the total float that will impact the succeeding activities. Independent float, Ind. F., is the portion of free float that cannot be impacted by preceding activities nor can it impact succeeding activities. In other words, it is the only float that truly belongs to that activity. Those are definitions that we don't usually deal with on a daily basis in the construction industry, but experts may have to understand and deal with in some delay claim cases.

Since we defined both total float and free float as characteristics that may be shared among activities, and since many activities in construction projects are performed by different companies, the big question is: Who owns the float? We mentioned earlier that the owner and the general contractor may agree on that point in their contract. But the issue is still far from over. There might still be disputes between the general contractor and a subcontractor, between two subcontractors, or between a vendor and the general or subcontractor. Generally, if there is a language in the contract that specifies obligations from the general contractor towards the owner, it usually becomes applicable to any subcontractor. Thus, if the general contractor grants ownership of the float to the owner, the owner then owns float for all activities whether performed by the general contractor or any subcontractor. The case may not be so simple when the general contractor owns the float. It may reach an agreement with the subcontractor for the distribution of the float. Some jurisdictions have determined the distribution of float through case law, legislation or contracts, but others have not. Researchers have studied this topic extensively and have come up with many suggestions and algorithms to distribute the float. There is still no "industry standard" for this issue and contracting parties have to make sure this issue is discussed and agreed on before signing the contract.

CHAPTER 13 EXERCISES

1. Define a construction claim delay.
2. Who can initiate a construction claim delay?
3. How can owners minimize the number of change orders?
4. The earlier the owner decides on a change, the less cost and trouble. Can you elaborate on this statement and provide a practical example?
5. What are the major reasons for change orders?
6. Define *force majeure*. Why is it preferred over the term "act of God"?
7. What are the types of delay claims?

8. If the owner adds additional items of work to the project, would this action automatically entitle the contractor to time extension? Explain.
9. What can the scheduler—as part of the project management team—do to prevent delay claims and/or help resolve them? List the items that you must document.
10. List the methods usually used in resolving claims. Briefly explain each one. Classify them into binding and nonbinding methods.
11. Why is CPM important in proving/disproving construction delay claims?
12. Define:
 - a. As-built schedule
 - b. As-planned schedule
 - c. Comparison schedule
 - d. Accelerated schedule
13. If a subcontractor's activity has 5 days of total float, does it have the authority to use that float however he likes? Explain your answer.
14. Can the owner require ownership of the float in the contract? If yes, can the owner add a 3-day work item to a path that has 5 days of total float without giving the contractor any time extension? (*Hint:* answer is not a simple yes or no).

Chapter **14**

Schedule Risk Management¹



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¹This chapter was written with contributions from Mr. Chris Carson, PSP, CCM, Corporate Director of Project Controls, Alpha Corporation, Norfolk, Virginia.

INTRODUCTION

Schedule risks are both threats and opportunities to the success of a project. Threats tend to reduce the success of meeting the project goals and opportunities tend to increase the success. Risk management is the process of identifying, analyzing, qualifying and quantifying the risks, and developing a plan to deal with them. This is routinely done during baseline schedule development as well as during schedule updates.

Implementation of risk management starts with early planning in both budgetary cost estimating and preliminary master scheduling in order to determine budgets and schedules with a comfortable level of confidence in the completion date and final cost.

While there are entire volumes addressing risk in construction projects, it is important to note that the issue of time-related risk has not been universally incorporated into planning. Assessing cost risk is more intuitive, and very often addressed through the use of heuristics, so it has become more of a standard of the industry than time-related risk management. Most estimators will automatically add a contingency to a cost estimate to cover the risk of performance based on the type of project and circumstances pertaining to the undertaking of the project. Estimators estimate this contingency using their own rules of thumb developed over years of estimating as well as estimating manuals such as Means' *Cost Data* or *CostWorks*.² However, when it comes to developing the critical path method (CPM) schedules, risk management is often overlooked or underestimated.

The purpose of this chapter is to provide an overview of risk management and the assessment process as well as best practices for incorporation of risk management into CPM schedule development and maintenance. For more detailed information about schedule risk, the reader should refer to risk management books, particularly those that focus on project management. One of the best resources available is David Hulett's new book, *Practical Schedule Risk Analysis*.³

Any risk management program starts with a good and accurate CPM schedule, created through the use of best practices and checked for quality, reasonableness, and appropriateness of the network model. Without a well-designed and developed CPM baseline schedule, a risk management process will not be effective. The risk analysis depends upon accurate and consistent calculations of the network logic, the appropriateness of the sequencing and phasing, and a reasonable approach to estimating activity durations.

Most CPM schedules are not adjusted for risk but rather are developed as if there were one right answer for the schedule's numerical data. Generally, activity durations are established by calculation of the quantity of work represented by an activity divided by the production rate, or by sheer "gut feeling" of the project manager or crew leader. This production rate is normally established by the contractor's historical records or an estimating system, such as Means', that provides an accurate database of

²R.S. Means/*Reed Construction Data*

³Published by Gower Publishing Limited, 2009

average production rates. Once those durations are calculated, they are often used as deterministic values, which assumes that the durations are accurate and unlikely to change. This assumption ignores the fact that the schedule is attempting to predict how long it will take to complete an activity at some unknown time in the future, using an unknown crew composition, with variable experience, and working in unknown conditions. Risk management recognizes the uncertainty in duration estimating and provides a system to brainstorm other risks that may occur during the project. Probability distributions are the best way to model planned activity durations, as noted by Hulett “The best way to understand the activity durations that are included in the schedule is as *probabilistic statements of possible durations* rather than a deterministic statement about how long the future activity will take.”⁴

TYPES OF RISK IN CONSTRUCTION PROJECTS

Everything that has ever gone wrong on a construction project is a potential risk on the next project. Many project managers instinctively develop a lessons-learned list of historical risks and take steps to minimize their exposure to those risks in the future.

Risks vary by industry and even by construction project type as well as by personnel involved with the project. A roadway or bridge project has a different group of risks than a facility or building, and the selected contractors may have different degrees of influence on the level of risks to performance.

If an owner attempts to save money in preconstruction services by limiting the extent of field investigation or development of as-built data, there will be a higher risk of discovery of unknown problems. The experience and competence of the architects and engineers handling the design of the project, as well as their quality control in development of working drawings, directly affect the construction effort and, consequently, the risk associated with the plans and specifications.

Even if the owner has been proactive in preconstruction investigation, there is always a risk of unforeseen conditions. This can be a function of the type of soils encountered, the local municipality, and its culture and history of keeping good records of obsolete utilities. If the city in which the project is to be built has a history of requiring contractors to remove all abandoned underground lines, there is a much lower risk of underground conflicts.

The selection of the project team can impact positively or negatively the probability of successful project completion. Design-bid-build projects that use procurement philosophies allowing all financially capable contractors to participate will likely experience a much higher level of risk to on-time performance than a procurement philosophy that requires qualification of proposed contractors to ensure that they have the appropriate experience and resources to construct the project. A single weak subcontractor on a project will increase risk of performance and require more management than may be anticipated. If this is not considered, everyone will be

⁴ Same reference.

surprised when that subcontractor fails and has to have their work augmented or corrected. Problems related to the management and possible termination of a failing subcontractor usually has serious negative impacts on the project.

The reputation of the construction manager (CM) as well as the corporate culture will affect project performance. If the CM defines success with minimum time extensions as the only benchmark, there will likely be more conflict and a higher need for dispute resolution efforts. In addition, the management abilities of the CM directly affect many project tasks, such as review of shop drawings and response to requests for information in order to resolve questions about the construction.

Work by outside or third parties can carry significant risks of influence on the project's success. For example, a light rail station to be built on top of a parking garage under construction by a different contractor will run an increased risk of completion on time. The project has no control over—and little ability to influence—the completion of the parking garage, which quickly becomes vital to completion of the light rail project.

Most projects are affected by local weather conditions, which, when adverse, can significantly impede progress. Most specifications require the contractor to take into account the normal local weather conditions in his schedule planning, which includes normal adverse weather, but also allow for time extensions when unusually adverse weather occurs. Best practices would require the contractor to research the local historical weather records in order to plan for three to five year average weather conditions. Different parts of the country and the world have a wide variance in weather conditions, so planning or failure to plan for the risk of local weather can significantly affect project success.

Local political situations, especially in volatile political climates, may hamper all efforts to construct a project efficiently. Countries with unstable political or economical systems will have higher risks in successful project completion than those with more stable systems. Countries or regions subject to wars, terrorism, turmoil, or other types of violence also run greater risks to successful project completion than others. If the locality has a policy of requiring deep investigation into environmental issues or stringent or complicated bureaucracy, projects built in that locality will have a higher risk of late permits and conflict during construction.

Another large risk on any project is the experience and reputation of the project team for safe construction practices. Safety violations and accidents can shut down a job completely. Even minor safety failures can distract the project team and impede timely performance. If a contractor has a poor safety record, the risk of delays because of safety violations is increased and should be taken into account during schedule development.

A large volume of change orders on a project will affect employee morale; there is nothing worse than asking a craftsman to rip out recently installed high-quality woodwork for a requested change. If the CM has a good change management program in place, including and most importantly good planning, the risks of negative pressure from changes are lowered. Without the program, the risks may be significant enough to derail project completion.

Most conversations about risk are related to negative risks that impair successful performance, but often there are opportunities that would be overlooked without good risk assessment. A renovation project that calls for a three-story masonry wall to be demolished to the foundation in order to install a beam and column system might be redesigned with a pin beam temporary support structure, allowing the upper two stories to remain in place, saving time and money, as well as removing some risk. The brainstorming about risks needs to include looking for opportunities that could positively impact the project time for completion.

It seems obvious that failure to plan for the myriad of risks that often affect project performance will render the planning less accurate. Without risk management, every item that might appear on a risk register (a checklist of potential risks) is a surprise to the project team should it happen, diverting attention and emphasis from the project management and consuming valuable resources. Most disputes arise from risks that likely were not considered at the inception of the project and might have been eliminated or mitigated with good risk planning.

Once a company develops a regular risk management culture, the risk register generates many of the same risks on project after project. However, a company's "risk register" should not be a fixed template, used as is on all its projects. The list must be updated and customized for each project taking into consideration its own risks. These lessons learned, when incorporated into the project schedule through the risk management program, are invaluable in helping to minimize threats that carry negative impacts and take advantage of opportunities that bring positive impacts to project completion.

SCHEDULE RISK TYPES

Schedule risks fall into several broad areas:

1. General duration uncertainty
2. Specific risk events
3. Network logic risks that exist or are increased as a result of the activity relationships

Each of these types of risk is analyzed differently using different tools.

General duration uncertainty: General duration uncertainty is the risk resulting from these conditions:

- The deterministic durations estimated by the stakeholders are inaccurate or overly simplistic or are based on assumptions not necessarily correct or accurate
- The critical path identified in the deterministic approach may not be the same as the probabilistic critical path when risks are incorporated into the schedule
- The combinations of durations, where pessimistic durations may stack along a path—because of logic relationships—will significantly extend the predicted completion date

When discussing duration uncertainty, many project managers believe that their initial estimations of durations are accurate, and if the risk discussion continues, believe that their durations are the “most likely” durations. This seems logical and so the necessary discussion about the difference between deterministic and probabilistic schedule development rarely happens. Since the durations are estimates of future events, there is no certainty that the estimates will be accurate, and in addition, duration estimates are based on predicted crew production rates. Crew production rates are based on a number of variables, including the make up of the crew, the level of knowledge of the crew on the specific activity, weather conditions, the availability and condition of equipment, crowding of the workspace, and many others. All of these factors can affect the actual duration of the activity, making the original estimate unlikely to be achieved in some cases. An additional problem with using deterministic approaches with no risk analysis is that many assumptions are made in early development of the schedule but rarely if ever questioned or reviewed again during the project. The assumptions themselves can lead to higher risks if they prove to be false or inadequate.

So a probabilistic approach takes the concept of estimating durations based on average production rates to the next level; it looks at the range of possible project durations based on a spread (called “distribution” in statistics) in the estimated activity durations, commonly called a three-point estimate. The name “three-point estimate” came from its general definition that includes three duration estimates: the pessimistic, the most likely, and the optimistic. This allows for a compiling of all general risks to the duration into this three point estimate by providing a range of durations that can be used in the risk analysis. It also helps accuracy when there is a higher level of unknowns about the project as is often the case in early stages of any project but especially design-build projects, where the design is under development at the same time as the schedule.

There is also a risk of stacking of inaccurate or changed durations along the same path, which would magnify the uncertainty of duration estimating. With the right risk management approach, the uncertainty of activity durations is more likely to be taken into account in the schedule’s predictions.

Use of the Monte Carlo technique makes general duration uncertainties relatively easy to analyze, as well as risks from activity relationships and some specific event risks. Monte Carlo analysis runs a large number of iterations based on the spread of the duration estimates, so that many combinations of durations are used. This probabilistic approach recognizes that the more accurate way to model durations is through the use of statistics, where if enough iterations are run, the results will generally fall into one of the common probability distributions of activity duration. One of those probability distributions that is commonly seen and used is the *normal distribution*, which graphs into a bell-shaped curve with the most likely duration at the highest peak of the curve and smaller probabilities as the curve diminishes in both directions. An understanding of statistics is important in order to use Monte Carlo analysis for risk management, especially in choosing the probability distribution as well as knowing how to evaluate the three-point estimates for use in the analysis. There are several features in the Monte Carlo computer simulation that produce interesting and useful results from the analysis, such as the ability to provide global or filtered duration

estimate spreads and the ability to adjust risk by Activity Code. The Monte Carlo analyses provide statistically significant “confidence levels” for the probabilistic prediction of completion dates and—since schedules are dealing with unknowns—enable the schedules to have higher probabilities of meeting the chosen completion date.

The Monte Carlo methods are available in numerous software packages, such as PertMaster (acquired by Primavera Systems which was later acquired by Oracle), which can be linked to the CPM software by the same entity. There are also spreadsheet versions of Monte Carlo techniques, such as @Risk, published by the Palisade Corporation. The use of three-point estimates for risk analysis of uncertainties in duration originated in the late 1950s during the Navy’s Polaris missile program. That program was called PERT, for Program Evaluation and Review Technique.⁵ PERT developed independently of and concurrently with CPM methodology and used the three-point estimate process to provide a weighted average duration for use in the network calculations.

Specific event risks: Specific risk events are potential impacts on the schedule that may or may not occur such as accidents and other events that are hard to predict. Specific event risks include several types of risks that are analyzed by several methods, but the initial step is a brainstorming session in which project team members identify as many potential risk events as possible and create a risk register or checklist of those events. The process of identifying potential risks to a project is a valuable effort that helps the project management team to start thinking about risk issues and produces a more realistic schedule.

Another type of specific risk event includes additional scope of work activities that may or may not happen, activities that are present in the schedule but may require unplanned multiple cycles to complete, or activities that have significant variability. It is important when brainstorming these risks to review historical records and experiences to determine which of these types of risks may occur in the project underway. These risks are probably dependent on other factors such as the personnel involved, the type of project, or the timeframe and budget.

There are several methods to analyze specific risk events. Modeling a specific risk by creating a “fragnet” of activities to represent the scope of work due to the risk (called a “what-if scenario”) is one good way to attempt to determine the potential ramifications of realization of the risk. This is the same approach that would be taken during a project if a changed condition appeared to impact the schedule and the project management team needed to assess the potential ramifications of that change. In this situation, the contractor would prepare a prospective Time Impact Analysis (TIA). A prospective TIA is prepared by using the current updated schedule, inserting a linked group of activities that model the changed condition, and recalculating the schedule to see if the finish date changes. This linked group of activities is called a fragmentary network, or fragnet. The amount of change to the finish date is an indication of number of days that the changed condition affected the critical path and

⁵ Explained in details in chapter 11.

delayed the project. An excellent description of a prospective TIA is provided by the Association for the Advancement of Cost Engineering International (AACEI) in their Recommended Practice No. 52R-06, “Time Impact Analysis – As Applied in Construction.”⁶ Specific risks can also be incorporated into a Monte Carlo analysis to provide a probabilistic approach to modeling the risks.

Network logic risks: Network logic risks are those that generally occur as a result of project management decisions made about the sequencing of activities determined by the activity relationships. If a number of paths originate or terminate in one activity, there is a significantly increased risk of delay to path activities causing delay to the project. Network logic risks include any risks that predominately relate to the schedule network such as activities that occur at a “hub” or convergence point. A single activity that controls multiple activities of subsequent work, such as environmental controls, dry-in, above-ceiling inspections, or temporary traffic relocation, will cause serious delays and disruption should it not be completed on time. Activities that require the same resource and have tight sequencing predictions are at a much higher risk of failure if resources are not as available as the schedule predicted, and failure in one activity will likely be reflected in all other activities that require that same resource. These network logic risks are often discovered only through technical analysis of the schedule components. A good review of the schedule should identify these risks if the reviewer is knowledgeable and is provided direction from the risk management plan.

Once the types of risk are understood, a good risk management plan is prepared, including a brainstorming meeting with the major project stakeholders. A master risk register is an invaluable tool for facilitating the brainstorming session, which is often called a risk workshop. This register is a logical place to collect lessons learned on a corporate level from many project experiences. With a good risk register, organized by industry and type of risk, the process of brainstorming moves quicker and is focused with a more comprehensive list of risks.

Just as a schedule development session should be a dedicated meeting with the project management team, the risk workshop should be treated as a standalone process, requiring participation by the major stakeholders for the project. At a minimum, the project management team should participate, but the involvement by others provides valuable insight from those with other views and experiences. The output of the risk workshop should be a fully developed risk register identifying all potential risks to the program, no matter who carries the responsibility for resolution of the risks.

DEFINITION OF RISK TERMS

The Project Management Institute (PMI) defines project risk in its *Project Management Body of Knowledge* (PMBOK) as “an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective, such as time, cost, scope, or quality. A risk may have one or more causes and, if it occurs, one or more impacts.”

⁶AACEI Recommended Practice No. 52R-06, “Time Impact Analysis – As Applied in Construction.”

PMBOK adds “Risk conditions could include aspects of the project’s or organization’s environment that may contribute to project risk, such as poor project management practices, or dependency on external participants who cannot be controlled.”

Risk Management: A process designed to examine uncertainties occurring during project delivery and to implement actions dealing with those uncertainties in order to achieve project objectives

The definition of risk management in PMBOK, 4th Edition, is: “systematic process of identifying, analyzing, and responding to project risk.”

Risk definition by AACEI Cost Engineering Terminology⁷ is: “the degree of dispersion or variability around the expected or ‘best’ value, which is estimated to exist for the economic variable in question, e.g., a quantitative measure of the upper and lower limits which are considered reasonable for the factor being estimated.”

Time Contingency: An amount of time added to the base estimated duration to allow for unknown impacts to the project schedule, or to achieve a certain level of confidence in the estimated duration.

Probability: A measure of the likelihood of occurrence of an event.

Risk register: A checklist of potential risks developed during the risk identification phase of risk management.

Risk allocation: A determination of how to respond to risks, which can include shifting risk, avoiding risks, preventing or eliminating risks, and incorporating risks into the schedule.

Deterministic: A calculated approach to estimating single activity duration using work quantity divided by estimated production rate.

Probabilistic: The determination of risk likelihood and consequences to establish duration ranges or risk-adjusted durations that can be used in a schedule in recognition that there are no certainties in estimating future durations.

Monte Carlo analysis: A probabilistic approach to determining confidence levels of completion dates for a project schedule by calculating durations as probability distributions.

Probability distribution: The spread of durations in a statistically significant population that is used for the range of durations in probabilistic scheduling approaches.

Confidence level: A measure of the statistical reliability of the prediction of project completion.

What-if scenario: A modeling of a risk for use in a CPM schedule in order to predict the ramifications of an identified risk.

Qualitative analysis: The determination of the likelihood of a risk occurring on the project, as well as assessing the severity of that risk should it occur and prioritizing the resultant list of risks.

Quantitative analysis: The assigning of a probability to the qualitative description of the risk, ranking the risks, and calculating the potential impact from both individual risks as well as the cumulative effect of all risks identified.

Exculpatory clauses: Disclaimer verbiage that is designed to shift risk.

⁷AACEI, Association for the Advancement of Cost Engineering International, Cost Engineering Terminology

IMPORTANCE OF GOOD PLANNING FOR RISK MANAGEMENT

The quality of the risk management plan will control the usefulness of the risk analysis. This quality is achieved through developing a good and encompassing master risk register in a brainstorming workshop with experienced attendees, and following that process with analysis and risk allocation. This is combined with a process of continuing risk monitoring during updates as well as continuous cycles of risk management.

Participants in the workshop will often comment that they cannot take certain risks into account because they do not have control of the risks or they have no idea if that risk will actually happen. One of the typical issues is repeated cycles of shop drawings, where experience tells us that a complicated design may cause structural steel shop drawings to be rejected, requiring revision and resubmission. Some stakeholders feel that this is beyond their ability to plan for and therefore, the schedule should ignore it and assume the risk will not happen. Accepting this assumption minimizes the risk identification and analysis process. This type of risk should be identified, and then during the qualitative analysis, it will be weeded out as a low priority or incorporated as a high priority. However, if the risk is just not included on the risk register, the opportunity to analyze it is lost.

With a thorough and organized risk workshop, based on a good master risk register, and participation by the major stakeholders as well as the project management team, the output of the risk analysis will be very useful. The most likely risks will be identified and analyzed, and with the rest of the risk management steps, the schedule will evolve into a risk-adjusted schedule, capable of reasonable analysis and realistic completion predictions.

IMPORTANCE OF GOOD CPM SCHEDULING PRACTICES FOR RISK ASSESSMENT

Although there are significant benefits in brainstorming and identifying potential risks on a construction process through raising the awareness of those issues, the efficient way to evaluate and analyze those risks is through some computerized risk management approaches. Whether it is modeling-specific risk events or running Monte Carlo calculations for duration uncertainties, these approaches depend on the quality of the CPM schedule. If the schedule model does not reflect the complete scope of work, does not utilize a good network that produces accurate calculations, and contains scheduling components used inappropriately, then the results from the risk analysis will not be useful. With risk assessment based on a well-developed CPM schedule, the results will reflect more probable accounting of those risks.

Good CPM scheduling practices include capturing the full and complete scope of work in the schedule. This could be achieved by using a work breakdown structure (WBS), which would then be reconciled with the chart of accounts or estimate to ensure that all activities carrying cost are included on the lowest level of each column of the WBS. Including the full scope of work also requires some level of consistency in the

amount of detail in each trade so that no single trade can control the network calculations because of the number of activities in that trade.

Another important practice is to limit the use of relationships among activities to mostly finish-start relationships with minimal use of lags.⁸ This improves the ability of the Monte Carlo analysis software to provide accurate results from those calculations. Some Monte Carlo software programs do not calculate accurately with negative lags, so those should be minimized in any schedule that is intended to be adjusted for risk through Monte Carlo.

In addition, the level of detail in the schedule is an important requirement for use with risk analysis. There must be enough detail to isolate each activity by responsibility. This means that, for a schedule to be used in risk analysis, an activity should only model one trade. A rough-in activity should be broken down into separate activities for mechanical, electrical, plumbing, and fire sprinkler work. The rough-in should also be separated between wall rough-ins and ceiling rough-ins, and by area designation plan if those areas tend to progress differently. This allows evaluation of each trade for different assumptions of risk, as well as evaluation of areas for different risks. For example, if a plumbing subcontractor shows up on the risk register after the workshop as a high risk because of their reputation, then a different factor for risk or a different spread of duration estimates can be used to account for that risk. On a very simple level, without Monte Carlo analysis, a time contingency could be added to the plumbing activities to allow more time than predicted, especially on those activities that are vital to opening up other significant areas of work.

The use of constraints can affect the validity and accuracy of risk calculations because constraints may sequester float or prevent the network from calculating correctly. It may be necessary in the risk analysis to remove constraints in order to see the impact of those constraints on project completion. The fewer constraints, the easier it is to incorporate risk management. In addition, the use of mandatory constraints that do not allow the network to calculate float accurately in either direction, delay or acceleration, is problematic and might render the schedule an inappropriate candidate for a risk analysis.

Just as in any analysis of a schedule, the more calendars that exist in the schedule, the harder it is to analyze, whether for delay or risk. Multiple calendars with many shifts from calendar to calendar along critical paths will amplify or reduce the total float values. This can affect risk analysis and, at the least, can require additional work in the analysis.

The risk management plan is based on CPM network calculations, whether using Monte Carlo analysis or what-if scenarios. So if the network does not calculate correctly, the value from risk management is severely reduced. This means that one of the generally accepted scheduling best practices, the limitation of open-ended activities to the first and last activities, is vital to risk management analysis.

⁸ Overlapping activities can be accurately represented by splitting the predecessor. See the discussion in chapter 5 and Figure 5.8.

With Monte Carlo analysis, the iterations are run with multiple values of activity durations, so those durations have to be reasonable, comparable, and ideally limited to one update period or less. The estimated durations, whether single estimates or three-point estimates, should be calculated by accurate quantities and appropriate production rates. This means that the durations will be based on reasonable resource planning that reflects the contractor's ability to staff the project. Unusually large durations might artificially skew the results in either Monte Carlo or what-if scenarios. In addition to best practices in duration estimating, logic must be depicted accurately to eliminate any unnecessary or redundant relationships.

Careful examination of the critical path and near-critical-paths is vital in developing a CPM schedule for a risk analysis effort. Activities driving the completion of the project and those that appear critical during updates must be logical and make sense. At this time, a reexamination of all assumptions that were used in the schedule development is important, and that includes verification that there is no logic missing that might allow activities to inappropriately carry high float. The validity of the critical path is an essential basis of good CPM scheduling practices, which is reinforced by the needs of risk assessment of the schedule.

RISK SHIFTING IN CONTRACTS

Contract language may have a significant impact on how much of the risk each party carries. Sometimes called exculpatory clauses, this language attempts to shift or apportion undetermined risk. Contracts are often used to control or assign risk to various parties, or just to assign it to a party other than the owner. Many owners, developers, and contractors prefer using standard contract forms, such as those specially developed by organizations such as the American Institute of Architecture (AIA), the Construction Management Association of America (CMAA), and the Associated General Contractors (AGC) in the United States and FIDIC or NEC in Europe and the Middle East, because such contract forms were written and updated by professionals and are widely known and used. However, many others insist on writing their own contracts or making amendments to the standard forms so that they can change certain conditions, which may—and usually does—affect the risk of the contracting parties.

One example of this risk shifting is the use of clauses stating that geotechnical reports and information are provided to bidders for information only, and the owner is not responsible for any usage or interpretation of the geotechnical information. This is an attempt to limit the owner's exposure to delays because of differing site conditions.

Another example is that of the typical "no damages for delay" language that sometimes shows up in contracts, which does not typically shift the time performance risk, but only the costs for the delay. This language attempts to move the risk of the costs of delays from the responsibility of the owner to the contractor, so that the sole remedy is a time extension.

Construction manager and contractor insurances are means to handle the shifted risk of contracts and limit the liability of those parties. These types of insurance can

provide some level of protection against the adverse consequences of unknown problems that might affect the completion of the project. Builder's risk policies provide insurance that will replace materials and provide for damage repair that can be invoked fairly quickly in the event of vandalism or property losses, allowing the project to resume production and minimize delayed completion risks.

An astute owner realizes that the more that risk is shifted to the contractor, the higher the cost and, sometimes, the longer the performance time of the project will be. A fair risk allocation is essential for a successful, economical, and timely completed project. Unfair risk allocation results in risks being distributed among the construction team, creating disharmony and adversarial relationships among the very team members that are needed to resolve the problems at hand.

As noted in the CMAA's *Capstone: The History of Construction Management Practice and Procedures*:

Following the timely identification and assessment of risks, a rational approach to risk allocation can proceed based upon the following general principles:

- Risk should be assigned to the party who can best control it.
- Risk should be assigned to the party who can bear the risk at the lowest cost.
- Risk should be assigned to the Owner when no other party can control the risk or bear the loss.
- Assumption of risk by the other parties to the construction process results in increases in cost (visible or hidden) to the Owner⁹

The risk management plan is the place to identify all risks and determine how to deal with these risks. This provides much better protection through a fair and objective allocation of risk, producing a clear understanding of the risk objectives by the entire project team.

In some contracts, owners may try to shift some risks to the contractor as part of what they perceive as negotiation. Contractor's profit is usually proportional to the risk taken by the contractor. It is important for any owner to understand that there is always a price for shifting the risk, whether declared or hidden. Perhaps in some instances if the owner knew the real cost of shifting certain risks, he would have preferred not to shift them.

An example of the above is when buying a new car or home. A standard warranty comes usually with every new vehicle and covers manufacturer's defects up to a certain time period (e.g., 36 months) or mileage (e.g., 36,000 miles), whichever comes first. Of course, the salesperson will try to sell the buyer (owner) an "extended warranty" policy that extends most of the original warranty terms in time and mileage and perhaps adds a few attractive items. A buyer who considers himself a good negotiator may manage to obtain this extended warranty policy at "no extra cost." This is a

⁹ *Capstone: The History of Construction Management Practice and Procedures*, 2003 Edition, Construction Management Association of America, Inc. (CMAA)

myth! In most cases, the buyer would have received a price discount on the vehicle, roughly equivalent to the dealer's cost on the extended warranty policy, in lieu of the policy itself.

SCHEDULE RISK MANAGEMENT STEPS

The Project Management Institute (PMI), in its Project *Management Body of Knowledge* (PMBOK), 4th Edition, has a chapter dedicated to project risk management. It deals with all aspects of project risks and serves as the basis for schedule risk management. PMBOK suggests that project risk management includes:

- identifying risks, defined as “the process of determining which risks may affect the project and documenting their characteristics”;
- performing qualitative risk analysis, defined as “the process of prioritizing risks for further analysis or action by assessing and combining their probability of occurrence and impact”;
- performing quantitative risk analysis, defined as “the process of numerically analyzing the effect of identified risks on overall project objectives”;
- planning risk responses, defined as “the process of developing options and actions to enhance opportunities and to reduce threats to project objectives”; and
- monitoring and controlling risk, defined as “the process of implementing risk response plans, tracking identified risks, monitoring residual risks, identifying new risks, and evaluating risk process effectiveness throughout the project.”

Therefore, we can say that schedule risk management for construction includes the following processes:

1. Risk management planning
2. Identification of schedule risks
3. Performing qualitative analysis of the identified risks and establishing priorities
4. Performing quantitative analysis of the qualified risks
5. Responding to and addressing risks by avoiding, shifting, preventing, or accepting risks and incorporating remaining risks into the schedule and providing mitigation plans where appropriate
6. Monitoring and updating the risk management plan during update cycles, including evaluating existing risks as well as starting the identification cycle for new risks

1. *Risk management planning:* Risk management starts with developing a risk management plan. The plan should provide direction to the project management team in the use of risk management, both in the baseline schedule development and for the

schedule updates. This should include determining how the risk management will be carried out as well as developing a master risk register that would serve to facilitate risk identification. The plan development will serve to encourage the project management team to recognize that managing risk is a formal procedure, with a regimented process to be used as the approach to a standardized plan. This risk management process should be incorporated into the procedures for design and development of the baseline schedule as well as the procedures for each schedule update.

It is important for any company or organization to have a level of risk management incorporated into its work culture. A good way to initiate the use of risk management is through a separate brainstorming session that is designed to develop the master list of risks. Development of this master risk register will improve the efficiency of the risk identification and provides a storage place for capturing historical information and lessons learned from the experience of the project team.

The organization of the master risk register is important, since it will help categorize and isolate historical risks that have been encountered in previous projects, many of which are still potential risks for the next project. The development of this master risk register could be simply capturing categories or leading to the development of a more formal structure such as a Risk Breakdown Structure (RBS) as recommended by PMI. As noted in PMBOK, “The RBS is a hierarchically organized depiction of the identified project risks arranged by risk category and subcategory that identifies the various areas and causes of potential risks.” The RBS example in the PMBOK shows the first level of the structure containing: “Technical,” “External,” “Organizational,” and “Project Management,” with each category subdivided into subcategories such as technology, subcontractors, resources, and communication. Categories might be project-type driven, even to the point of maintaining separate master risk registers for transportation projects from facility projects, which helps maintain relevance in the register.

Some typical examples of useful categories might include: plans and specifications, quality control, contractors and subcontractors, owner influences, unforeseen conditions, weather, cost and schedule constraints, change management, claims and disputes, project management, safety, political and cultural risks.

Subcategories such as whether a constructability review was performed are particularly important. If it was, the plans probably provide much better direction for construction and will result in fewer requests for information that turn into change orders. The reputation of the designer has an impact on the quality of the drawings, which will affect change orders as well. Physical quality control issues such as the distance from the nearest concrete batch plant to the project are important to review for risk. The author was involved in a large bridge project that was constructed in a remote location with a local batch plant that did not provide the capacity to supply the project. This raised the risk of performance in high concrete placement periods, such as the counterweight fill for the bascule equipment, and as a result of the risk management, the project was able to look into setting up a batch plant on site. Limited suppliers for a piece of highly technical equipment will raise the procurement risk. This makes new technology or specialized technology a higher risk for the project. Even techniques that

are common in some parts of the country (or the world) may not be common at the project location or for the project CM or contractor. A wharf constructed in Virginia was designed with roller-compacted concrete, a technique that had only been performed on the west coast, and the first concrete placement was a disaster. The contractor suffered some inefficiency from a learning curve because of lack of experience, but fortunately that was identified before the schedule was approved.

These subcategories are used to collect and organize risk factors, such as the stage of completion of the contract documents, the age of subsurface information, the availability of as-built drawings, the water table, the contract type and delivery method, the experience of the project management team and subcontractors, the quality of the schedule, the availability of skilled labor, and many other issues. In the brainstorming session, the participants, preferably involving all project management team members, should just list every problem that they have experienced, and then attempt to categorize it. It is useful to identify the solution to the problem when it was solved and how the risk was actually handled at the time.

2. Identifying schedule risks: The next step in risk management is identifying risks for the project in hand. Facilitating a risk workshop is a good way to start the next step of this process. With a good master risk register in hand, and an experienced and knowledgeable facilitator, a short meeting with the specific project management team and other important stakeholders can be efficient and revealing. The risk discussion should be broken down into the general types of risk discussed earlier in the chapter; general duration uncertainty, specific risk events, and network logic risks.

3. Performing qualitative analysis: Once specific risk events are identified and recorded in the risk register, the next step in risk management is to analyze the risks qualitatively. This process involves making judgments about the likelihood of occurrence for each risk as well as prioritizing the risks, based on a combination of likelihood and severity of consequences. Qualitative analysis of risks also includes the determination of the range of durations for the three-point duration estimates that are used in Monte Carlo analyses.

In deciding on the three-point duration estimates, consider that the pessimistic estimate should provide for the longest duration that is realistically possible, whereas the optimistic estimate should provide for the shortest time that can realistically be imagined for that activity. The most likely estimate of duration is the duration that is most likely to occur, taking into account all known factors of project conditions, resources, and difficulty of performance. These duration ranges will be used in the Monte Carlo analysis used for duration uncertainties to produce a distribution of project durations with the probability of success, as well as other useful metrics.

The qualitative descriptions for risk generally fall into five categories that range from high to low likelihood: remote, unlikely, likely, highly likely, near certainty.

- Remote determinations should indicate it is reasonable to assume that the risk will not happen.
- Unlikely indicates a small likelihood but a risk that is possible, particularly over the lifetime of the project.

- Likely determinations would carry the expectation that the project probably will see the risk occur at some time during the project.
- Highly likely determinations would indicate that the risk will occur at least one time, so the priority for this qualitative judgment should be high.
- Near certainty indicates that planning should include the expectation that it will occur more than once in the project.

At the beginning of the qualitative analysis of risk portion of the workshop, the facilitator should explain the qualitative terms chosen for the program, and ensure that the participants have common understanding of the range and judgments. This will take some discussion to ensure that the stakeholders feel comfortable with providing a description of their qualitative assessment of the risk, whether it is a near certainty or unlikely. Remind the participants that this is historically based using lessons learned. If no one in the risk workshop, for example, has ever run into a specific risk, it should carry a remote likelihood of occurrence. Conversely, a problem that has been witnessed by all participants on almost all projects would be described as a near certainty of showing up on this project.

In conjunction with the likelihood of occurrence is the issue of consequence. This is every bit as important as the likelihood that a risk will happen. The consequences are the ramifications from the effects of the risk if (or when) it happens. So identifying the risk and the likelihood do not tell the entire story, and are not sufficient for analysis. Qualitative assessment of consequences is an attempt to understand how the risk will affect the project in all aspects, from direct impacts to secondary disruption and inefficiencies.

The descriptions of consequence include the range of impacts from no impact to disaster: negligible, acceptable, marginal, critical, and catastrophic.

- Negligible consequences indicate that there would be minimal or no schedule impact.
- Acceptable consequences indicate that there would be some slippage of contractual milestones, but there would be float available to recover the overall schedule.
- Marginal consequences would indicate that the risk would cause some critical path items to be impacted and result in minor delays that would require recovery efforts.
- Critical consequences indicate that there would be major and potentially lengthy delays to a single critical path item.
- Catastrophic consequences indicate multiple delays to critical path items, or multiple critical paths, that result in lengthy delays to the project.

Once these initial qualitative assessments are made, they can be used to determine priorities and consequences, still during the qualitative analysis stage of risk management. A risk that has a high likelihood of occurring with a serious consequence to the project's success should be considered the highest priority of any risk, just as those with

low likelihood and minor consequences are low-priority risks. The output from the qualitative analysis process is a list of prioritized risks, ordered from the highest to the lowest priority, as well as the three-point estimates of durations for activities.

4. Performing quantitative analysis: The next step after completing the qualitative assessment is the quantitative analysis of the risks. Qualitative descriptions, used to identify the likelihood and consequences of risk, are then aligned with quantitative probabilities in a process often called probability mapping. The qualitative descriptions are used to make it easier to evaluate risks, and once those are completed, this probability mapping converts those descriptions into values that can be used in the software risk calculations. A common probability mapping might correlate the following ranges of probability with these qualitative descriptions: Remote, less than or equal to 20%; unlikely, 21% to 40%; likely, 41% to 60%; highly likely, 61% to 80%; near certainty, greater than 80%. During the mapping and discussion of each risk, the estimated location in the probability range can be determined and recorded. The output from the quantitative analysis is the prioritized risk register with assigned rankings, sorted by the combination of the probability and the consequence. This enables the start of the next step, responding to the risks, or factoring the risks into the Monte Carlo or what-if scenario analyses.

5. Responding to and resolving risks: Now that the risks are listed and analyzed, the next step is resolving risks by various means. These means include avoiding, shifting, or preventing all possible risks, and accepting remaining unresolved risks and incorporating those risks into the schedule, as well as documenting the decisions. Part of documenting the decisions should include preparing a risk mitigation plan for those unresolved risks and acting on that plan. The risk mitigation plan might include just monitoring unresolved risks to ensure that they don't become a driver of productivity or delay. The plan might include adding time contingencies to the activities representing a specific risk on a certain scope of work, like the craft activities mentioned earlier. This risk mitigation plan should include identification of the progress stages necessary to investigate new risks in case it is determined unnecessary to do so at each schedule update.

Contractors will often add a cost contingency to cover risks, such as the likelihood of inability to complete a project by the contractual completion date. This could include making a judgment about the difference between the contractual completion date and the scheduled prediction for completion, and adding the costs of paying liquidated damages for that difference or accelerating the schedule. Such a risk may encourage the contractor to withdraw from bidding or contracting on a project because of the risk in order to pursue lower-risk projects.

Now that the risk mitigation plan and resolved risks have been incorporated into the schedule, the risk assessment of the baseline schedule is complete and the final product is a risk-adjusted schedule. This product is the result of a good plan, with decisions made at every step along the way based on appropriate assumptions and accurate assessment of the risks to the project. This product is not a black-box risk management approach, where the schedule is dumped into proprietary software for risk adjustments, based on unknown assumptions and decisions.

6. Monitoring and updating the risk management plan: With the first schedule update, the next step comes into play: monitoring and updating the risk management plan during updates. This step also includes evaluating existing unresolved risks with each update, as well as starting the identification cycle for new risks again. This new cycle comprises the same steps that were performed for the baseline schedule. New risks should be identified, qualitatively and then quantitatively analyzed, prioritized, and responded to or resolved. New risks that cannot be resolved will need to be added to the risk mitigation plan in order to determine a plan of action and incorporation into the schedule. This cycle would continue until the completion of the project or the determination that all risks have been actualized or disappeared.

Some scheduling software programs include ways to monitor and control risk and offer the ability to perform some level of analysis. An example is Primavera Project Management, which has a directory button that displays risks and allows some level of monitoring of those risks. This type of schedule software package with standardized components can help with this last step in a risk management plan, monitoring and control of risks during the schedule update cycle.

EXPECTED VALUE

Statisticians combine the likelihoods of different outcomes of an event with their corresponding potential consequences in what is known as the Expected Value:

$$E(X) = \sum_i x_i \cdot p(x_i)$$

Where

- $E(X)$ is the “expected value” of an event X such as an accident, hurricane, or shop drawing rejection
- i is the domain of all possible outcomes such as catastrophic, severe, significant, mild, light, negligible
- x_i is the value of consequence of outcome i
- $p(x_i)$ is the probability of occurrence of outcome i

For example, for a hurricane that may strike the area where the project is located, these likelihoods and outcomes are estimated:

Outcome	Likelihood	Impact on Schedule
Negligible	20%	No delay
Mild	30%	5 days delay
Significant	25%	12 days delay
Major	20%	20 days delay
Catastrophic	5%	50 days delay

The Expected Value of the hurricane event is

$$E = 0.20 \cdot 0 + 0.30 \cdot 5 + 0.25 \cdot 12 + 0.20 \cdot 20 + 0.05 \cdot 50 = 11 \text{ days}$$

It is important to note that the Expected Value is a hypothetical, not real, value. It is adjusted by the likelihood of occurrence. However, the party assuming the risk must account for the possibility of all outcomes and whether or not he/she can take that risk. In the preceding example, there is likelihood, albeit small, that a catastrophic hurricane will cause a 50-day delay in the completion of the project. The contractor and owner must bear in mind that such an outcome may happen. In a different example, a 55-year-old person is contemplating investing his entire savings in an investment venture with several possible outcomes:

Outcome	Likelihood
Double his money	20%
Make 50% profit	30%
Break even	30%
Lose his money	20%

Assuming the person's capital is \$100,000, the expected value is:

$$\begin{aligned} E &= -100,000 + 0.20 \cdot 200,000 + 0.30 \cdot 150,000 + 0.30 \cdot 100,000 + 0.20 \cdot 0 \\ &= +15,000 \end{aligned}$$

or¹⁰

$$E = 0.20 \cdot 100,000 + 0.30 \cdot 50,000 + 0.30 \cdot 0 + 0.20 \cdot (-100,000) = +15,000$$

Even though the investment has a positive (attractive) value overall, the investor must bear in mind that there is a 20% chance his entire savings are lost. In such case, the investor may not be willing to take such risk.

The contractor, on the other side, should not overreact, perhaps by taking into consideration the event outcome or consequence only without considering the likelihood. This may lead to a situation where the risk mitigation costs more than the Expected Value of the event itself.

Companies or investors who diversify their investments or projects are generally at lower risk of suffering a catastrophic loss at the level of the corporation or organization. If the probability of a catastrophic loss (or adverse condition) for each project is low (e.g., 20%), the probability of catastrophic loss at n projects simultaneously is $n \cdot 20\%$ (2% if 10 projects). This is true only if the events in the different projects are independent.

¹⁰The two equations are equivalent: The first one considers all payments, including the initial investment, which comes in as a negative value. All other payments (profit/loss) are adjusted by the probability. The second equation considers only profit/loss after the initial investment.

APPLICATION IN SCHEDULING

Historically, schedule risk management has been reserved mostly for large complex international projects with severe risk events, such as long lead shipping components, but the scheduling industry has started to recognize that the use of strictly deterministic schedule development has some drawbacks. As noted earlier, risk has been considered for years in the cost estimating side of project controls, through processes ranging from Monte Carlo analyses to simple gut feeling estimation of contingencies. Few estimators would provide a project cost estimate that did not account for escalation and uncertainties in the estimate; however, schedulers are just now starting to take the same approach with time risk.

Much of the benefit of a schedule risk management program lies in the risk workshop. Once the project management team has participated in a formal risk workshop and discussed common project problems, thought through the likelihood of encountering those same problems, and worked out risk allocations, they see the benefits of schedule risk management. If a project team embarks on a second project designed by the same architect and engineers, and the first project generated a high volume of requests for information in order to build the project, that team will think twice about how to manage the new project. If the team has participated in a project that had a good constructability review performed, and witnessed a small volume of requests for information, then they recognize the lowered risk of performance because of good quality control of the design documents.

The discussion about the three-point duration estimates alone is useful to enable the project team to evaluate duration estimates, rather than casually providing the durations or calculating durations strictly from third-party references that may or may not be accurate for a specific project location or condition. This is an important phase of planning: the development of realistic durations and logic relationships driven by a statistical approach to common problems that are historically known to be present on projects.

Some of the details generated by a Monte Carlo analysis provide flags for monitoring specific activities. The power of a computer program that has identified the activities falling on the most critical paths because of calculations using a high number of iterations performed is amazing. If 10 activities are identified by this criticality index, these activities can be monitored and reported so that they do not suffer any delays. Identification of hub activities, where multiple paths merge into a single activity is very useful for listing activities that require special scrutiny. Tornado charts can identify a simple prioritized list of risks by sensitivity, the combination of likelihood and consequences, providing the analyst with targets for careful monitoring. There are many Monte Carlo analysis resources available for anyone with an interest in this topic, but this text is not designed to provide more than an overview of risk management.

Risk analysis emphasizes that delays are often actually caused by near-critical path activities that slip and cause delay. The author has been involved in many dispute resolution cases where the schedule analysis exposes delay that is caused by what is referred to as a mid-period critical path shift, meaning the critical path at the beginning of the period is not the same as the critical path at the end of the period. Often participants

in a dispute look at the critical path at the beginning of the period, assess the changes to that path and never look at other paths that may overtake the current critical path.

With good risk management, those parallel critical paths are examined statistically, providing results that are typically realistic across many projects. While individual projects may and can differ, especially because of project management decisions and responses to threats during construction, in the larger project experience, the statistics provide a level of realism for planning and monitoring.

EXAMPLES OF RISK ADJUSTMENT

Some examples of risk-adjusted schedules include the development of a 3,200-activity baseline schedule for a firing range for a state prison system. This project was a design-bid-build municipal project and, as such, the project was awarded on a low-bid basis. The contractor for the project used the pricing from an earthwork subcontractor with historical records showing low productivity in excavation. During development of the schedule, while brainstorming specific risks for the risk register, this risk was identified. The risk was incorporated in the schedule by increasing durations for all work to be done by this subcontractor. During routine updates, the durations of this subcontractor's activities were reviewed to examine performance in case the risk was still not covered.

Another example of a risk analysis involved a new port project that needed a high volume of sand fill, with multiple ways to supply the sand. After determination of the preferred method of sand supply, a resource-driven analysis schedule was developed and resource loaded. This resource-loaded schedule provided what-if scenario schedules by changing the resources and allowing them to drive the completion date. After a number of runs with different resources, the best combination of resource quantity and lead time was used to select the method of supply.

Another project in which the author provided risk analysis and participated in the schedule review was an airport construction project that required a separate project to build a people mover facility on the roof. This mover was designed to run passenger vehicles from the airport to a remote station that provided central access to a number of other modes of transportsations: buses, car parking, and taxis. During the risk workshop, the construction of this station was identified as under the control of the state Department of Transportation (DOT). The qualitative analysis showed that the timing of the station's completion date was unlikely and the consequence was catastrophic, with the combination sensitivity forcing this risk to the top of the priority list. During the pre-scheduling session with the contractor, the risk register was produced with this high-priority risk discussed. All agreed that steps should be taken to prevent the risk materializing by good communication with the DOT and their contractor, and this was done by joint periodic meetings between the project management personnel of both projects. The risk response also required some level of incorporation of the risk into the schedule. The contractor did so very well, ensuring that the sequencing was done so that start of construction in this station was pushed as late as possible and carried several months of float. That risk workshop and resolution prevented later arguments and potential high risks existing in the baseline schedule.

CONCLUSION

There are many other examples; however, the important point is that the use of a risk management program increases the attention given to risks and provides an objective and scientific approach to risk management that allows for better results in predicting project completion. The contractor can plan demobilization and cash flow more accurately, and the owner can plan for opening of the facility and assumption of maintenance and operations with a greater level of confidence.

Risk management is another tool in the scheduler's tool chest that will pay dividends and promote more accurate and believable predictions of completion, but it is a process that must start early and then continue until the end of the project. With a commitment to risk management, schedulers that are trained in risk assessment, a good risk management program, and involvement of the project management team, any schedule can be developed into a risk-adjusted schedule that has a higher probability of being completed on the predicted completion date.

CHAPTER 14 EXERCISES

1. Compare the cost risk and time risk in any typical construction project; include similarities, differences, means of identifying the risks, and responses to each.
2. Talk to a project manager for a local construction project and ask how risk management is handled. If no formal risk management plan is used, discuss how the project is protected against typical project risks. Discuss the benefits of formal risk management.
3. Mention five different risks that may have to be considered in a typical infrastructure construction project consisting of bridges and/or roadways.
4. Pick a random project (any type, not necessarily construction) that you are either leading or involved with. Hold a meeting with project team members (minimum four people). Hold a brainstorming session and prepare a “risk register” for your project.
5. In the previous question, pick 2–3 risks and estimate the cost and time impact in two different scenarios:
 - a. These risks were considered at the early stages of the project (i.e., planning) with a response prepared as part of the risk management plan.
 - b. These risks were not considered until they were imminent or after the fact.
6. What are the major three types of schedule risks?
7. Mention at least two of risks of each type in question 6.
8. In an excavation for a building foundation in a downtown area, there are many risks. Mention five of them and categorize them in the three groups of schedule risks.

9. A contractor in your locale, while working on a road project, submits a claim for extending the completion date due “adverse weather.” His claim was based on the fact that heavy rain prevented work on the project for 13 days during the months of August and September. How do you respond to such claim? Assume: Case I, you are part of the owner’s organization, and Case II, you are part of the contractor’s organization.
10. From past experience, you believe that the chances for approval of a subcontractor’s shop drawings are:
 - a. 50% from first submission
 - b. 30% from second submission
 - c. 20% from third submissionIf estimated durations for shop drawing activities are: 45 days for first submission, 14 days for first review, 14 days for each re-submission, and 7 days for each review (after the first). What is the duration you assign for the entire cycle of the above process, using the “Expected Value” equation?
11. What is the duration you assign for the entire cycle in the previous example, based on the “worst-case scenario”? Do you believe that such duration is realistic? Why or why not?
12. Arrange a meeting with a project manager for a local construction project. Before the meeting, prepare your own list of risks that would have had been identified in the risk register if you were the PM providing a risk analysis. During the meeting with the PM, request a copy of the risk register. If such a copy is not available, ask the PM for the risks considered at the planning stage for the project and what the management’s response was.
13. In the previous question, compare your own risk register to the list given to you by the PM. If you have any risks on your own list that do not exist on the PM’s list, ask the PM (in a professional manner) about these risks and whether they were considered.
14. Choose two activities in the project chosen in question 12. Ask the PM about the durations used in the CPM schedule for these two activities. Ask the PM if these durations represent the “most likely” case? If so, ask for the durations for the “optimistic” and “pessimistic” cases for each activity. Do you believe, considering the optimistic and pessimistic durations, that the most likely durations are reasonable? Why or why not? If not, calculate the “expected duration” using the PERT or three-point formula.
15. From the project chosen in question 12, separate your list of risks into those that can be avoided, shifted, prevented, or accepted as unresolved. Explain how the unresolved risks can be incorporated into the schedule with a mitigation plan.
16. From the project chosen in question 12, perform a risk analysis for one of the routine schedule updates, and identify any newly discovered risks.

Computer Project

You are scheduling a project: a two-story concrete office building with an area of about 4,000 square feet (SF) per floor. The first floor has a slab on a grade (SOG). The second floor is made of a cast-in-place (CIP) concrete slab, carried by both concrete columns and concrete masonry unit (CMU) walls. The roof is made of wood trusses topped with sheathing and asphalt shingles. The schedule logic includes many simplifying assumptions.

GENERAL GUIDELINES

1. This is an individual project but group discussion is allowed and encouraged.
2. Your work will be done mainly on the computer. Some written parts may be required. Make sure that your reports are marked clearly with your name, the date, the report's name, the page number, and so forth.
3. Write down any assumptions you make. Submit a written copy with your report.
4. The recommended software is Primavera Project Manager (P6 or P3), Primavera Contractor, or SureTrak. Alternatively, you may use Microsoft (MS) Project, but if you do, remember that combination relationships will not work in this program.
5. The project comprises no more than 60 activities so that the student version of Primavera software can be used.
6. The assignments pertain to topics covered in the body of this book. Be sure to keep an electronic copy of each assignment.

7. Make the start date 02-AUG-2010. Leave the finish date open.
8. In all calendars, enter the following as nonworkdays: New Year's Day (January 1), Martin Luther King Day (3rd Monday of January), Memorial Day (last Monday of May), July 4, Labor Day (1st Monday of September), Thanksgiving (4th Thursday of November) and the day after, and Christmas (December 25).¹ If a holiday falls on a nonworkday, take the nearest workday as a holiday. In addition, enter two rain days per month. Try to distribute these rain days as evenly as possible.
9. The general contractor (GC) will be doing mainly the structural work, using his or her own workforce, but he/she will use the following subcontractors for other work:

Nickname	Full Name	Type of work
ACAL	All Seasons AC & Heating	HVAC ^a
WALL	Wall to Wall	Drywall, Stucco and Paint
MART	Master Art Landscape	Site work and landscaping
MASE	Mase & Company	Masonry
ROSS	Ross Carpentry & Framing	Wood Framing
PLMX	Plumbing Experts	Plumbing
RABT	Rabbit-the-Roofer	Roofing
TACO	Tile and Carpet Co., Inc.	Flooring
WINT	Windows & Doors NT	Doors and Windows
ZAPP	Zapp Electric Co.	Electrical

^a Heating, ventilation, and air-conditioning

10. Four areas are designated in the project: ALL (for all of the project), 1st (for first-floor activities), 2nd (for second-floor activities), and ROOF (for roof activities).

Activity ID	Activity Title	Duration (days)	IPA ^a	Rel Type ^b	Lag (days)	Resp ^c	Area
1000	NTP ^d	—	—			GC	ALL
1010	Mobilization	3	1000			GC	ALL
1020	Clear & grub	12	1010			GC	ALL
1030	Excavation	7	1020	SS	4	GC	ALL
1040	Foundation	15	1030	SS	3	GC	ALL
			1030	FF	1		

(continued)

¹If you live in a country other than the U.S., you may assign your country's holidays instead. However, depending on the number of holidays and their distribution, your completion date may slightly differ.

Activity ID	Activity Title	Duration (days)	IPA ^a	Rel Type ^b	Lag (days)	Resp ^c	Area
1050	Fill, compact, and treat soil	3	1040			GC	ALL
1060	1st floor plumbing rough-in	3	1050			PLMX	1st
1070	SOG	4	1060			GC	1st
1080	1st floor columns	7	1050			GC	1st
1090	1st floor external CMU walls	10	1070			MASE	1st
1100	1st floor internal CMU walls	14	1070			MASE	1st
1110	2nd floor suspended slab	8	1080, 1090, 1100			GC	2nd
1120	2nd floor plumbing rough-in	3	1110 1110	SS FF	1 -1 ^e	PLMX	2nd
1130	1st floor electrical rough-in	4	1090, 1100, 1280 1090, 1100, 1280	SS FF	2 2	ZAPP	1st
1140	1st floor HVAC ductwork \ rough-in	6	1110			ACAL	1st
1150	1st floor door & window frames	5	1090, 1100, 1280 1090, 1100, 1280	SS FF		WINT	1st
1160	2nd floor columns	7	1110		3	GC	2nd
1170	2nd floor external CMU walls	12	1110			MASE	2nd
1180	2nd floor internal CMU walls	16	1110		2	MASE	2nd
1190	Roof trusses	8	1160, 1170, 1180			ROSS	Roof
1200	2nd floor electrical rough-in	4	1170, 1180, 1280 1170, 1180, 1280	SS FF	2 2	ZAPP	2nd
1210	2nd floor HVAC ductwork \ rough-in	6	1190			ACAL	2nd
1220	2nd floor door & window frames	5	1170, 1180, 1280 1170, 1180, 1280	SS FF		WINT	2nd
1230	Roof sheathing	5	1190			ROSS	Roof
1240	Roof felt	1	1230			RABT	Roof
1250	Building dry-in ^f	—	1240			GC	ALL
1260	Soffit & facia	3	1250			ROSS	Roof
1265	Roof shingles	6	1240			RABT	Roof
1270	Roof insulation	2	1250			ROSS	Roof
1280	Internal partition framing	12	1250			ROSS	ALL
1290	1st floor: hang doors & windows	10	1150, 1280			WINT	1st
1300	1st floor drywall	8	1280			WALL	1st
1310	1st floor HVAC air handler	5	1140, 1300			ACAL	1st

(continued)

Activity ID	Activity Title	Duration (days)	IPA ^a	Rel Type ^b	Lag (days)	Resp ^c	Area
1320	1st floor suspended ceiling	8	1300			WALL	1st
1330	1st floor plumbing: install fixtures	2	1060, 1300			PLMX	1st
1340	1st floor paint/wall covering	10	1320 1330	SS	4	WALL	1st
1350	1st floor electrical finish	6	1130, 1320			ZAPP	1st
1360	1st floor flooring	12	1340, 1350			TACO	1st
1370	2nd floor: hang doors & windows	10	1220, 1280			WINT	2nd
1380	2nd floor drywall	8	1300			WALL	2nd
1390	2nd floor HVAC air handler	5	1210, 1380			ACAL	2nd
1400	2nd floor suspended ceiling	8	1270, 1380			WALL	2nd
1410	2nd floor plumbing: install fixtures	2	1120, 1380			PLMX	2nd
1420	2nd floor paint/wall covering	11	1400 1410	SS	4	WALL	2nd
1430	2nd floor electrical finish	6	1200, 1400			ZAPP	2nd
1440	HVAC: install equipment	1	1310, 1390			ACAL	ALL
1450	2nd floor flooring	10	1420, 1430			TACO	2nd
1460	Stucco & paint to ext. walls	8	1260			WALL	ALL
1470	Site work ^e	15	1020, 1090			MART	ALL
1480	Plumbing finish	2	1330, 1410			PLMX	ALL
1490	HVAC thermostat & test	1	1350, 1430, 1440			ACAL	ALL
1500	Electrical final	4	1340, 1350, 1420, 1430			ZAPP	ALL
1510	Building cleanup	2	1265, 1290, 1360, 1370, 1450, 1460, 1480, 1490, 1500			GC	ALL
1520	Final check/CO ^h	1	1470, 1510			GC	ALL

^a Immediately preceding activity.^b Relationship type: SS, start to start; FF, finish to finish. If blank, the relationship is FS, finish to start.^c Responsibility.^d Notice to Proceed. Make this activity a start milestone.^e The negative lag means 2nd-Floor Plumbing Rough-In must finish 1 day before completion of 2nd-Floor Slab. Note also that the start of this activity lags 1 day behind the start of the slab activity. This makes the plumbing activity completely contained within the slab activity.^f Make this activity a finish milestone.^g Insert a constraint so that Site Work will not finish till about 1 week before the end of the entire project.^h Certificate of occupancy.

Assignment 1**Do the following:**

1. Create the project and call it “Tampa Office Building–01.”² You may choose the name you like. Enter the specified start date. Enter the nonworkdays in the calendar. Enter the Responsibility and Area codes and values.
2. Enter all the activities listed in the preceding table, along with their information (duration, relationships, lag, responsibility, and area).
3. Schedule the project. Make sure there are no errors. Check all dates.
4. Determine the calculated finish date. Go back to the Site Work activity and put in the appropriate constraint.
5. Schedule again. Print the scheduling report. As an option for a better-looking report, save the report, then open it in your word processor. Work on improving how it looks.
6. Print the following:
 - a. The scheduling report. Record the expected finish date (should be 18-MAR-2011³) for use in the next assignments.
 - b. A tabular report listing all activities, ordered by Activity ID. Compare this with the preceding table to make sure that nothing is missing.
 - c. A tabular report listing all activities, ordered by ES (early start), TF (total float). This report shows all early and late dates and total float.
 - d. A tabular report similar to the previous one. Mask late dates and total float. Check if the program automatically renames early dates as scheduled dates. If not, do so yourself.
 - e. A tabular report for activities scheduled to start during the month of September 2010.
 - f. A bar chart showing all activities, organized by Area, ordered by ES, TF.
 - g. A bar chart showing all activities, organized by Responsibility, ordered by ES, TF.
 - h. A bar chart showing only critical or near-critical ($TF \leq 3$) activities. Do not organize it. Sort by ES, TF. Display the relationships.
 - i. A logic diagram. In each box (node), show the activity ID; also show the early dates, the late dates, and the original duration. You may have to work on the size of the box so that the writing inside is legible and the report is not enormous.
 - j. A logic diagram for the activities under the electrical subcontractor only.

²If you are using Primavera Project Planner (P3), you must select a name with four characters. You may choose TOB0.

³Finish date may vary by a day or two depending on the choice of the rain days in March 2011.

7. Make at least one backup copy of the project on an external medium (e.g., CD, flash drive).

COST LOADING

In this exercise, the GC is cost loading his or her schedule but will follow two approaches. For self-performed activities, the GC will resource load them (i.e., assign the proper amount of labor and equipment, plus add the cost of materials, if any).⁴ For subcontracted activities, the GC will add only the cost of these activities (no resource loading).

Activity ID	Activity Title	Resources ^a					Cost ^b
		Laborer	Forman	Carpenter	Excavator		
1000	NTP	—	—	—	—	—	\$0
1010	Mobilization	3	1	—	1	—	\$2,000
1020	Clear & grub	4	1	—	2	—	\$0
1030	Excavation	3	1	—	1	—	\$0
1040	Foundation	3	1	2	1	—	\$5,000
1050	Fill, compact, and treat soil	2	1	—	1	—	\$1,000
1060	1st floor plumbing rough-in	—	—	—	—	—	\$2,500
1070	SOG	2	1	1	—	—	\$1,500
1080	1st floor columns	2	1	2	—	—	\$1,200
1090	1st floor external CMU walls	—	—	—	—	—	\$9,200
1100	1st floor internal CMU walls	—	—	—	—	—	\$7,800
1110	2nd floor suspended slab	2	1	2	—	—	\$3,000
1120	2nd floor plumbing rough-in	—	—	—	—	—	\$2,500
1130	1st floor electrical rough-in	—	—	—	—	—	\$6,000
1140	1st floor HVAC ductwork \ rough-in	—	—	—	—	—	\$7,000
1150	1st floor Door & Window Frames	—	—	—	—	—	\$3,500
1160	2nd floor columns	2	1	1	—	—	\$1,200
1165	Roof Shingles	—	—	—	—	—	\$8,000
1170	2nd floor external CMU walls	—	—	—	—	—	\$11,500
1180	2nd floor internal CMU walls	—	—	—	—	—	\$8,500
1190	Roof trusses	—	—	—	—	—	\$10,000
1200	2nd floor electrical rough-in	—	—	—	—	—	\$6,000
1210	2nd floor HVAC ductwork \ rough-in	—	—	—	—	—	\$7,000
1220	2nd floor door & window frames	—	—	—	—	—	\$2,600
1230	Roof sheathing	—	—	—	—	—	\$3,500
1240	Roof felt	—	—	—	—	—	\$400

(continued)

⁴In some computer scheduling programs, this must also be achieved by adding a resource called *Lump Sum*, which is used for cash amounts only.

Activity ID	Activity Title	Resources ^a					Cost ^b
		Laborer	Forman	Carpenter	Excavator		
1250	Building dry-in	—	—	—	—	\$0	
1260	Soffit & facia					\$2,500	
1270	Roof insulation					\$4,000	
1280	Internal partition framing					\$4,500	
1290	1st floor: hang doors & windows					\$5,200	
1300	1st floor drywall					\$6,500	
1310	1st floor HVAC air handler					\$4,000	
1320	1st floor suspended ceiling					\$7,500	
1330	1st floor plumbing: install fixtures	—	—	—	—	\$7,500	
1340	1st floor paint/wall covering					\$5,700	
1350	1st floor electrical finish					\$15,000	
1360	1st floor flooring					\$11,000	
1370	2nd floor: hang doors & windows					\$4,200	
1380	2nd floor drywall					\$7,000	
1390	2nd floor HVAC air handler					\$4,000	
1400	2nd floor suspended ceiling					\$7,500	
1410	2nd floor plumbing: install fixtures					\$7,500	
1420	2nd floor paint/wall covering					\$5,400	
1430	2nd floor electrical finish					\$17,000	
1440	HVAC: Install equipment					\$22,000	
1450	2nd floor flooring					\$8,500	
1460	Stucco & Paint to ext. walls					\$7,000	
1470	Site work					\$30,000	
1480	Plumbing finish					\$4,500	
1490	HVAC thermostat & test					\$5,000	
1500	Electrical final					\$9,500	
1510	Building cleanup	3	1	—	—	\$200	
1520	Final check/CO	1	1	—	—	\$0	

^a Resources for the general contractor's self-performed activities. Author has used only three labor categories and one equipment category for simplicity.

^b When used for self-performed activities, it reflects the general contractor's materials cost only (total cost excluding labor and equipment). For subcontracted work, cost includes all expenses.

Assignment 2

Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–02.” Add all the information mentioned in the preceding table to the schedule.

2. Print the following reports:
 - a. A tabular report showing the quantity of each resource used by each activity. You may need to use a filter to select activities with resources (Responsibility = GC).
 - b. A tabular report showing the cost (in dollars) for all activities. Organize it by Responsibility.
 - c. A tabular report showing the cost (in dollars) for all activities. Summarize it by Responsibility.
 - d. A tabular report showing cost per month. Organize it by Responsibility.

UPDATING THE PROJECT

On 01-SEP-2010, the project manager is doing the first update, with Data date = 31-AUG-2010 and the following information:

Activities 1000 NTP and 1010 Mobilization were finished on time.

Activity 1020 Clear & Grub started on time. It finished on 27-AUG-2010.

Activity 1030 Excavation started on 16-AUG-2010. As a result of unexpectedly hard soil, the contractor had to acquire different equipment. Excavation was finished on 27-AUG-2010.

Activity 1040 Foundation started on 19-AUG-2010. As of the data date, the percent complete for this activity is 44%. The expected remaining duration is 10 days.

Activity 1110 2nd Floor Suspended Slab was modified by the engineer and will require 10 days' duration.

Assignment 3

Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–03.”
2. In the new copy, update activity progress according to the preceding list. Schedule the project with new Data date = 31-AUG-2010.
3. Print the following reports:
 - a. A tabular report listing all activities, ordered by ES, TF. Note that every finished event has one date (i.e., actual date) instead of the range (Early – Late) it had before. Also, float disappears from any finished activity.

- b. A bar chart showing all activities, organized by Responsibility, ordered by ES, TF. Note how a new vertical line now separates completed items from future items. This line represents the data date.
4. Now go back to the project data (function name differs depending on your software) and assign a finish date equal to the date you originally obtained in assignment 1.
 5. Reprint the tabular report from step 3a. Note the negative float that appeared with many activities. Print this report.
 6. Print a report similar to the previous one, but apply a filter to include only activities with negative float.

CHANGE ORDER

The owner issued a change order to add a vault. The vault will be built on the first floor but will require a thickened SOG and concrete walls. The additional work will include the following new and modified activities:

Activity ID	Activity Title	Duration (days)	IPA	Rel Type	Lag (days)	Resp
1070	SOG	5	1060			GC
1080	1st floor columns	7	1050			GC
1085	FRP vault walls	6	1070			GC
			1080	FF		GC
1087	Vault door	2	1085			WINT
1110	2nd floor suspended slab	8	1080, 1085, 1090, 1100			GC
1300	1st floor drywall	8	1087, 1280			WALL

In addition to the information above, the following table provides resource and cost for new and affected activities:

Resources						
Activity ID	Activity Title	Laborer	Forman	Carpenter	Excavator	Cost
1070	SOG	2	1	1	—	\$2,000
1080	1st floor columns	2	1	1	—	\$900
1085	FRP Vault walls	2	1	1	—	\$800
1087	Vault door	—	—	—	—	\$3,000
1110	2nd floor suspended slab	2	1	2	—	\$3,000
1300	1st floor drywall					\$7,000

Assignment 4

Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–04.”
2. Add the new activities listed in the previous table, and make any needed adjustments to existing activities.
3. Schedule the project, and record the calculated finish date; compare it with the date you obtained in assignment 1. The difference, if any, is due to the change order.
4. Print the following:
 - a. The scheduling report.
 - b. A tabular report listing all activities, ordered by Activity ID.
 - c. A tabular report listing all activities, ordered by ES, TF. Make sure that you show all early and late dates, and total float.
 - d. A bar chart showing all activities, organized by Responsibility, ordered by ES, TF.
 - e. A tabular report showing the quantity of each resource used by each activity.
 - f. A tabular report showing the cost (in dollars) for all activities. Organize it by Responsibility. Reschedule the project.

RESOURCE LEVELING

Assignment 5

Using the resource information given in assignment 2, do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–05.”
2. Assign resources to the appropriate activities (as mentioned in assignment 2).
3. Apply a filter to include only the GC’s activities.
4. Print a resource usage profile for each of the four resources (i.e., units of the resource used per day).
5. Level the Laborer resource to a limit of 7 without delaying the project. Print another resource usage profile for Laborer.
6. If the GC has only 6 laborers, what solution would you suggest? (Print a report.)
7. Level the Foreman resource to a limit of 2 without delaying the project. Print another resource usage profile for Foreman. (Print a report.)
8. On what date do you need to have carpenters on the job site? What is the minimum number of carpenters you can hire without delaying the project?

9. Can you help the contractor find a plan to do the job with only 2 excavators?
 Outline your plan. (Print a report.)

SCHEDULE COMPRESSION

Assignment 6

Assume the cost of overhead for the project is \$500 per day. This cost is not included in the following table, so it must be added manually after you calculate the project duration. Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–06.”
2. Enter the normal cost for each activity as shown in the following table.
 Calculate the total cost (with normal duration).

Note: Some of this assignment will force a splitting of some activities (i.e., an interruption and resumption at a later date). In most cases, you must do this manually.

Activity ID	Activity Title	Duration (days)		Cost \$	
		Norm	Crash	Norm	Crash
1000	NTP	—	—	—	—
1010	Mobilization	3	2	4,000	5,000
1020	Clear & grub	12	6	12,000	16,000
1030	Excavation	7	5	14,000	17,020
1040	Foundation	15	11	22,000	30,000
1050	Fill, compact, and treat soil	3	2	4,000	4,500
1060	1st floor plumbing rough-in	3	2	2,500	2,800
1070	SOG	4	3	10,000	11,000
1080	1st floor columns	7	5	7,000	7,800
1090	1st floor external CMU walls	10	6	9,200	11,800
1100	1st floor internal CMU walls	14	8	7,800	9,200
1110	2nd floor suspended slab	8	6	12,000	13,600
1120	2nd floor plumbing rough-in	3	2	2,500	2,800
1130	1st floor electrical rough-in	4	2	6,000	7,400
1140	1st floor HVAC ductwork\rough-in	6	4	7,000	7,500
1150	1st floor Door & Window Frames	5	3	3,500	4,100
1160	2nd floor columns	7	5	7,000	7,800
1170	2nd floor external CUM walls	12	7	11,500	13,300
1180	2nd floor internal CMU walls	16	9	8,500	10,100
1190	Roof trusses	8	6	10,000	11,000
1200	2nd floor electrical rough-in	4	3	6,000	6,200
1210	2nd floor HVAC ductwork\rough-in	6	4	7,000	7,500
1220	2nd floor door & window Frames	5	3	2,600	3,000

(continued)

Activity ID	Activity Title	Duration (days)		Cost \$	
		Norm	Crash	Norm	Crash
1230	Roof sheathing	5	3	3,500	4,100
1240	Roof felt	1	1	400	400
1260	Soffit & facia	3	2	2,500	3,000
1265	Roof shingles	6	4	8,000	10,000
1270	Roof insulation	2	1	4,000	4,200
1280	Internal partition framing	12	9	4,500	5,300
1290	1st floor: hang doors & windows	10	5	5,200	6,100
1300	1st floor drywall	8	6	6,500	6,900
1310	1st floor HVAC air handler	5	3	4,000	4,400
1320	1st floor suspended ceiling	8	5	7,500	8,000
1330	1st floor plumbing: install fixtures	2	2	7,500	7,500
1340	1st floor paint/wall covering	10	6	5,700	6,300
1350	1st floor electrical finish	6	4	15,000	15,800
1360	1st floor flooring	12	8	11,000	12,000
1370	2nd floor: hang doors & windows	10	5	4,200	4,800
1380	2nd floor drywall	8	6	7,000	7,600
1390	2nd floor HVAC air handler	5	3	4,000	4,400
1400	2nd floor suspended ceiling	8	5	7,500	8,000
1410	2nd floor plumbing: install fixtures	2	2	7,500	7,500
1420	2nd floor paint/wall covering	11	7	5,400	6,000
1430	2nd floor electrical finish	6	4	17,000	17,400
1440	HVAC: Install equipment	1	1	22,000	22,000
1450	2nd floor flooring	10	7	8,500	9,100
1460	Stucco & paint to ext. walls	8	6	7,000	7,800
1470	Site work	15	11	30,000	32,000
1480	Plumbing finish	2	2	4,500	4,500
1490	HVAC thermostat & test	1	1	5,000	5,000
1500	Electrical final	4	3	9,500	9,700
1510	Building cleanup	2	1	1,000	1,400
1520	Final check/CO	1	1	400	400

3. Accelerate the project by 2 days. When accelerating by 2 days, you may have to do so 1 day at a time. Record the total cost. When compressing an activity, reflect the increase in its direct cost as an extra cost (acceleration cost) in its budget in the scheduling program. You may have to create an Excel spreadsheet to calculate the total cost.
4. Accelerate the project by an additional 2 days. Record the total cost.
5. Accelerate the project 1 extra day at a time. Determine the least cost and least-cost duration. Print a tabular report and a bar chart displaying all activities, along with their durations, organized by Responsibility.
6. Keep accelerating until the project is completely crashed. Determine the crash duration and the associated crash cost.
7. On a separate page, record the following:

- a. Normal duration (number of days and date) and normal cost
- b. Least-cost duration and least cost
- c. Crash duration and crash cost

SCHEDULE COMPRESSION 2

Assignment 7

The GC is trying to accelerate the schedule by requiring certain crews to work on Saturdays. Most likely, this will increase the indirect cost—because of overtime pay—but we will not calculate cost in this exercise. Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–07.”
2. Create a new calendar called “Six-Workday Week.” Maintain the same holidays and rain days as on the regular calendars.
3. Choose certain activities to switch to the “Six-Workday Week” calendar. Start with critical activities. Make sure that this change will contribute to an earlier project completion date. This process will start simple but become more complicated as you accelerate the schedule.
4. Keep working on the acceleration until the project calculated finish date is no later than 04-MAR-2011.
5. Print a tabular report and a bar chart. Add a column in each report showing the calendar.

DELAY CLAIM 1: UNFORESEEN CONDITIONS

While excavating, the contractor discovered contaminated soil that forced him/her to change plans. He/she incurred extra cost because of the hauling and disposal of the contaminated soil. In addition, excavation took 12 workdays rather than 7 workdays. The contractor issued a claim to the owner, requesting the following:

1. A 1-week (5-workdays) time extension.
2. An extra \$23,600 (to cover extra excavating, hauling, and disposing of contaminated soil, plus the GC’s overhead for the extra week of duration).

Assignment 8

Do you think the contractor’s claims are legitimate? Analyze both claims (time and cost) separately. Explain your answers.

DELAY CLAIM 2: CHANGE IN OWNER'S REQUIREMENTS

(Note: This delay claim is independent of delay claim 1.)

The owner decided to add an awning at the building's entrance. It will require three activities:

Activity ID	Activity Title	Duration	IPA	Rel Type	Lag	Resp	Cost
1103	Embed awning attachments to wall	1	1090	FF		MASE	\$500
1105	Decorative posts (to support awning)	1	1070			AWNE	\$2,000
1107	Hang awning	1	1103, 1105, 1460			AWNE	\$7,500

Assignment 9

Do the following:

1. Make a copy of the Tampa Office Building–01 project. Call it “Tampa Office Building–09.”
2. Add the preceding activities to the project. You must add AWNE as a new Responsibility code with the description “Annie’s Awnings.” Make activity 1510, Building Cleanup, a successor to activity 1107. Also, activity 1107 becomes an additional predecessor to activity 1470, Site Work.
The GC is requesting, in addition to the cost of the change order (\$10,000), a 3-day time extension because the change order “disrupted his plans and affected other activities.” The owner disputed the time extension.
3. Argue from the contractor’s viewpoint: Why is this a legitimate request? What supporting argument would you present? Make any necessary assumptions to support your point (e.g., contract language, timing of the change order).
4. Argue from the owner’s viewpoint: Why is this request unacceptable? What supporting argument would you present? Make any necessary assumptions to support your point.

Sample Reports

The sample reports in this appendix were produced by using Primavera Project Manager, P6, and Primavera Project Planner, P3, software. In these reports, an asterisk next to a date indicates a constraint.

TABULAR REPORTS

REPORT 1: Report 1 (Table B.1) is a list of activities with information such as the original duration, remaining duration, percent complete, early start, early finish, late start, late finish, and total float. For new projects that have not started yet, the remaining duration and percent complete may be omitted. Note that when an event (start or finish) happens, the early and late dates for the event are replaced with the actual date (followed by *A* in the report). Obviously, total float disappears from completed activities. Milestones are represented by a single date: start or finish. Activity codes may be used to group (organize) activities. In this case, we grouped them by Responsibility. When grouping, you may use the software Subtotal function, which provides summary information per grouping code at the top of the group (or you may choose the bottom of the group). Note, however, that you must read these subtotals with caution. They include only what you see and exclude any activities that were filtered out. This applies to their attributes such as duration and cost.

REPORT 2: Report 2 (Table B.2) is a list of activities such as those in report 1, but we hid the late start, late finish, and total float. Note that the early start and early finish were renamed just “Start” and “Finish.” We grouped by department (with a subtotal at the bottom) and listed the activity code Responsibility and the calendar that each activity will follow.

Table B.1. Tampa Office Building — Update as of 31-Aug-2010

Responsibility	Activity ID	Activity Name	Original Duration	Remaining Duration	Activity % Complete	Start	Finish	Late Start	Late Finish	Total Float
General Contractor			169	148		02-Aug-10 A	25-Mar-11	23-Aug-10	17-Mar-11	-5
1000	NTP		0	0	100	02-Aug-10 A			23-Aug-10	
1010	Mobilization		3	0	100	02-Aug-10 A	04-Aug-10 A	23-Aug-10	23-Aug-10	
1020	Clear & grub		12	0	100	05-Aug-10 A	27-Aug-10 A	23-Aug-10	23-Aug-10	
1030	Excavation		7	0	100	16-Aug-10 A	27-Aug-10 A	23-Aug-10	23-Aug-10	
1040	Foundation		15	8	44	19-Aug-10 A	15-Sep-10	23-Aug-10	02-Sep-10	-5
1050	Fill, compact, and soil treatment		3	3	0	15-Sep-10	20-Sep-10	03-Sep-10	08-Sep-10	-5
1080	1st floor columns		7	7	0	20-Sep-10	29-Sep-10	01-Oct-10	12-Oct-10	9
1070	SOG		4	4	0	23-Sep-10	29-Sep-10	16-Sep-10	21-Sep-10	-5
1110	2nd floor suspended slab		10	10	0	21-Oct-10	04-Nov-10	13-Oct-10	27-Oct-10	-5
1160	2nd floor columns		7	7	0	04-Nov-10	16-Nov-10	11-Nov-10	19-Nov-10	4
1250	Building Dry-in		1	1	0	27-Dec-10	28-Dec-10	17-Dec-10	17-Dec-10	-5
1510	Building clean-up		2	2	0	22-Mar-11	24-Mar-11	15-Mar-11	16-Mar-11	-5
1520	Final check/CO		1	1	0	24-Mar-11	25-Mar-11	17-Mar-11	17-Mar-11	-5
All seasons AC & Heating			86	86		04-Nov-10	04-Mar-11	22-Feb-11	14-Mar-11	7
1140	1st floor HVAC ductwork/ rough-in		6	6	0	04-Nov-10	15-Nov-10	22-Feb-11	01-Mar-11	66
1210	2nd floor HVAC ductwork/ rough-in		6	6	0	16-Dec-10	27-Dec-10	22-Feb-11	01-Mar-11	42
1310	1st floor HVAC air handler		5	5	0	28-Jan-11	04-Feb-11	02-Mar-11	08-Mar-11	21
1390	2nd floor HVAC air handler		5	5	0	11-Feb-11	18-Feb-11	02-Mar-11	08-Mar-11	13
1440	HVAC: Install equipment		1	1	0	18-Feb-11	21-Feb-11	11-Mar-11	11-Mar-11	13
1490	HVAC thermostat & test		1	1	0	03-Mar-11	04-Mar-11	14-Mar-11	14-Mar-11	5
Wall to Wall			44	44		03-Jan-11	04-Mar-11	11-Jan-11	14-Mar-11	7
1460	Stucco & paint to ext. walls		8	8	0	03-Jan-11	17-Jan-11	01-Mar-11	14-Mar-11	37
1300	1st floor drywall		8	8	0	18-Jan-11	28-Jan-11	11-Jan-11	20-Jan-11	-5

1380	2nd floor drywall	8	8	0	28-Jan-11	11-Feb-11	21-Jan-11	01-Feb-11	-5
1320	1st floor suspended ceiling	8	8	0	28-Jan-11	11-Feb-11	01-Feb-11	14-Feb-11	2
1340	1st floor paint/wall covering	10	10	0	03-Feb-11	21-Feb-11	07-Feb-11	22-Feb-11	2
1400	2nd floor suspended ceiling	8	8	0	11-Feb-11	23-Feb-11	02-Feb-11	15-Feb-11	-5
1420	2nd floor paint/wall covering	11	11	0	17-Feb-11	04-Mar-11	08-Feb-11	24-Feb-11	-5
Master Art Landscape		16	16		14-Oct-10	05-Nov-10	22-Feb-11	16-Mar-11	94
1470	Site work	15	15	0	14-Oct-10	05-Nov-10*	22-Feb-11	16-Mar-11	80
Mase & Company		46	46		29-Sep-10	02-Dec-10	22-Sep-10	19-Nov-10	-8
1100	1st floor internal CMU walls	14	14	0	29-Sep-10	21-Oct-10	22-Sep-10	12-Oct-10	-5
1090	1st floor external CMU walls	10	10	0	29-Sep-10	14-Oct-10	28-Sep-10	12-Oct-10	-1
1180	2nd floor internal CMU walls	16	16	0	04-Nov-10	02-Dec-10	28-Oct-10	19-Nov-10	-5
1170	2nd floor external CMU walls	12	12	0	04-Nov-10	23-Nov-10	03-Nov-10	19-Nov-10	-1
Ross Carpentry & Framing		33	33		02-Dec-10	18-Jan-11	22-Nov-10	28-Feb-11	30
1190	Roof trusses	8	8	0	02-Dec-10	16-Dec-10	22-Nov-10	06-Dec-10	-5
1230	Roof Sheathing	5	5	0	16-Dec-10	23-Dec-10	08-Dec-10	14-Dec-10	-5
1280	Internal partition framing	12	12	0	28-Dec-10	18-Jan-11	20-Dec-10	10-Jan-11	-5
1270	Roof insulation	2	2	0	28-Dec-10	30-Dec-10	31-Jan-11	01-Feb-11	21
1260	Soffit & facia	3	3	0	28-Dec-10	03-Jan-11	24-Feb-11	28-Feb-11	37
Plumbing Experts		108	108		20-Sep-10	17-Feb-11	09-Sep-10	14-Mar-11	18
1060	1st floor plumbing rough-in	3	3	0	20-Sep-10	23-Sep-10	09-Sep-10	15-Sep-10	-5
1120	2nd floor plumbing rough-in	1	1	0	02-Nov-10	03-Nov-10	03-Feb-11	03-Feb-11	57
1330	1st floor plumbing: install fixtures	2	2	0	28-Jan-11	01-Feb-11	03-Feb-11	04-Feb-11	4
1410	2nd floor plumbing: install fixtures	2	2	0	11-Feb-11	15-Feb-11	04-Feb-11	07-Feb-11	-3
1480	Plumbing finish	2	2	0	15-Feb-11	17-Feb-11	11-Mar-11	14-Mar-11	16

(continued)

Table B.1. (Continued)

Responsibility		Original Duration	Remaining Duration	Activity % Complete	Start	Finish	Late Start	Late Finish	Total Float
Activity ID	Activity Name								
Rabbit-the-Roof		11	11		23-Dec-10	07-Jan-11	16-Dec-10	14-Mar-11	47
1240	Roof felt	1	1	0	23-Dec-10	27-Dec-10	16-Dec-10	16-Dec-10	-5
1265	Roof Shingles	6	6	0	27-Dec-10	07-Jan-11	03-Mar-11	14-Mar-11	43
Tile and Carpet Co., Inc.		21	21		21-Feb-11	22-Mar-11	23-Feb-11	14-Mar-11	-5
1360	1st floor flooring	12	12	0	21-Feb-11	11-Mar-11	23-Feb-11	14-Mar-11	2
1450	2nd floor flooring	10	10	0	04-Mar-11	22-Mar-11	25-Feb-11	14-Mar-11	-5
Windows & Doors NT		20	20		11-Jan-11	08-Feb-11	18-Feb-11	14-Mar-11	25
1220	2nd floor door & window frames	5	5	0	11-Jan-11	18-Jan-11	18-Feb-11	24-Feb-11	26
1150	1st floor door & window frames	5	5	0	18-Jan-11	25-Jan-11	18-Feb-11	24-Feb-11	21
1370	2nd floor: hang doors & windows	10	10	0	18-Jan-11	01-Feb-11	25-Feb-11	14-Mar-11	26
1290	1st floor: hang doors & windows	10	10	0	25-Jan-11	08-Feb-11	25-Feb-11	14-Mar-11	21
Zapp Electric Co.		41	41		14-Jan-11	14-Mar-11	07-Feb-11	14-Mar-11	1
1130	1st floor electrical rough-in	4	4	0	14-Jan-11	20-Jan-11	07-Feb-11	14-Feb-11	16
1200	2nd floor electrical rough-in	4	4	0	18-Jan-11	24-Jan-11	11-Feb-11	16-Feb-11	16
1350	1st floor electrical finish	6	6	0	11-Feb-11	21-Feb-11	15-Feb-11	22-Feb-11	2
1430	2nd floor electrical finish	6	6	0	23-Feb-11	03-Mar-11	17-Feb-11	24-Feb-11	-4
1500	Electrical final	4	4	0	04-Mar-11	14-Mar-11	07-Mar-11	14-Mar-11	1
Total		169	148		02-Aug-10 A	25-Mar-11	23-Aug-10	17-Mar-11	-5

Source: © Primavera Systems, Inc.

Table B.2. Apex Project — List of Activities (asterisk indicates a constraint on the activity)

Department	Activity ID	Activity Name	Orig Dur	Rem Dur	%	Calendar	Resp	Start	Finish
Engineering Department									
	CS300	System Design	30	30	0	Conveyor System Calendar 1	MF	01-Apr-03*	12-May-03
	CS310	Review and Approve Design	8	8	0	Conveyor System Calendar 1	MF	13-May-03	22-May-03
	CS430	Prepare Drawings for Conveyors	10	10	0	Conveyor System Calendar 1	MF	23-May-03	05-Jun-03
	CS440	Review and Approve Drawings for Conveyors	7	7	0	Conveyor System Calendar 1	MF	06-Jun-03	17-Jun-03
	BA400	Design Building Addition	23	0	100	Office Building Addition Calendar 1	GG	04-Jun-02 A	04-Jul-02 A
	BA469	Assemble Technical Data for Heat Pump	3	0	100	Office Building Addition Calendar 1	GG	18-Jul-02 A	22-Jul-02 A
	BA470	Review Technical Data on Heat Pumps	10	0	100	Office Building Addition Calendar 1	GG	23-Jul-02 A	05-Aug-02 A
	BA501	Review and Approve Designs	9	0	100	Office Building Addition Calendar 1	GG	05-Jul-02 A	17-Jul-02 A
	BA530	Review and Approve Brick Samples	10	0	100	Office Building Addition Calendar 1	JN	23-Jul-02 A	05-Aug-02 A
	BA560	Review and Approve Flooring	10	0	100	Office Building Addition Calendar 1	LH	30-Jul-02 A	12-Aug-02 A
	AS100	Define System Requirements	14	0	100	Automated System Calendar 1	KL	04-Jun-02 A	21-Jun-02 A
	AS101	System Design	30	0	100	Automated System Calendar 1	KL	24-Jun-02 A	02-Aug-02 A
	AS102	Approve System Design	5	0	100	Automated System Calendar 1	KL	05-Aug-02 A	09-Aug-02 A
	AS204	Prepare Drawings for Temp Control Equipment	14	0	100	Automated System Calendar 1	KL	22-Jul-02 A	08-Aug-02 A
	AS205	Review and Approve Temp Control Equipment	5	0	100	Automated System Calendar 1	KL	09-Aug-02 A	15-Aug-02 A
	AS216	Prepare Drawings for System Controller	4	0	100	Automated System Calendar 1	KL	22-Jul-02 A	25-Jul-02 A
	AS217	Review and Approve System Controller	5	0	100	Automated System Calendar 1	KL	26-Jul-02 A	02-Aug-02 A
Subtotal			270	55				04-Jun-02 A	17-Jun-03 A

(continued)

Table B.2. (Continued)

Department	Activity ID	Activity Name	Orig Dur	Rem Dur	%	Calendar	Resp	Start	Finish
Purchasing Department									
CS400	Prepare and Solicit Bids for Conveyors	12	12	0	0	Conveyor System Calendar 1	KL	17-Jun-03	03-Jul-03
CS410	Review Bids for Conveyors	2	2	0	0	Conveyor System Calendar 1	KL	03-Jul-03	07-Jul-03
CS420	Award Contract	1	1	0	0	Conveyor System Calendar 1	KL	07-Jul-03	08-Jul-03
CS450	Fabricate and Deliver Conveyors	34	34	0	0	Conveyor System Calendar 1	KL	08-Jul-03	25-Aug-03
BA407	Prepare and Solicit Bids for Flooring	5	0	100	0	Office Building Addition Calendar 1	LH	13-Aug-02 A	19-Aug-02 A
BA408	Review Bids for Flooring	3	0	100	0	Office Building Addition Calendar 1	LH	20-Aug-02 A	22-Aug-02 A
BA409	Award Contract for Flooring	1	0	100	0	Office Building Addition Calendar 1	LH	23-Aug-02 A	23-Aug-02 A
BA411	Prepare and Solicit Bids for Heat Pump	3	0	100	0	Office Building Addition Calendar 1	JN	06-Aug-02 A	08-Aug-02 A
BA412	Review Bids for Heat Pump	2	0	100	0	Office Building Addition Calendar 1	JN	09-Aug-02 A	12-Aug-02 A
BA413	Award Contract for Heat Pump	1	0	100	0	Office Building Addition Calendar 1	JN	13-Aug-02 A	13-Aug-02 A
BA421	Prepare and Solicit Bids for Brick Exterior	3	0	100	0	Office Building Addition Calendar 1	JN	06-Aug-02 A	08-Aug-02 A
BA422	Review Bids for Brick	3	0	100	0	Office Building Addition Calendar 1	JN	09-Aug-02 A	13-Aug-02 A
BA423	Award Contract for Brick	1	0	100	0	Office Building Addition Calendar 1	JN	14-Aug-02 A	14-Aug-02 A
BA450	Assemble Brick Samples	3	0	100	0	Office Building Addition Calendar 1	JN	18-Jul-02 A	22-Jul-02 A
BA480	Assemble and Submit Flooring Samples	8	0	100	0	Office Building Addition Calendar 1	LH	18-Jul-02 A	29-Jul-02 A
BA550	Fabricate and Deliver Heat Pump and Controls	88	0	100	0	Office Building Addition Calendar 1	JN	14-Aug-02 A	13-Dec-02 A
BA600	Deliver Brick	58	0	100	0	Office Building Addition Calendar 1	JN	15-Aug-02 A	05-Nov-02 A
BA620	Fabricate and Deliver Flooring	58	0	100	0	Office Building Addition Calendar 1	LH	26-Aug-02 A	13-Nov-02 A

AS200	Prepare and Solicit Bids for Temp Control Equip	3	0	100	Automated System Calendar 1	MF	16-Aug-02 A	21-Aug-02 A
AS201	Review Bids for Temp Control Equipment	5	0	100	Automated System Calendar 1	MF	21-Aug-02 A	27-Aug-02 A
AS202	Award Contract for Temp Control Equipment	0	0	100	Automated System Calendar 1	MF	28-Aug-02 A	28-Aug-02 A
AS213	Prepare and Solicit Bids for System Controller	7	0	100	Automated System Calendar 1	KL	02-Aug-02 A	13-Aug-02 A
AS214	Review Bids for System Controller	4	0	100	Automated System Calendar 1	KL	13-Aug-02 A	19-Aug-02 A
AS215	Award Contract for System Controller	1	0	100	Automated System Calendar 1	KL	19-Aug-02 A	20-Aug-02 A
AS218	Fabricate and Deliver System Controller	24	0	100	Automated System Calendar 1	KL	20-Aug-02 A	23-Sep-02 A
AS206	Fabricate & Deliver Temp Control Equipment	17	0	100	Automated System Calendar 1	MF	28-Aug-02 A	19-Sep-02 A
Subtotal		287	49				18-Jul-02 A	25-Aug-03 A
Construction Department								
BA750	Brick Exterior Walls	7	7	0	Standard 5 Day Workweek	JN	24-Jan-03	03-Feb-03
BA840	Rough-In Plumbing/ Piping	1	1	0	Office Building Addition Calendar 1	JN	24-Jan-03	24-Jan-03
BA860	Install Elevator Rails and Equipment	1	1	0	Office Building Addition Calendar 1	JN	24-Jan-03	24-Jan-03
BA770	Install Door and Window Frames	1	1	0	Office Building Addition Calendar 1	JN	31-Jan-03	31-Jan-03
BA790	Install Exterior Doors and Windows	2	2	0	Office Building Addition Calendar 1	JN	03-Feb-03	04-Feb-03
BA780	Insulation and Built-Up Roofing	10	10	0	Office Building Addition Calendar 1	JN	04-Feb-03	17-Feb-03
BA741	Close-In Phase Begins	0	0	0	Office Building Addition Calendar 1	JN	04-Feb-03	
BA800	Building Enclosed	0	0	0	Office Building Addition Calendar 1			17-Feb-03
BA850	Install Wiring and Cable	15	15	0	Office Building Addition Calendar 1	JN	18-Feb-03	10-Mar-03
BA830	Insulate Ducts	2	2	0	Office Building Addition Calendar 1	JN	18-Feb-03	19-Feb-03
BA831	Set Heat Pump	5	5	0	Office Building Addition Calendar 1	JN	20-Feb-03	26-Feb-03

(continued)

Table B.2. (Continued)

Department Activity ID	Activity Name	Orig Dur	Rem Dur	%	Calendar	Resp	Start	Finish
BA983	Relocate HVAC Chiller	3	3	0	Standard 5 Day Workweek	JN	27-Feb-03	03-Mar-03
BA870	Connect Equipment	3	3	0	Office Building Addition Calendar 1	JN	11-Mar-03	13-Mar-03
BA871	Start Up and Test HVAC	1	1	0	Office Building Addition Calendar 1	JN	14-Mar-03	14-Mar-03
BA880	Rough In Complete	0	0	0	Office Building Addition Calendar 1	JN		14-Mar-03
BA890	Drywall in Offices	15	15	0	Office Building Addition Calendar 1	LH	17-Mar-03	04-Apr-03
BA913	Install Elevator Cab and Finishes	2	2	0	Office Building Addition Calendar 1	JN	17-Mar-03	18-Mar-03
BA930	Paint Building Interior	15	15	0	Office Building Addition Calendar 1	LH	26-Mar-03	15-Apr-03
BA900	Install Ceiling Grid	15	15	0	Office Building Addition Calendar 1	LH	07-Apr-03	25-Apr-03
BA899	Finishes Phase Begins	1	1	0	Office Building Addition Calendar 1	LH	07-Apr-03	07-Apr-03
BA902	Install AC Grills and Registers	5	5	0	Office Building Addition Calendar 1	JN	17-Apr-03	23-Apr-03
BA901	Install Lighting Fixtures	3	3	0	Office Building Addition Calendar 1	LH	17-Apr-03	21-Apr-03
BA910	Install Floor and Carpeting	5	5	0	Office Building Addition Calendar 1	LH	28-Apr-03	02-May-03
BA911	Finish Carpentry and Millwork	5	5	0	Office Building Addition Calendar 1	LH	05-May-03	09-May-03
BA912	Install Plumbing Fixtures	2	2	0	Office Building Addition Calendar 1	LH	05-May-03	06-May-03
BA940	Touch-Up and Cleanup	1	1	0	Office Building Addition Calendar 1	LH	12-May-03	12-May-03
BA941	Test and Balance HVAC Equipment	1	1	0	Office Building Addition Calendar 1	JN	13-May-03	13-May-03
BA950	Finishes Milestone	0	0	0	Office Building Addition Calendar 1	LH	14-May-03	14-May-03
BA960	Punch List	2	2	0	Office Building Addition Calendar 1	LH	14-May-03	15-May-03
BA970	Building Addition Complete	0	0	0	Office Building Addition Calendar 1	LH	16-May-03	16-May-03
CS305	Start Up & Debug System	9	9	0	Conveyor System Calendar 1	JN	11-Dec-03	24-Dec-03

BA630	Begin Building Construction	0	0	100	Office Building Addition	KL	18-Jul-02 A
BA640	Site Preparation	18	0	100	Office Building Addition	KL	18-Jul-02 A 12-Aug-02 A
BA650	Excavation	10	0	100	Office Building Addition	KL	13-Aug-02 A 26-Aug-02 A
BA660	Install Underground Water Lines	5	0	100	Office Building Addition	KL	27-Aug-02 A 02-Sep-02 A
BA670	Install Underground Electric Conduit	5	0	100	Office Building Addition	KL	27-Aug-02 A 02-Sep-02 A
BA680	Form/Pour Concrete Footings	10	0	100	Office Building Addition	KL	03-Sep-02 A 16-Sep-02 A
BA681	Concrete Foundation Walls	10	0	100	Office Building Addition	KL	17-Sep-02 A 30-Sep-02 A
BA690	Form and Pour Slab	5	0	100	Office Building Addition	KL	01-Oct-02 A 07-Oct-02 A
BA700	Backfill and Compact Walls	2	0	100	Office Building Addition	KL	08-Oct-02 A 09-Oct-02 A
BA701	Foundation Phase Complete	0	0	100	Office Building Addition	KL	09-Oct-02 A
BA702	Begin Structural Phase	0	0	100	Office Building Addition	KL	07-Nov-02 A
BA710	Erect Structural Frame	20	0	100	Office Building Addition	KL	10-Oct-02 A 06-Nov-02 A
BA712	Floor Decking	14	0	100	Office Building Addition	KL	07-Nov-02 A 26-Nov-02 A
BA720	Erect Stairwell and Elevator Walls	10	0	100	Office Building Addition	KL	18-Dec-02 A 31-Dec-02 A
BA730	Concrete First Floor	15	0	100	Office Building Addition	KL	27-Nov-02 A 17-Dec-02 A
BA731	Concrete Basement Slab	10	0	100	Office Building Addition	KL	18-Dec-02 A 31-Dec-02 A
BA732	Structure Complete	0	0	100	Office Building Addition	KL	01-Jan-03 A 01-Jan-03 A
BA809	Rough-In Phase Begins	0	0	100	Office Building Addition	JN	27-Dec-02 A
BA810	Set Mechanical and Electrical Equipment	15	0	100	Office Building Addition	JN	06-Dec-02 A 26-Dec-02 A
BA820	Install HVAC Ducts	10	0	100	Office Building Addition	JN	27-Dec-02 A 09-Jan-03 A
BA735	Concrete Second Floor	15	0	100	Office Building Addition	KL	18-Dec-02 A 07-Jan-03 A
Subtotal		374	238				18-Jul-02 A 24-Dec-03 A

(continued)

Table B.2. (Continued)

Department	Activity ID	Activity Name	Orig Dur	Rem Dur	%	Calendar	Resp	Start	Finish
Information Systems Department									
	AS110	Test & Debug Line B	19	5	74.17	Automated System Calendar 1	JM	02-Dec-02 A	16-Dec-02
	AS109	Test & Debug Line A	19	5	74.17	Automated System Calendar 1	JM	02-Dec-02 A	16-Dec-02
	AS108	Install System Controller	13	7	47.62	Automated System Calendar 1	KL	02-Dec-02 A	18-Dec-02
	AS250	Install Bar Rails	4	3	23.8	Automated System Calendar 1	KL	09-Dec-02 A	13-Dec-02
	AS270	Trim Robot Paths Line B	2	2	0	Automated System Calendar 1	KL	13-Dec-02	16-Dec-02
	AS260	Trim Robot Paths Line A	2	2	0	Automated System Calendar 1	KL	13-Dec-02	16-Dec-02
	AS112	Start-Up Line B	8	8	0	Automated System Calendar 1	JM	17-Dec-02	26-Dec-02
	AS111	Pilot Start Line A	2	2	0	Automated System Calendar 1	JM	17-Dec-02	18-Dec-02
	AS265	Path Refinement and Shakedown-Line A	4	4	0	Automated System Calendar 1	JM	19-Dec-02	24-Dec-02
	AS275	Path Refinement and Shakedown-Line B	4	4	0	Automated System Calendar 1	JM	27-Dec-02	01-Jan-03
	AS113	Install Processor/ Software/Data Tapes	3	3	0	Automated System Calendar 1	LH	02-Jan-03	06-Jan-03
	AS150	Production Start	0	0	0	Automated System Calendar 1	LH	02-Jan-03	
	AS114	Calibrate Robot Controller & Power Up	1	1	0	Automated System Calendar 1	KL	07-Jan-03	07-Jan-03
	AS115	Load System Software	1	1	0	Automated System Calendar 1	LH	08-Jan-03	08-Jan-03
	AS116	Program	14	14	0	Automated System Calendar 1	LH	09-Jan-03	28-Jan-03
	AS600	Manual Operation Ready	0	0	0	Automated System Calendar 1	LH	09-Jan-03	09-Jan-03
	AS280	Test Software	4	4	0	Automated System Calendar 1	LH	29-Jan-03	03-Feb-03
	AS285	Debug Software	6	6	0	Automated System Calendar 1	LH	04-Feb-03	11-Feb-03
	AS117	Startup Procedure Development	2	2	0	Automated System Calendar 1	LH	12-Feb-03	13-Feb-03

AS500	Automatic Operation Ready	0	0	0	Automated System Calendar 1	LH	12-Feb-03	12-Feb-03
AS118	Training Manuals/ System Operation	7	7	0	Automated System Calendar 1	JM	14-Feb-03	24-Feb-03
AS900	System Buyoff	0	0	0	Standard 5 Day Workweek	KL		24-Feb-03
CS311	Start Conveyor Installation	0	0	0	Conveyor System Calendar 1	JN	01-Apr-03	
CS315	Site Preparation	18	18	0	Conveyor System Calendar 1	JN	01-Apr-03	24-Apr-03
CS700	Install Conveyor 211	12	12	0	Conveyor System Calendar 1	JN	25-Aug-03	10-Sep-03
CS770	Operation Manuals	18	18	0	Conveyor System Calendar 1	KL	25-Aug-03	18-Sep-03
CS710	Install Conveyor 212	8	8	0	Conveyor System Calendar 1	JN	10-Sep-03	22-Sep-03
CS720	Install Conveyor 213	9	9	0	Conveyor System Calendar 1	JN	22-Sep-03	03-Oct-03
CS730	Install Conveyor 214	10	10	0	Conveyor System Calendar 1	JN	03-Oct-03	17-Oct-03
CS740	Field Piping	10	10	0	Conveyor System Calendar 1	JN	07-Nov-03	20-Nov-03
CS750	Field Wiring	10	10	0	Conveyor System Calendar 1	JN	07-Nov-03	20-Nov-03
CS760	Field Painting	4	4	0	Conveyor System Calendar 1	JN	05-Dec-03	11-Dec-03
CS800	Conveyor System Complete	0	0	0	Conveyor System Calendar 1	JN		24-Dec-03
AS103	Install Robot Base	14	0	100	Automated System Calendar 1	KL	15-Aug-02 A	04-Sep-02 A
AS104	Run Sealant, Air, and Water Piping	13	0	100	Automated System Calendar 1	KL	15-Aug-02 A	02-Sep-02 A
AS105	Install Temperature Control Equipment	29	0	100	Automated System Calendar 1	MF	20-Sep-02 A	30-Oct-02 A
AS106	Set & Connect Robots	3	0	100	Automated System Calendar 1	KL	30-Oct-02 A	05-Nov-02 A
AS219	Install System & Misc. Components	19	0	100	Automated System Calendar 1	KL	05-Nov-02 A	02-Dec-02 A
AS240	Installation Begins	0	0	100	Automated System Calendar 1	PR	15-Aug-02 A	
AS310	Site Preparation	3	0	100	Automated System Calendar 1	GG	12-Aug-02 A	14-Aug-02 A
AS315	Install Electrical Power	14	0	100	Automated System Calendar 1	JM	15-Aug-02 A	04-Sep-02 A
Subtotal		357	271				12-Aug-02 A	24-Dec-03 A

REPORT 3: Report 3 (Table B.3) is a list of activities with their predecessors and successors. Note that the list does not specify the type of relationship or the lag (if any). Other information may be listed, such as Activity Status.

Table B.3. List of Activities with Predecessors & Successors

Activity ID	Activity Name	Orig Dur	Activity Status	Predecessors	Successors
BA702	Begin Structural Phase	0	Completed	BA710	
BA712	Floor Decking	14	Completed	BA710	BA730
BA720	Erect Stairwell and Elevator Walls	10	Completed	BA730	BA732, BA860
BA730	Concrete First Floor	15	Completed	BA712	BA720, BA731, BA810, BA735
BA731	Concrete Basement Slab	10	Completed	BA730	BA732
BA732	Structure Complete	0	Completed	BA720, BA731	BA750
BA735	Concrete Second Floor	15	Completed	BA730	
BA741	Close-In Phase Begins	0	Not Started	BA750	
BA750	Brick Exterior Walls	7	Not Started	BA600, BA732	BA741, BA770, BA780
BA770	Install Door and Window Frames	1	Not Started	BA750	BA790
BA780	Insulation and Built-up Roofing	10	Not Started	BA750, BA790	BA800
BA790	Install Exterior Doors and Windows	2	Not Started	BA770	BA780, BA800
BA800	Building Enclosed	0	Not Started	BA780, BA790	BA830, BA831, BA850, BA890, BA913
BA809	Rough-In Phase Begins	0	Completed	BA810	
BA810	Set Mechanical and Electrical Equipment	15	Completed	BA730	BA809, BA820
BA820	Install HVAC Ducts	10	Completed	BA810	BA830, BA840
BA830	Insulate Ducts	2	Not Started	BA800, BA820	BA831
BA831	Set Heat Pump	5	Not Started	BA550, BA800, BA830	BA870, BA983
BA840	Rough-In Plumbing/Piping	1	Not Started	BA820	BA850
BA850	Install Wiring and Cable	15	Not Started	BA800, BA840	BA870
BA860	Install Elevator Rails and Equipment	1	Not Started	BA720	BA880
BA870	Connect Equipment	3	Not Started	BA831, BA850	BA871
BA871	Startup and Test HVAC	1	Not Started	BA870, BA983	BA880
BA880	Rough-In Complete	0	Not Started	BA860, BA871	BA890, BA913

BA890	Drywall in Offices	15	Not Started	BA800, BA880	BA899, BA900, BA930
BA899	Finishes Phase Begins	1	Not Started	BA890	
BA900	Install Ceiling Grid	15	Not Started	BA890	BA901, BA902, BA910
BA901	Install Lighting Fixtures	3	Not Started	BA900	BA910
BA902	Install AC Grills and Registers	5	Not Started	BA900	BA910
BA910	Install Floor and Carpeting	5	Not Started	BA620, BA900, BA901, BA902	BA911, BA912
BA911	Finish Carpentry and Millwork	5	Not Started	BA910	BA940
BA912	Install Plumbing Fixtures	2	Not Started	BA910	BA940
BA913	Install Elevator Cab and Finishes	2	Not Started	BA800, BA880	BA940
BA930	Paint Building Interior	15	Not Started	BA890	BA940
BA940	Touch-Up and Cleanup	1	Not Started	BA911, BA912, BA913, BA930	BA941
BA941	Test and Balance HVAC Equipment	1	Not Started	BA940	BA950
BA950	Finishes Milestone	0	Not Started	BA941	BA960
BA960	Punch List	2	Not Started	BA950	BA970
BA970	Building Addition Complete	0	Not Started	BA960	
BA983	Relocate HVAC Chiller	3	Not Started	BA831	BA871
CS305	Start-Up & Debug System	9	Not Started	CS730, CS740, CS750, CS760	CS800

REPORT 4: Report 4 (Table B.4) is an earned value report that shows earned value versus actual and planned costs. Also note the totals.

Table B.4. Earned Value Report

WBS							
Activity ID	Activity Name	Activity Status	Planned Cost (BCWS)	Actual Cost (ACWP)	Earned Value (BCWS)	Cost Variance	Variance At Completion
Caprini Corporation							
Apex Project							
Apex Construction							
Office Building Addition							
Design and Engineering							
BA400	Design Building Addition	Completed	\$5,520.00	\$5,520.00	\$5,520.00	\$0.00	\$0.00
BA469	Assemble Technical Data for Heat Pump	Completed	\$720.00	\$720.00	\$720.00	\$0.00	\$0.00

(continued)

Table B.4. (Continued)

WBS		Activity Status	Planned Cost (BCWS)	Actual Cost (ACWP)	Earned Value (BCWS)	Cost Variance	Variance At Completion
Activity ID	Activity Name						
BA470	Review Technical Data on Heat Pumps	Completed	\$2,400.00	\$2,400.00	\$2,400.00	\$0.00	\$0.00
BA501	Review and Approve Designs	Completed		\$0.00	\$1,800.00	\$0.00 (\$1,800.00)	(\$1,800.00)
Subtotal			\$8,640.00	\$10,440.00	\$8,640.00	(\$1,800.00)	(\$1,800.00)
Foundation							
BA630	Begin Building Construction	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA640	Site Preparation	Completed	\$3,096.00	\$532.69	\$3,096.00	\$2,563.31	\$2,563.31
BA650	Excavation	Completed	\$1,720.00	\$14.58	\$1,720.00	\$1,705.42	\$1,705.42
BA660	Install Underground Water Lines	Completed	\$1,320.00	\$6.11	\$1,320.00	\$1,313.89	\$1,313.89
BA670	Install Underground Electric Conduit	Completed	\$1,280.00	\$5.93	\$1,280.00	\$1,274.07	\$1,274.07
BA680	Form/Pour Concrete Footings	Completed	\$13,160.00	\$394.95	\$13,160.00	\$12,765.05	\$11,965.05
BA681	Concrete Foundation Walls	Completed	\$9,960.00	\$409.33	\$9,960.00	\$9,550.67	\$8,750.67
BA690	Form and Pour Slab	Completed	\$5,940.00	\$147.59	\$5,940.00	\$5,792.41	\$5,392.41
BA700	Backfill and Compact Walls	Completed		\$728.00	\$1.87	\$728.00	\$726.13
BA701	Foundation Phase Complete	Completed		\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$37,204.00	\$1,513.05	\$37,204.00	\$35,690.95	\$33,690.95
Structure							
BA702	Begin Structural Phase	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA710	Erect Structural Frame	Completed	\$11,600.00	\$470.74	\$11,600.00	\$11,129.26	\$9,529.26
BA712	Floor Decking	Completed	\$8,120.00	\$291.20	\$8,120.00	\$7,828.80	\$6,708.80
BA720	Erect Stairwell and Elevator Walls	Completed	\$1,600.00	\$360.89	\$1,600.00	\$1,239.11	\$1,239.11
BA730	Concrete First Floor	Completed	\$9,510.00	\$1,888.80	\$9,510.00	\$7,621.20	\$6,421.20
BA731	Concrete Basement Slab	Completed	\$14,600.00	\$3,591.36	\$14,600.00	\$11,008.64	\$9,408.64
BA732	Structure Complete	Completed		\$0.00	\$0.00	\$0.00	\$0.00
BA735	Concrete Second Floor	Completed	\$9,510.00	\$3,957.50	\$9,510.00	\$5,552.50	\$4,352.50
Subtotal			\$54,940.00	\$10,560.49	\$54,940.00	\$44,379.51	\$37,659.51

Mechanical/Electrical Systems

BA809	Rough-In Phase Begins	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA880	Rough In Complete	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00

Elevator

BA860	Install Elevator Rails and Equipment	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA913	Install Elevator Cab and Finishes	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00

Subtotal		\$0.00	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
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HVAC

BA411	Prepare and Solicit Bids for Heat Pump	Completed	\$384.00	\$384.00	\$384.00	\$0.00	\$0.00
BA412	Review Bids for Heat Pump	Completed	\$256.00	\$256.00	\$256.00	\$0.00	\$0.00
BA413	Award Contract for Heat Pump	Completed	\$128.00	\$128.00	\$128.00	\$0.00	\$0.00
BA550	Fabricate and Deliver Heat Pump and Controls	Completed	\$21,120.00	\$14,314.67	\$21,120.00	\$6,805.33	\$6,805.33
BA820	Install HVAC Ducts	Completed	\$1,260.00	\$630.00	\$1,260.00	\$630.00	\$630.00
BA830	Insulate Ducts	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA831	Set Heat Pump	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA871	Startup and Test HVAC	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA902	Install AC Grills and Registers	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA941	Test and Balance HVAC Equipment	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA983	Relocate HVAC Chiller	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$23,148.00	\$15,712.67	\$23,148.00	\$7,435.33	\$7,435.33

Plumbing and Electrical

BA810	Set Mechanical and Electrical Equipment	Completed	\$7,200.00	\$7,200.00	\$7,200.00	\$0.00	\$0.00
BA840	Rough-In Plumbing/Piping	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA850	Install Wiring and Cable	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA870	Connect Equipment	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$7,200.00	\$7,200.00	\$7,200.00	\$0.00	\$0.00
Subtotal			\$30,348.00	\$22,912.67	\$30,348.00	\$7,435.33	\$7,435.33

Exterior Finishes

BA741	Close-In Phase Begins	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA800	Building Enclosed	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00

(continued)

Table B.4. (Continued)

WBS		Activity Status	Planned Cost (BCWS)	Actual Cost (ACWP)	Earned Value (BCWS)	Cost Variance	Variance At Completion
Activity ID	Activity Name						
Brick							
BA421	Prepare and Solicit Bids for Brick Exterior	Completed	\$384.00	\$384.00	\$384.00	\$0.00	\$0.00
BA422	Review Bids for Brick	Completed	\$384.00	\$384.00	\$384.00	\$0.00	\$0.00
BA423	Award Contract for Brick	Completed	\$128.00	\$128.00	\$128.00	\$0.00	\$0.00
BA450	Assemble Brick Samples	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA530	Review and Approve Brick Samples	Completed	\$2,400.00	\$2,400.00	\$2,400.00	\$0.00	\$0.00
BA600	Deliver Brick	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA750	Brick Exterior Walls	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$3,296.00	\$3,296.00	\$3,296.00	\$0.00	\$0.00
Roof							
BA780	Insulation and Built-Up Roofing	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Doors and Windows							
BA770	Install Door and Window Frames	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA790	Install Exterior Doors and Windows	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$3,296.00	\$3,296.00	\$3,296.00	\$0.00	\$0.00
Interior Finishes							
BA890	Drywall in Offices	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA899	Finishes Phase Begins	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA940	Touch-Up and Cleanup	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA950	Finishes Milestone	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA960	Punch List	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA970	Building Addition Complete	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Plumbing and Lighting Fixtures							
BA901	Install Lighting Fixtures	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA912	Install Plumbing Fixtures	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$0.00	\$0.00	\$0.00	\$0.00	\$0.00

Floor and Carpeting							
BA407	Prepare and Solicit Bids for Flooring	Completed	\$640.00	\$640.00	\$640.00	\$0.00	\$0.00
BA408	Review Bids for Flooring	Completed	\$384.00	\$384.00	\$384.00	\$0.00	\$0.00
BA409	Award Contract for Flooring	Completed	\$128.00	\$128.00	\$128.00	\$0.00	\$0.00
BA480	Assemble and Submit Flooring Samples	Completed	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA560	Review and Approve Flooring	Completed	\$2,400.00	\$2,400.00	\$2,400.00	\$0.00	\$0.00
BA620	Fabricate and Deliver Flooring	Completed	\$13,920.00	\$5,453.06	\$13,920.00	\$8,466.94	\$8,466.94
BA910	Install Floor and Carpeting	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$17,472.00	\$9,005.06	\$17,472.00	\$8,466.94	\$8,466.94
Carpentry							
BA900	Install Ceiling Grid	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
BA911	Finish Carpentry and Millwork	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Paint							
BA930	Paint Building Interior	Not Started	\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$0.00	\$0.00	\$0.00	\$0.00	\$0.00
Subtotal			\$17,472.00	\$9,005.06	\$17,472.00	\$8,466.94	\$8,466.94
Subtotal			\$151,900.00	\$57,727.27	\$151,900.00	\$94,172.73	\$85,452.73
Subtotal			\$151,900.00	\$57,727.27	\$151,900.00	\$94,172.73	\$85,452.73
Subtotal			\$151,900.00	\$57,727.27	\$151,900.00	\$94,172.73	\$85,452.73
Subtotal			\$151,900.00	\$57,727.27	\$151,900.00	\$94,172.73	\$85,452.73
Total			\$151,900.00	\$57,727.27	\$151,900.00	\$94,172.73	\$85,452.73

REPORT 5: Report 5 (Table B.5) is a resource analysis showing budgeted units, actual units, and other data per resource.

Table B.5. Apex Project — Resource Control — Summary by Resource

Resource ID	Budgeted Units	Units % Complete	Actual Units	Actual This Period Units	Remaining Units	At Completion Units
Jeff Young	121.00	100.00%	121.00	-203.00	0.00	121.00
Wendy Resner	562.00	38.71%	200.74	-287.26	317.83	518.57

(continued)

Table B.5. (Continued)

Resource ID	Budgeted Units	Units % Complete	Actual Units	Actual This Period Units	Remaining Units	At Completion Units
Paul Kim	600.00	86.67%	520.00	-60.00	80.00	600.00
Ed Wood	308.00	10.39%	32.00	-65.00	276.00	308.00
Oliver Rock	260.00	98.46%	256.00	203.00	4.00	260.00
Ace Corp	1768.00	84.62%	1496.00	1496.00	272.00	1768.00
Field Eng-Senior	744.00	22.38%	166.47	166.47	577.53	744.00
Field Engineer	439.00	43.41%	190.23	190.23	248.00	438.23
Field Eng-Assistant	136.00	23.25%	31.62	-0.38	104.38	136.00
Hardware Specialist	223.00	81.89%	182.62	182.62	40.38	223.00
Programmer	168.00	0%	0.00	0.00	168.00	168.00
Software Engineer	40.00	0%	0.00	0.00	40.00	40.00
Elevator Installer	24.00	0%	0.00	0.00	24.00	24.00
Electrician	403.00	58.31%	235.00	235.00	168.00	403.00
Excavator	240.00	100%	240.00	144.00	0.00	240.00
Floor and Carpet Layer	40.00	0%	0.00	0.00	40.00	40.00
Finisher	256.00	100%	256.00	256.00	0.00	256.00
Finishes Carpenter	328.00	0%	0.00	0.00	328.00	328.00
Ironworker	672.00	100%	672.00	672.00	0.00	672.00
Laborer-Construction	504.00	79.37%	400.00	400.00	104.00	504.00
Mason	136.00	58.82%	80.00	80.00	56.00	136.00
Operating Engineer	264.00	75.76%	200.00	200.00	64.00	264.00
Plumber	168.00	85.71%	144.00	144.00	24.00	168.00
Painter	144.00	0%	0.00	0.00	144.00	144.00
Rough Carpenter	400.00	100%	400.00	400.00	0.00	400.00
Heating Ventilation & AC Technician	120.00	66.67%	80.00	80.00	40.00	120.00
Machinist	48.00	100%	48.00	48.00	0.00	48.00
100ft Crane	8.00	0%	0.00	0.00	8.00	8.00
Piping Material	40.00	80%	32.00	32.00	8.00	40.00
No Resource ID Name	128.00	0%	0.00	0.00	128.00	128.00
Total	—	64.7%	—	—	—	—

GRAPHIC REPORTS

REPORT 6: Report 6 (Figure B.1) is a bar (Gantt) chart that shows the original duration, early dates, late dates, and total float in the tabular section. The bar chart shows the float bar. The user may opt to hide it. The report is grouped by primary code (phase) and secondary code (department).

REPORT 7: Similar to report 6, report 7 (Figure B.2) has an addition and a deletion. We added the remaining duration and percent complete (since the project has already started) and omitted the late dates and total float. We also hid the float bar in the bar chart section. In both reports 6 and 7, relationship lines may be displayed in the bar chart section.

REPORT 8: Report 8 (Figure B.3) is a logic diagram grouped by phase. Note that completed activities are shown as boxes with two diagonal lines. Boxes representing in-progress activities are designated with one diagonal line. Activities that have not started do not have diagonal lines.

REPORT 9: Report 9 (Figure B.4) looks like a tabular report since the bar chart was hidden. The report shows activity status and budget information.

REPORT 10: Similarly to report 9, report 10 (Figure B.5) shows the bar chart. Such a report should be printed on wider paper or the font size will be too small.

REPORT 11: Report 11 (Figure B.6) is a bar chart that contains a resource usage profile.

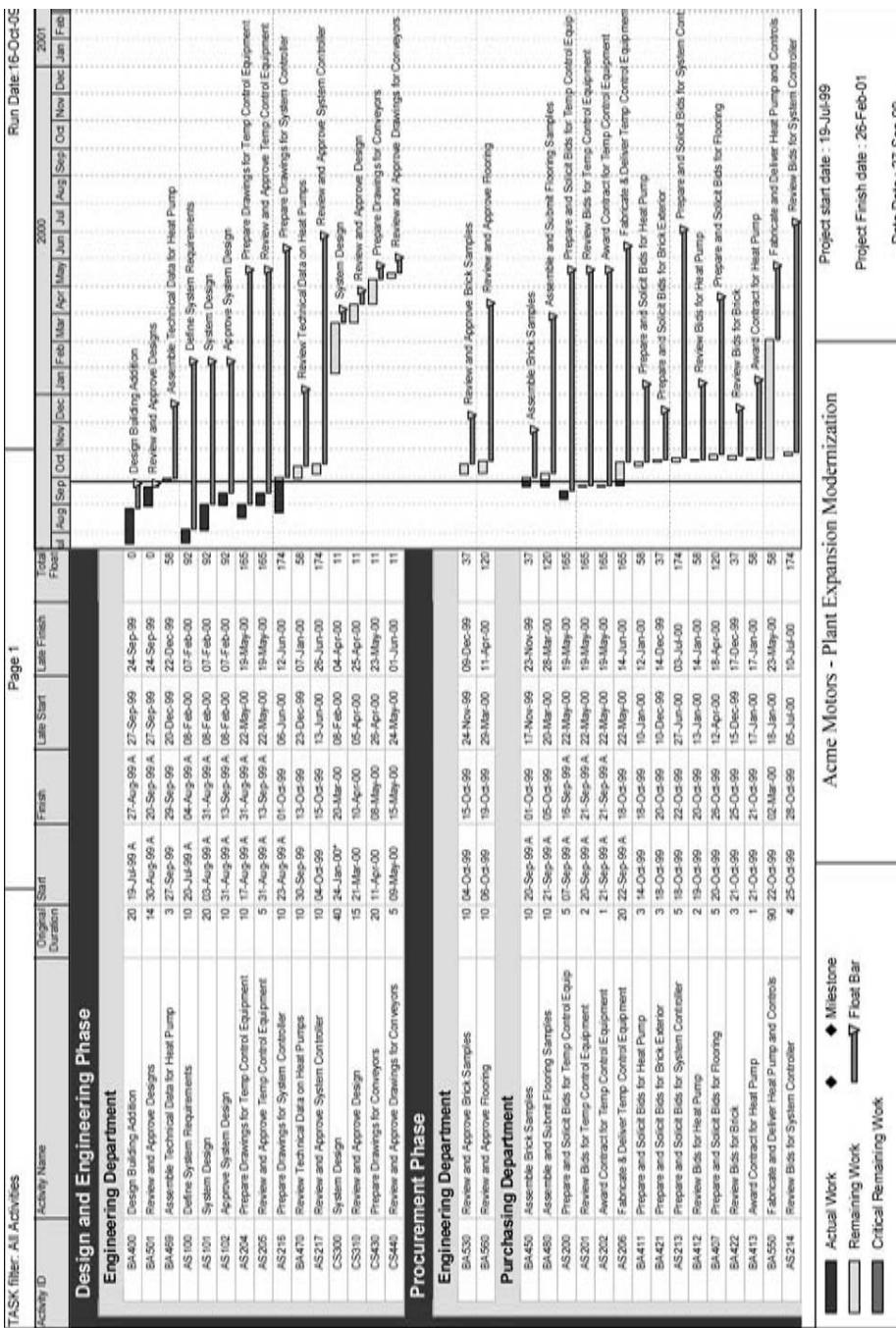


Figure B.1 Report 6: Asterisk indicates a constraint on the activity. (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

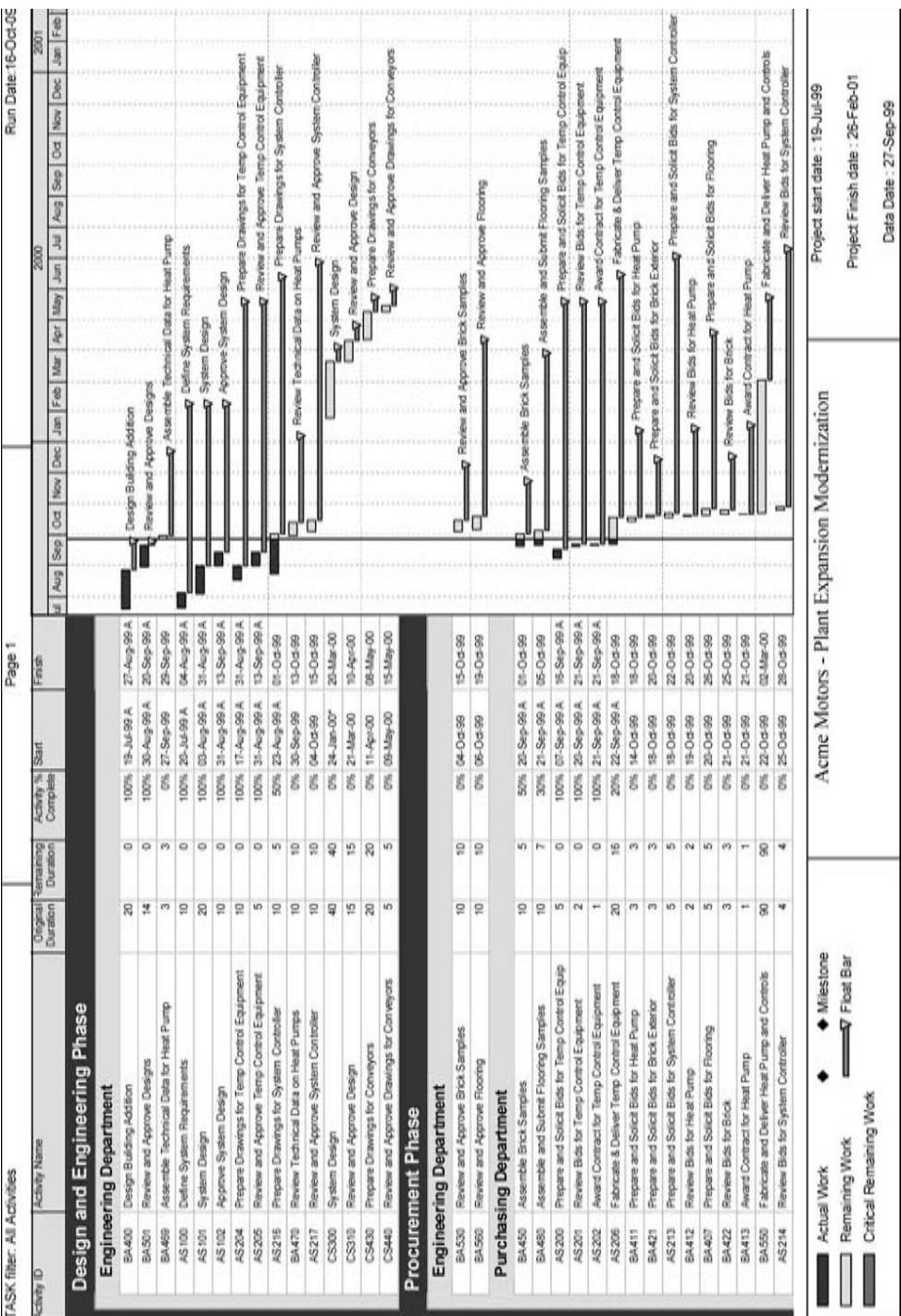


Figure B.2a Report 7 (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

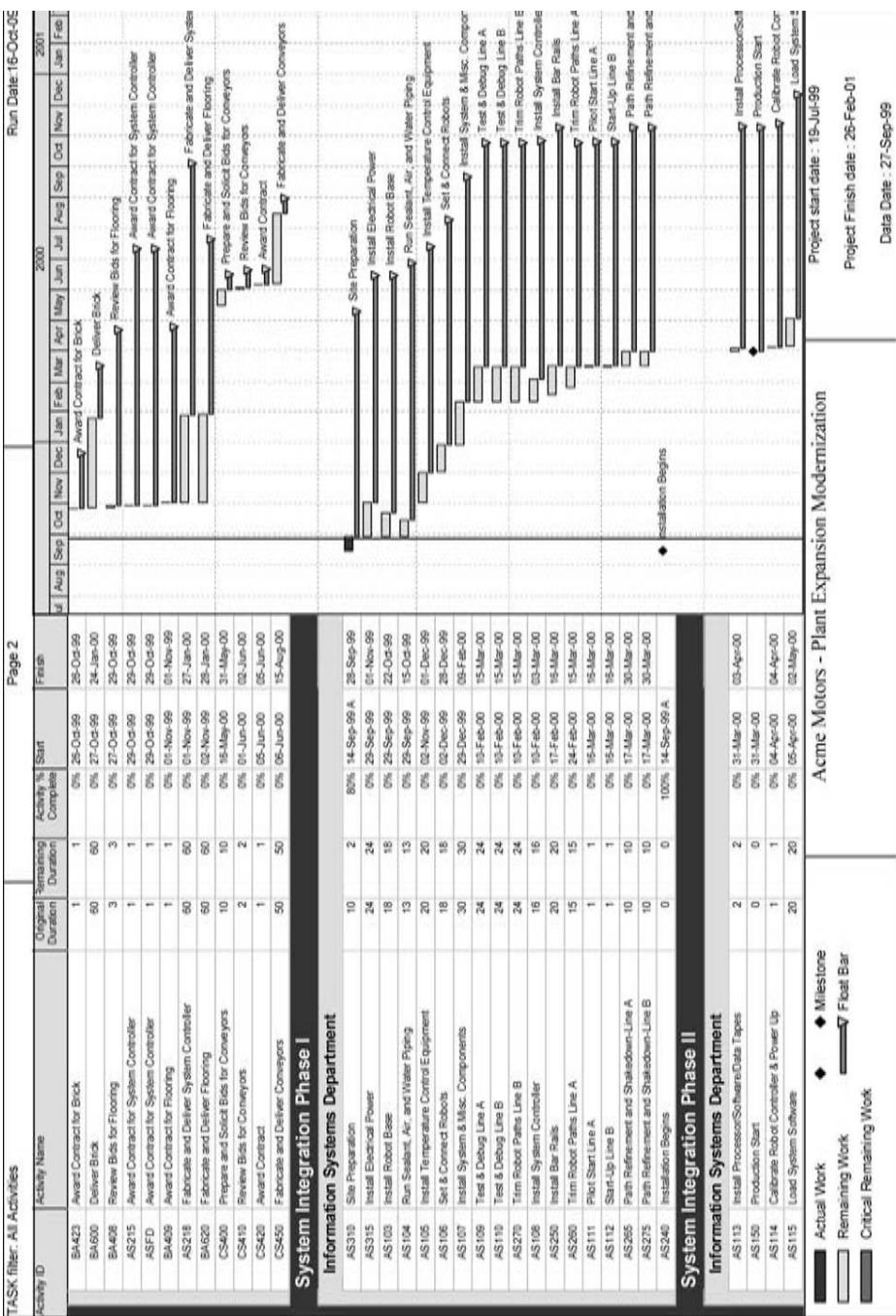


Figure B.2b (Continued)

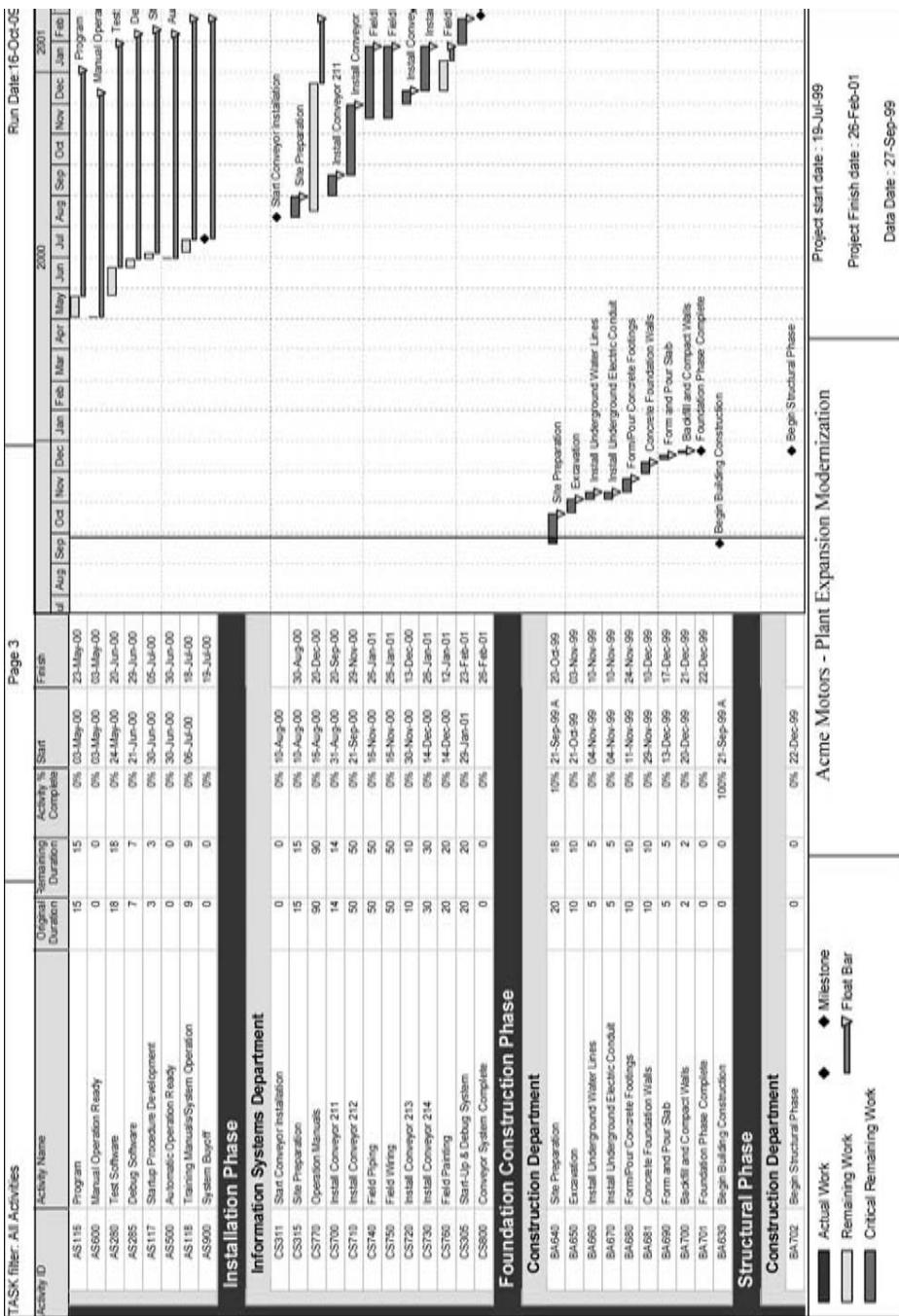


Figure B.2c (Continued)

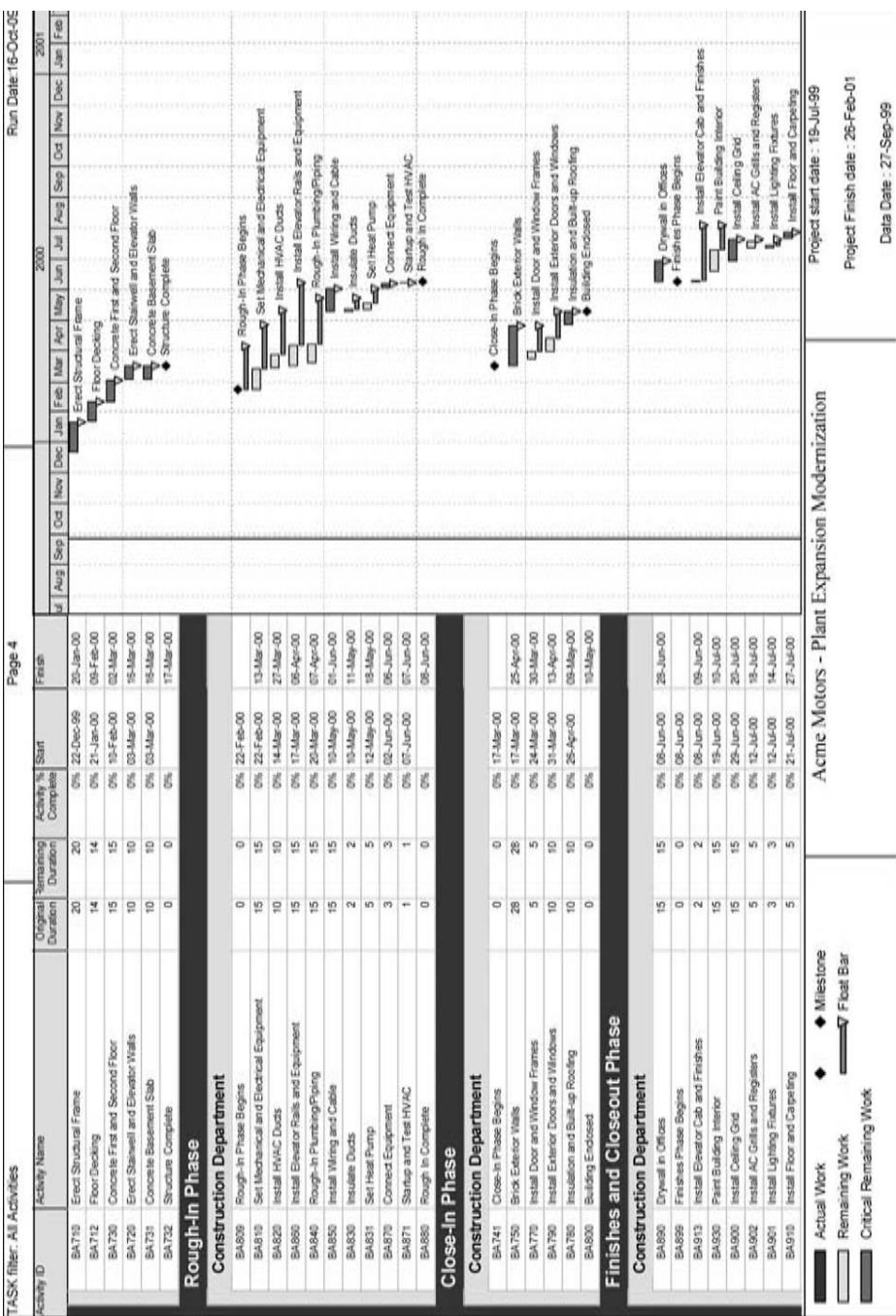


Figure B.2d (Continued)

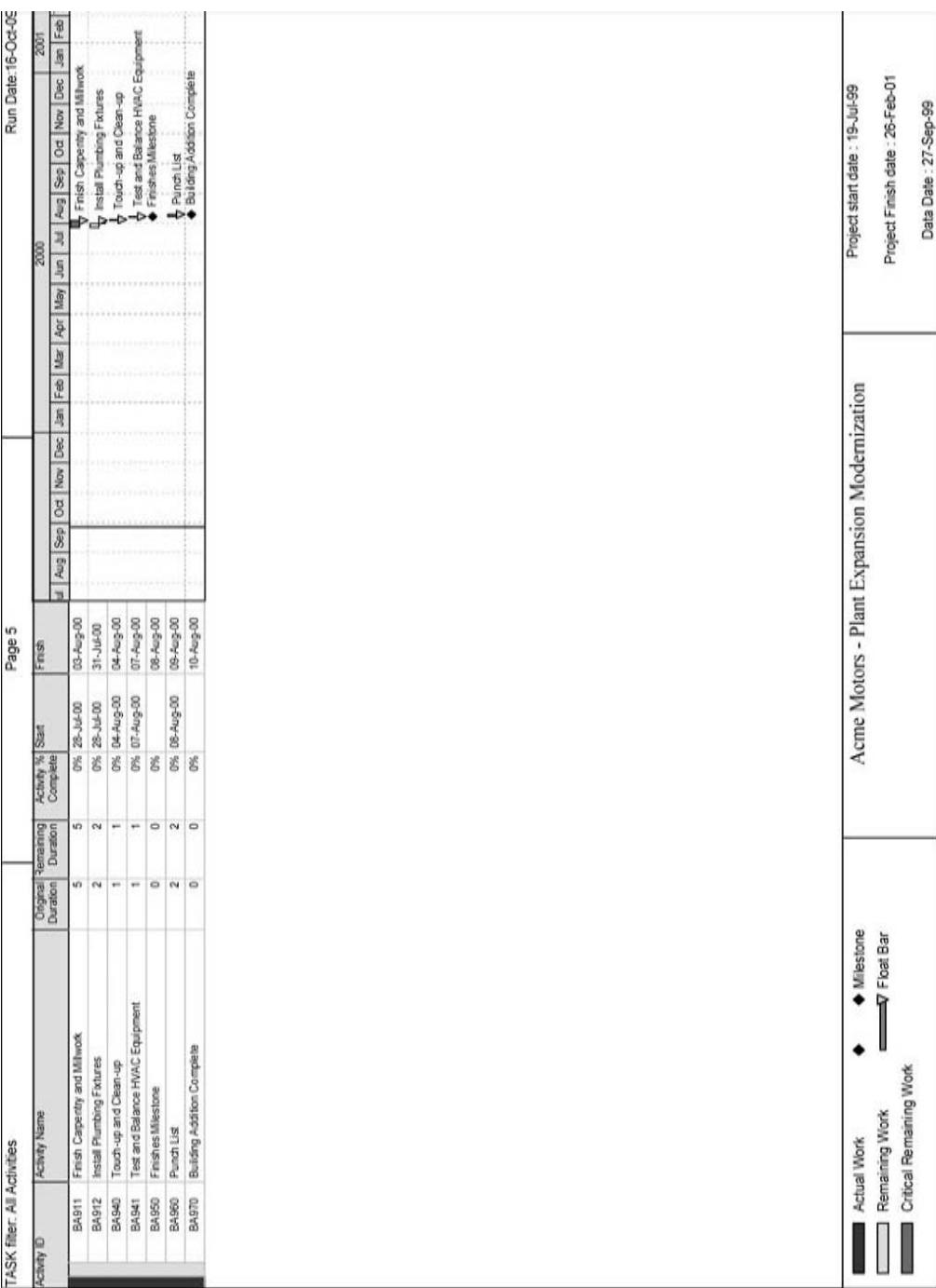


Figure B.2e (Continued)

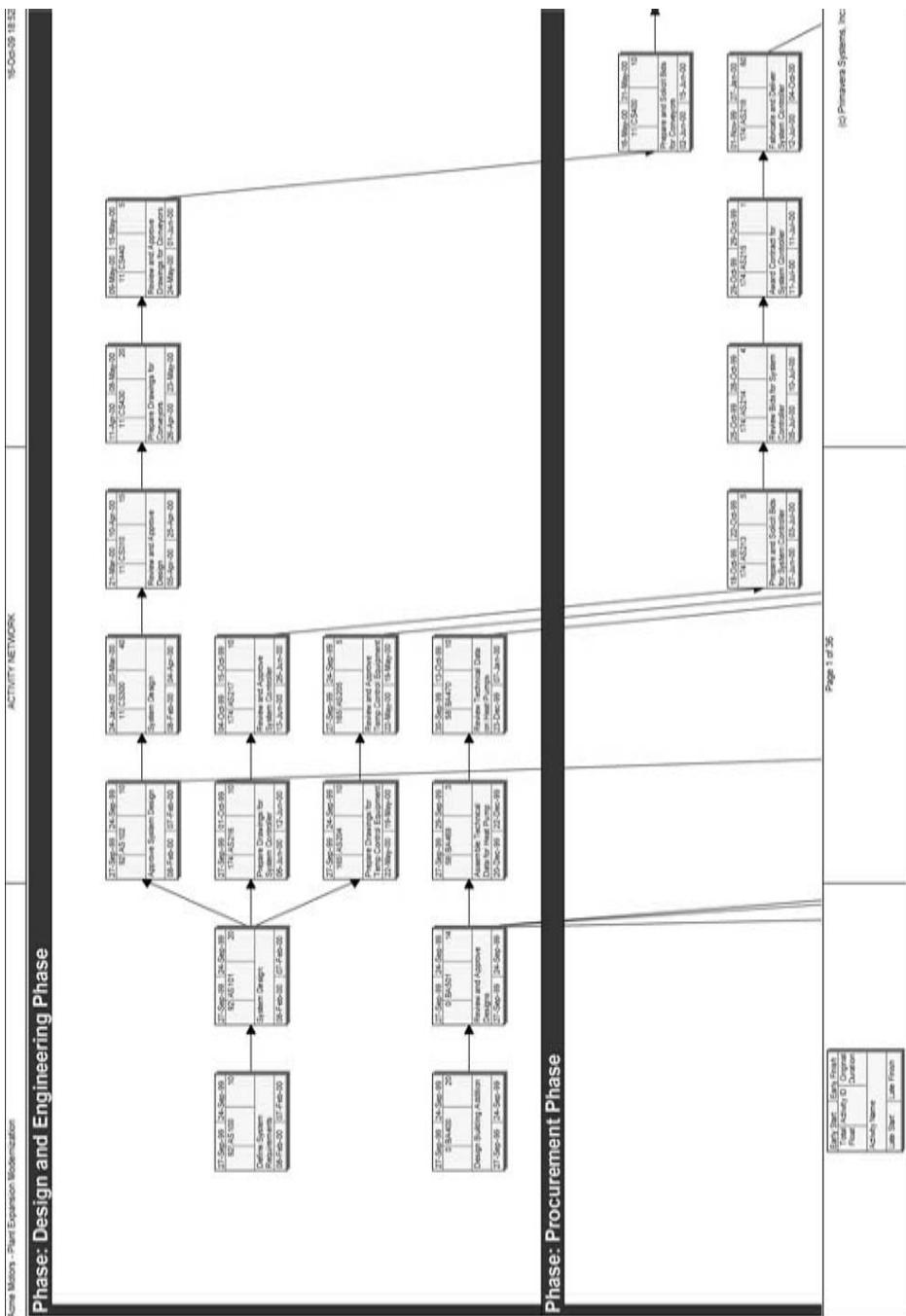


Figure B.3 Report 8 (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

Act ID	Description	Orig Dur	Rem Dur	% Comp	Early Start	Early Finish	Late Start	Late Finish	Total Float	Budg Cost	Act Cost to Date	Contract Comp	Cont Var
Plant Expansion and Modernization													
B4000	Design Existing Addition	20	0	100	15AUG99 A	27AUG99 A	15AUG99 A	27AUG99 A	9,600.00	9,600.00	0.00	0.00	0.00
AS100	Define System Requirements	10	0	100	20AUG99 A	01AUG99 A	20AUG99 A	01AUG99 A	-2,960.00	3,300.00	3,300.00	-340.00	0.00
AS101	System Design	20	0	100	03AUG99 A	11AUG99 A	03AUG99 A	11AUG99 A	16,640.00	16,640.00	16,640.00	0.00	0.00
B409	Assemble Technical Data for Heat Pump	3	3	0	13AUG99	17AUG99	13AUG99	17AUG99	0	560.00	0.00	560.00	0.00
AS103	Install Robot Base	18	18	0	17AUG99	01SEP99	17AUG99	01SEP99	60	1,824.00	0.00	1,824.00	0.00
AS104	Review Allt. and Hatch Piping	13	13	0	17AUG99	01SEP99	17AUG99	01SEP99	190	3,432.00	0.00	3,432.00	0.00
AS204	Prepare Drawings for Temp Control Equipment	10	0	100	17AUG99 A	01AUG99 A	17AUG99 A	01AUG99 A	1,760.00	1,936.00	1,936.00	-176.00	0.00
AS315	Install Electrical Power	24	24	0	17AUG99	20SEP99	17AUG99	20SEP99	0	12,389.00	0.00	12,389.00	0.00
B4010	Review Technical Data on Heat Pumps	10	10	0	18AUG99	01AUG99	18AUG99	01AUG99	560	600.00	0.00	600.00	0.00
AS211	Review and Approve System Controller	10	10	0	20AUG99	02SEP99	20AUG99	02SEP99	190	3,425.00	0.00	3,425.00	0.00
B4530	Review and Approve Brick Samples	10	10	0	20AUG99	02SEP99	20AUG99	02SEP99	370	240.00	0.00	240.00	0.00
AS216	Prepare Drawings for System Controller	10	5	50	23AUG99 A	18AUG99	23AUG99 A	18AUG99	190	1,760.00	880.00	1,760.00	0.00
B4560	Review and Approve Flooring	10	10	0	24AUG99	01SEP99	24AUG99	01SEP99	1200	240.00	0.00	240.00	0.00
AS4501	Review and Approve Designs	14	0	100	30AUG99 A	20SEP99	30AUG99 A	20SEP99	190	1,680.00	1,500.00	1,500.00	180.00
AS102	Approve System Design	10	0	100	31AUG99 A	13SEP99	31AUG99 A	13SEP99	190	2,546.00	2,546.00	2,546.00	0.00
AS205	Review and Approve Temp Control Equipment	5	0	100	31AUG99 A	13SEP99	31AUG99 A	13SEP99	190	2,236.00	2,900.00	2,900.00	-164.00
B4111	Prepare and Solicit Bids for Heat Pump	3	3	0	01SEP99	03SEP99	01SEP99	03SEP99	560	381.00	0.00	381.00	0.00
AS213	Prepare and Solicit Bids for System Controller	5	5	0	03SEP99	10SEP99	03SEP99	10SEP99	190	784.00	0.00	784.00	0.00
B4C12	Prepare and Solicit Bids for Brick Exterior	3	3	0	03SEP99	08SEP99	03SEP99	08SEP99	370	384.00	0.00	384.00	0.00
AS200	Prepare and Solicit Bids for Temp Control Equip	5	0	100	01SEP99 A	16SEP99 A	01SEP99 A	16SEP99 A	190	1,090.00	1,090.00	1,090.00	0.00
B4A12	Review Bids for Heat Pump	2	2	0	01SEP99	08SEP99	01SEP99	08SEP99	560	125.00	0.00	125.00	0.00
B4A07	Prepare and Solicit Bids for Flooring	5	5	0	03SEP99	11SEP99	03SEP99	11SEP99	1200	640.00	0.00	640.00	0.00
B4A13	Award Contract for Heat Pump	1	1	0	03SEP99	09SEP99	03SEP99	09SEP99	560	32.00	0.00	32.00	0.00
B4C22	Review Bids for Brick	3	3	0	03SEP99	13SEP99	03SEP99	13SEP99	370	96.00	0.00	96.00	0.00
B4550	Excavation	10	10	0	03SEP99	22SEP99	03SEP99	22SEP99	0	13,160.00	0.00	13,160.00	0.00
B4561	Fabricate and Deliver Heat Pump and Controls	90	90	0	03SEP99	17JAN00	03SEP99	17JAN00	560	2,300.00	0.00	2,300.00	0.00
AS214	Review Bids for System Controller	4	4	0	03SEP99	16SEP99	03SEP99	16SEP99	190	659.80	0.00	659.80	0.00
AS240	Installation Bright	0	0	100	14SEP99 A	14SEP99 A	14SEP99 A	14SEP99 A	0	0.00	0.00	0.00	0.00
Start Date: 15AUG99 Finish Date: 01FEB00 Data Date: 13AUG99 File Date: 22JUN04 Page Number: 1A © Primavera Sys. Inc.										Date:	Revised	Cleared	Approved
Acme Motors Plant Expansion and Modernization													

Figure B.4 Report 9 (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

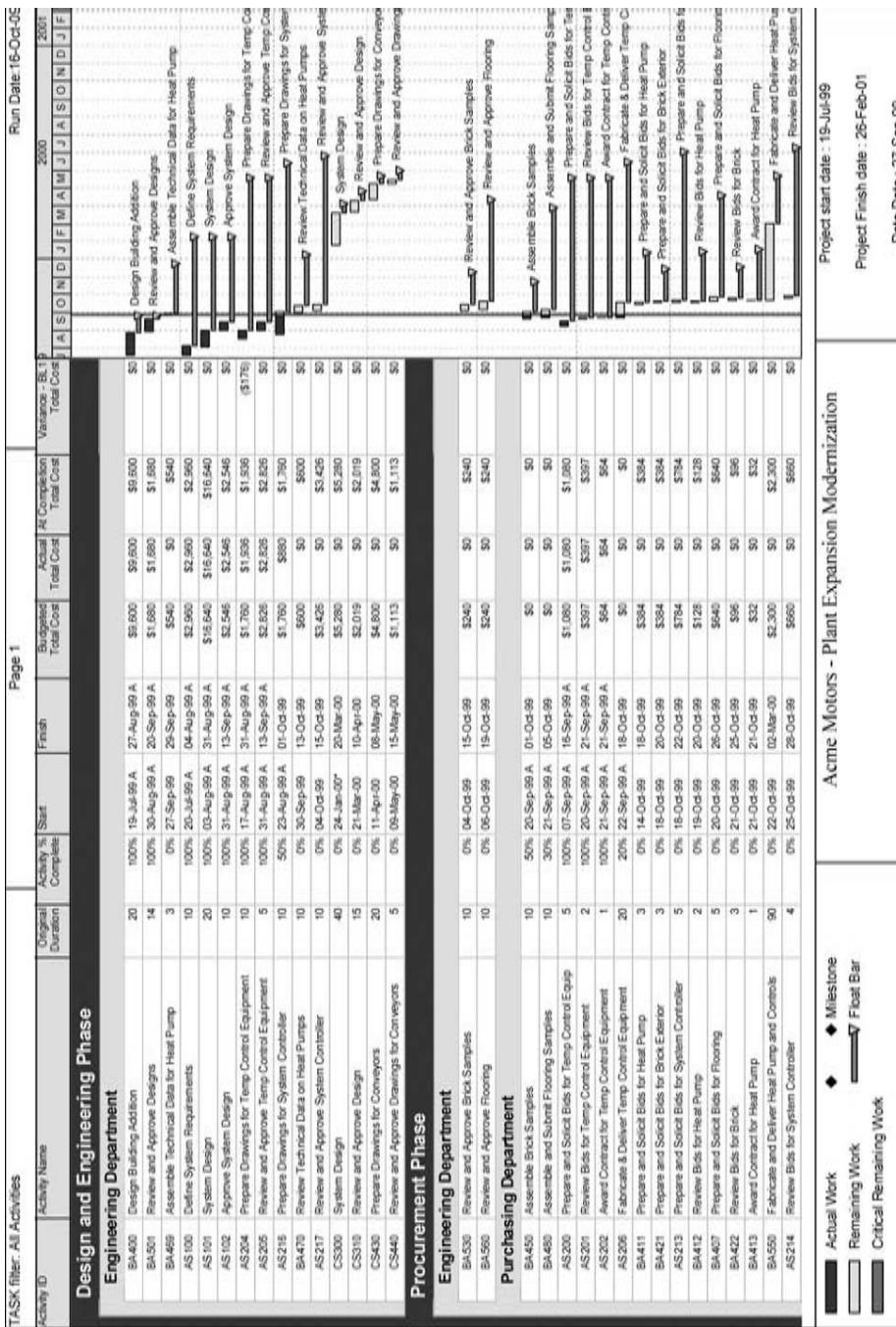


Figure B.5 Report 10 (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

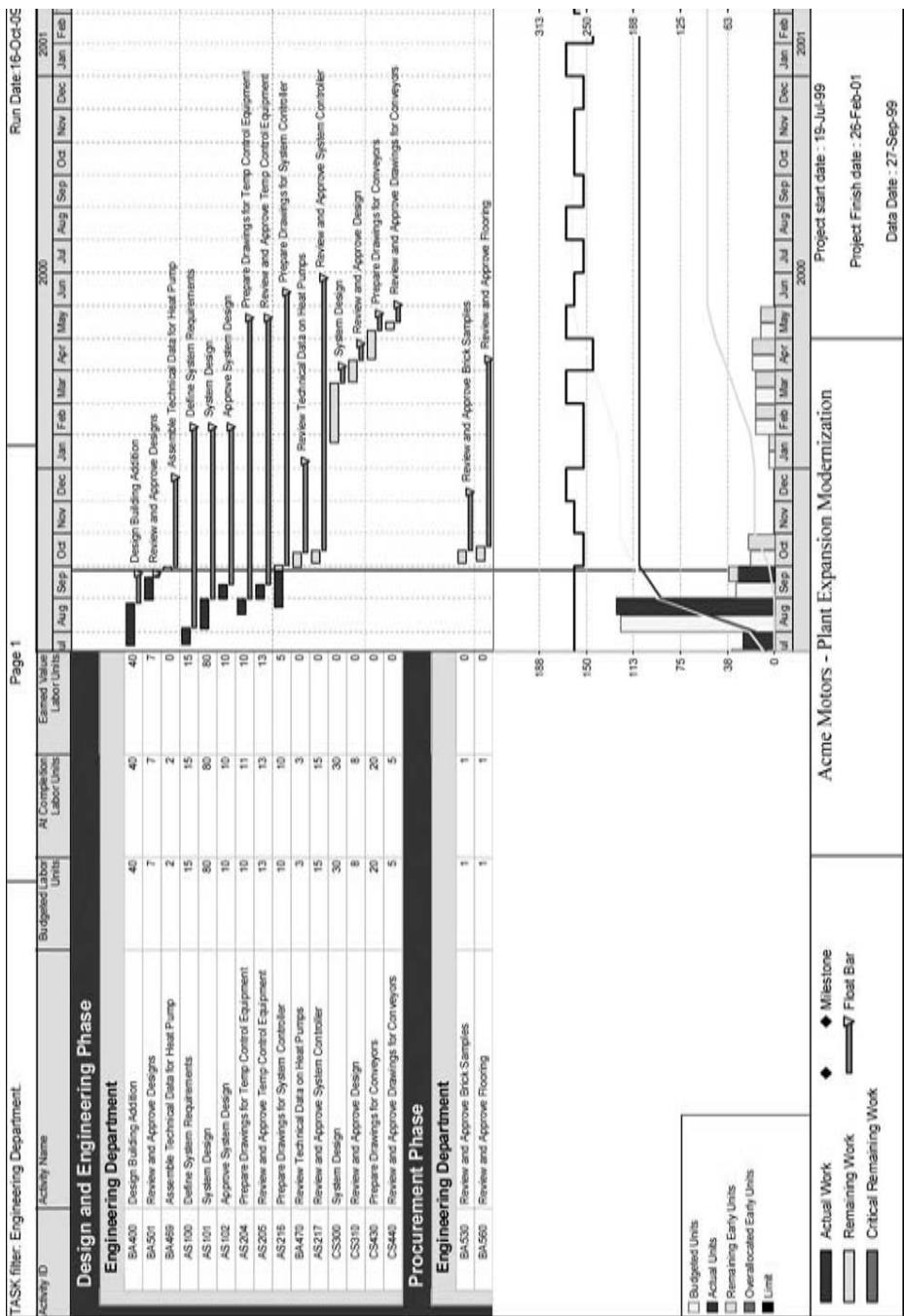


Figure B.6 Report 11 (Reprinted with permission from Primavera Systems, Inc. Primavera® and P6 are either trademarks or registered trademarks of Primavera Systems, Inc.)

Abbreviations

IMPORTANT NOTE: Many of the following abbreviations are subject specific. In this book, they are used within the context of the construction industry. One abbreviation or acronym may mean one thing in one discipline and something entirely different in another.

AAA	American Arbitration Association
AACEI	AACE International (formerly known as the American Association for Cost Engineers), http://www.aacei.org/
AASHTO	American Association of State and Highway Transportation Officials, http://transportational.org.aashtonest/
ABA	American Bar Association, http://www.abanet.org/
ABC	Associated Builders and Contractors, Inc., http://www.abc.org/ ; or Activity-Based Costing
AC	actual cost, air-conditioning (mechanical), or alternating current (electrical)
ACI	American Concrete Institute, http://www.aci-net.org/
ACWP	actual cost for worked performed
ADM	arrow diagramming method
ADR	alternate dispute resolution
A/E	architect or engineer
AFL-CIO	American Federation of Labor-Congress of Industrial Organizations, http://www.aflcio.org/
AGC	Associated General Contractors of America, http://www.agc.org/
AIA	The American Institute of Architects, http://www.aia.org/
ANSI	American National Standards Institute, http://www.ansi.org/
AOA	activity on arrow

AON	activity on node
ASAP	as soon as possible, a term to be avoided in contracts and construction agreements (a specific date should be specified); also, a type of constraint in MS Project software.
ASCE	American Society of Civil Engineers, http://www.asce.org/
ASME	American Society of Mechanical Engineers, http://www.asme.org/
ASTM	American Society for Testing and Materials, http://www.astm.org/
AUCA	American Underground Construction Association
BAC	budget at completion
B/C ratio	benefit-cost ratio
BCWP	budgeted cost for work performed
BCWS	budgeted cost for work scheduled
BF	Board-Foot; a measuring unit for rough carpentry, 1 BF = 1 ft × 1 ft × 1 in
BIM	Building Information Modeling
BIS	Building Information System
BOQ	Bill of Quantities
BOT	build-operate-transfer or board of trustees
CC	crash cost
CD	crash duration (in scheduling), compact disc (in information technology), or certificate of deposit (in banking)
CII	Construction Industry Institute, http://www.construction-institute.org/
CIP	cast-in-place (adj.)
CM	construction manager, or construction management (firm)
CMAA	Construction Management Association of America, http://cmaanet.org/
CMU	concrete masonry unit
CO	change order
CPI	cost performance index
CPM	critical path method
C/SCSC	cost/schedule control systems criteria
CSI	The Construction Specifications Institute, http://www.csinet.org/ ; or Cost-Schedule Index
CV	cost variance
cwt	Centum weight or hundredweight, a unit of measurement of weight equivalent to 100 lb in the United States used mostly for steel
CY	cubic yards
D/B	design-build
DD##	design development (## is the percent complete; e.g., DD30 means design development at 30% complete)
DML	Dynamic Minimum Lag; a new type of logical relationships in critical path method scheduling
DOD	Department of Defense

DOE	Department of Energy
DOT	Department of Transportation
DRB	dispute review board
DRF	double-restricted float
EA	each
EAC	estimate at completion
EBS	enterprise breakdown structure
EF	early finish time (or date)
EJCDC	Engineers Joint Contract Documents Committee
ENR	<i>Engineering News-Record</i> magazine, http://enr.construction.com/
	Default.asp
EPC	Engineer-Procure-Construct
ES	early start time (or date)
ETC	estimate to complete
EV	earned value
EVA	earned value analysis
EVM	earned value management
FCV	forecasted cost variance
FF	finish-to-finish (relationship) or free float
FF&E	Furniture, Furnishings and Equipment (architecture); Field Fabricate & Erect (structural steel); or Furniture, Fixtures & Equipment (real estate)
FICA	Federal Insurance Contributions Act
FIDIC	The International Federation of Consulting Engineers (the acronym stands for the French version of the name), http://www.fidic.org/
FRP	formwork, rebar, place (for concrete members)
FS	finish-to-start (relationship)
FSV	forecasted schedule variance
GC	general contractor
GERT	graphical evaluation and review technique
HVAC	heating, ventilation, and air-conditioning
IAI	International Alliance for Interoperability, http://www.iai-na.org/
IEEE	Institute of Electrical and Electronics Engineers, http://www.ieee.org/
Ind. F	independent float
Int. F	interfering float
IPA	immediately preceding activity
IPD	Integrated Project delivery
IROR	internal rate of return (on an investment)
IRR	internal rate of return (on an investment)
ISA	immediately succeeding activity
ISO	International Organization for Standardization (ISO 9000, ISO 14000), http://www.iso.ch/iso/en/ISOOnline.frontpage
IT	information technology
LC	least cost
LCD	least-cost duration

LD	Liquidated Damages (usually written as plural; LD's)
LEED	Leadership in Energy and Environmental Design
LF	late finish time (or date) or linear feet
LLI	long lead item
LOB	Line of Balance Method
LS	late start time (or date)
LSM	linear scheduling method
MARR	minimum attractive rate of return
MBF	1,000 board feet
MEP	mechanical, electrical, and plumbing
MGD	million gallons per day
MSDS	materials safety data sheet
NAHB	National Association of Home Builders, http://www.nahb.org/
NASA	National Aeronautics and Space Administration, http://www.nasa.gov/home/index.html
NC	normal cost
ND	normal duration
NEC	New Engineering Contract
NLT	no less than
NSPE	National Society of Professional Engineers, http://www.nspe.org/
NTP	Notice to Proceed
NTS	not to scale
OBS	organizational breakdown structure
OSHA	Occupational Safety and Health Administration, http://www.osha.gov/
P3	Primavera Project Planner—the original software developed by Primavera Systems in 1983 and was preceded later on by the enterprise version P3e, which later was named after its version P5, P6.
P6	Primavera Project Management—the enterprise version of Primavera P3. It was introduced in the late 1990s as P3e (Primavera Project Planner for the Enterprise). It changed versions and names and then took on the version number: P5 for version 5.x and P6 for version 6.x
PC	percent complete. This abbreviation has many interpretations depending on the context.
PCA	Portland Cement Association; http://www.portcement.org/
PCM	pure agency construction management
PDM	precedence diagramming method
PE	professional engineer
PEP	program evaluation procedure
PERT	program evaluation and review technique
PF	project finish
PM	project manager or project management
PMC	Project Management Consultant
PMI	Project Management Institute, http://www.pmi.org/

PMI-COS	Project Management Institute-College of Scheduling, http://www.pmicos.org/
PMO	Project Management Office
PMP	Professional Project Manager (certified by PMI). It is also used sometimes to indicate Project Management Plan.
PS	project start
PV	planned value
QA/QC	quality assurance/quality control
QS	Quantity Surveyor
R&D	research and development
RFA	request for approval
RFC	request for change
RFI	request for information
RFP	request for proposal
RFQ	request for quotation
ROR	rate of return (on an investment)
SC	substantial completion
SD	standard deviation
SDK	software development kit
SF	start-to-finish (relationship) or square foot
SFCA	square foot contact area (unit of measure for concrete formwork)
SPI	schedule performance index
SQ	square (unit of measure for roofs; equal to 100 square feet)
SRF	single-restricted float
SS	start-to-start (relationship)
SV	schedule variance
TB	total (planned) budget
TCM	total cost management
TF	total float
TQM	total quality management
URF	unrestricted float
VAR	variance
VE	value engineering
WBS	work breakdown structure
ZFF	zero free float (Constraint)
ZTF	zero total float (Constraint)

Glossary

- Accelerated Schedule**—A schedule submitted usually by the contractor, implementing adjustments to the original project schedule to accelerate the completion date, without changing the project scope, in order to meet contract/owner's stipulated finish date, achieve financial gains, and/or avoid losses.
- Acquisition**—The obtaining of supplies, services, or property to meet the needs of a project. Also see *Procurement*
- Act of God**—See *Force Majeure*
- Activity**—A basic unit of work as part of the total project, that is easily measured and controlled. It is time and resource consuming. Also called *Task*.
- Activity Description**—A short phrase or label used in a project schedule describing the type of work in this activity. In many cases, it also references location of work and/or other information pertaining to the work in this activity. For example: “Concrete placement, suspended slab, 16th floor”
- Activity Duration**—The number of time units (weeks, days, hours, etc.) required to complete this activity. There are four types of duration: *original* (or *planned*) *duration*, *actual duration*, *remaining duration*, and *at completion duration*.
- Activity ID**—A unique identity given—by the scheduler or scheduling program—to each activity in the schedule. It is usually made of numerical, alphabetic, or combination characters. For example: ASD4230
- Activity on Arrow (AOA) Network**—A network diagram showing sequence of activities, in which each activity is represented by an arrow connecting between two nodes (circles), each node representing an event.
- Activity on Node (AON) Network**—A network diagram where activities are represented by a node (box) linked by lines representing logic dependencies.
- Activity Percent Complete**—A completion percentage of the work in an activity based on a chosen method of measuring work progress.

Actual Cost (AC)—see *Actual Cost for Work Performed (ACWP)*.

Actual Cost at Completion—See *At Completion Total Cost*

Actual Cost for Work Performed (ACWP)—Total costs (direct and indirect) incurred in performing work during a given time period.

Actual Cost This Period—Actual cost incurred from previous *Data Date* to current *Data Date*.

Actual Cost to Date—Actual cost incurred from start of work throughout current *Data Date*.

Actual Duration—The number of time units consumed to complete an activity, if completed, or consumed on the activity so far, if not completed yet.

Addenda—Plural of *Addendum*.

Addendum—A document describing an addition, change, correction, or modification to contract documents. An addendum is issued by the design professional or owner to all bidders during the bidding period but prior to the award of contract. Addenda become part of the contract documents.

Alternate Dispute Resolution (ADR)—Any procedure or combination of procedures voluntarily used to resolve a dispute without going to court. These procedures may include, but are not limited to, assisted settlement negotiations, conciliation, facilitation, mediation, fact-finding, mini-trials, and arbitration.

A+B Contracting Method—A bidding/contracting method that factors time plus cost to determine the low bid. Under the A + B method, each submitted bid has two components: “A”: dollar amount for contract items, and “B”: days required to complete project. Bid days are multiplied by a hypothetical cost per day, set by the owner, and added to the A component to obtain the total bid: A + (B* cost per day) = total bid. Also called Cost plus time or biparameter bidding/contracting method.

Application for Payment—see *Payment Request*.

Arbitration—The process by which parties agree to submit their disputes to the determination of a third, impartial party (referred to as the arbitrator), rather than pursuing their claims before a judge and jury in a court of law. Parties often agree in advance to binding arbitration of disputes, either as a clause in the contract or at the occurrence of a dispute. This method of avoiding litigation can save both time and money.

Arrow Diagramming Method (ADM)—see *Activity on Arrow (AOA) Network*.

As-Built Schedule—A schedule prepared after the project has started and reflects work occurrence as actually happened in reality rather than what was planned to happen. Activities are plotted by their actual start and actual finish disregarding any logic.

As Late As Possible—A constraint in some computer scheduling programs that forces the maximum delay in starting an activity without delaying succeeding activities. Also called the *Zero Free Float* constraint.

As-of Date—see *Data Date*

As-Planned Schedule—The schedule submitted by the contractor—as usually required by the contract—and approved by the owner before the start of the project (and sometimes before the signing of the contract.)

At Completion Cost—See *At Completion Total Cost*

At Completion Duration (ACD)—The duration of an activity after its completion.

For activities not started yet, *At Completion Duration* is same as the *Original Duration*. For in-progress activities, *At Completion Duration* is equal to the summation of *Actual Duration* and *Remaining Duration*. For completed activities, *At Completion Duration* is equal to *Actual Duration*.

At Completion Total Cost—Total costs (direct and indirect) incurred in an activity, group of activities, or the entire project; throughout the completion of the overall assigned work.

Backward Pass—The process of going on a network from finish to start; calculating late dates for all activities. Backward pass starts with the imposed finish date of the project, if given. If not, it starts with the finish date calculated by the *Forward Pass*. Dates calculated by the *Backward Pass* along with those calculated by the *Forward Pass*, help identify the critical path and calculate float for all activities.

Backward Resource Leveling—Leveling resources, starting from project finish and going (backward) through all project activities, fulfilling their resource requirements and maintaining the total resource usage within the set limits. With such restrictions, the project may have a longer duration than originally allowed and project start may have to occur before the scheduled date.

Bar chart—A graphical representation of project activities shown in a time-scaled bar line with no links shown between activities. Originally developed by Mr. Henry L. Gantt in 1917. Also called a *Gantt Chart*.

Baseline—The original approved plan for a project, including approved changes. It usually includes *Baseline Budget* and *Baseline Schedule*. It is used as a benchmark for comparison with actual performance (see *Project Control*).

Baseline Budget—The project's original approved budget, including any approved changes.

Baseline Schedule—A schedule prepared by the contractor before the start of the project—and usually approved by the owner—typically used for performance comparison.

Beginning-of-Day Convention—When any date mentioned for an activity means the start of the day. Usually used only by computer software for start dates.

Beneficial Occupancy—The use of a premises (or a portion of it) for its intended purpose, even though the project work may not be complete. This term is almost same as *Substantial Completion*. See also *Certificate of Substantial Completion*.

Beta Distribution—A continuous probability with a probability distribution function defined on the interval $[0, 1]$. It is used in PERT with three time estimates for the completion of an activity: the optimistic duration, the most likely duration, and the pessimistic duration. Using these three durations, the beta distribution allows the calculation of the means and variances of activity completion times. The beta distribution also has an advantage over the normal distribution in that it can be skewed right (towards the pessimistic duration), can be skewed left (towards the optimistic duration), or can be symmetrical.

Bill of Quantity (BOQ)—In the United States, this term may mean a list of all materials and their corresponding quantities required in a project. In the U.K., this term is equivalent to the term *Schedule of Values*.

Biparameter contracting method—See *A+B Contracting Method*

Budget at Completion (BAC)—The sum of the total budgets throughout the completion of work on an activity, group of activities, or the entire project.

Budgeted Cost for Work Performed (BCWP)—The sum of the approved cost estimates (including any overhead allocation) for activities (or portions of activities) completed during a given period (usually project-to-date). See also *Earned Value*.

Budgeted Cost for Work Scheduled (BCWS)—The sum of the approved cost estimates (including any overhead allocation) for activities (or portions of activities) scheduled to be performed during a given period (usually project-to-date).

Building Information Modeling (BIM)—Building Information Modeling is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The process produces the Building Information Model (also abbreviated BIM), which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components. (Source: Wikipedia online)

Calculated Finish Date—The completion date of the project as calculated in the *Forward Pass* of the *Critical Path Method*.

Calendar—Calendars show the days on which work on activities may be performed.

Calendar Unit—The smallest unit of time used for activity duration and scheduling the entire project.

Central Limit Theorem (CLT)—The central limit theorem demonstrates that in large enough samples, the distribution of a sample mean approximates a normal curve, regardless of the shape of the distribution of the population from which they were drawn. The larger the value of the sample size, the better the approximation to the normal distribution.

Certificate of Completion—A written document forwarded to the general contractor by the architect, engineer, or owner stating that construction is complete according to the contract agreement (approved plans, specifications, change orders, etc.).

Certificate of Occupancy—A written document issued by a local governmental agency stating that the building or facility is in a condition to be occupied (i.e., in compliance with public health and building codes).

Certificate of Substantial Completion—A written document forwarded to the general contractor by the architect, engineer, or owner indicating that the project is substantially complete. This document initiates the time period for the final payment to the contractor.

Change of the Critical Path—A partial or complete change in the *Critical Path* on a CPM schedule that was caused by a change in the duration of an activity(s) and/or a change in the logic of the schedule. Practically, the *Critical Path* changes if a

near-critical path has increased to exceed the original *Critical Path* or if the original *Critical Path* has decreased to become shorter than another path in the schedule.

Change Order (CO)—Formal written documents, signed by the owner, directing the contractor to make changes from the original contract. A change order can be used for adding, deleting, or substituting work items. A change order usually—but not always—has an impact on the project’s cost and schedule. Also called Variation Order (VO).

Claim—A request from one contracting party (usually the contractor) to another party (usually the owner) for additional compensation, a time extension, or both. See *Delay Claims*.

Combination Relationship—Two activities related (or connected) by two logical relationships, usually start-to-start and finish-to-finish.

Comparison Schedule—The original (usually *As-Planned*) schedule is revised to incorporate any claimed delays. Typically for a delay claim, the contractor submits two schedules: one without the causative factors (factors allegedly causing the schedule delays) and one with the causative factors (called the “impacted” schedule). By comparing the two schedules, the contractor hopes to prove that the delay was caused by the alleged factors.

Compensable Delays—Project delays, caused by the actions or inactions of another party (usually the owner), that entitle the contractor to a time extension, monetary compensation, or both.

Concurrent Delay—A combination of two or more independent causes of delay during the same period.

Constraint—An externally imposed restriction affecting when an activity can start and/or finished. Constraints may conflict with logical relationships. Individual scheduling programs provide the user with a variety of constraint types, some of which can override logic and some of which are subject to logic.

Constructability—“The optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives” (Construction Industry Institute 1986a, p. 2). Or “The practice of peer reviewing the plans and specifications prior to issuing for bid with the intent of correcting errors, omissions, inconsistencies or discrepancies.” (R. S. Means Illustrated Construction Dictionary, 4th edition, 2010)

Constructive Acceleration—Schedule acceleration by the contractor that occurs when a delay takes place beyond a contractor’s control, and yet the owner expects the project to be completed by the original contract completion date. The contractor usually files a claim for this acceleration after the completion of the contract.

Contiguous Activity—An activity that cannot be split or paused. Once work starts on a contiguous activity, it has to continue until its completion.

Contingency—See *Contingency Fees* or *Schedule Contingency*

Contingency Fees—Amounts included in the construction budget to cover the cost of unforeseen events that will most likely occur during the life of the project. Such fees are estimated or calculated directly proportional to the risk taken in the project.

Contract—A legally binding agreement that obligates one party (the architect, engineer, constructor, etc.) to offer products and/or services under certain terms (budget, schedule, specifications); and obligates the other party (owner) to pay for these products/service.

Contract Closeout—The completion and settlement of the contract, including resolution of any open items. From a financial management standpoint, closeout involves settling all financial and accounting matters between the contractor and the owner.

Contractor-Created Float—Schedule float that was created as a result of the contractor's work being completed in a shorter than planned period of time. This float may be created by shorter actual durations for performed activities, a change in the logic, different calendars (6- or 7-day rather than 5-day week), or a combination of these factors. This float is not a part of the total float calculated in the original baseline schedule.

Cost Accounting—“The systematic recording and analysis pf the costs of materials, labor, and overhead incident to production” (Merriam-Webster 2004)

Cost at Completion—see *Actual Cost at Completion*.

Cost Breakdown—See *Schedule of Values*.

Cost-Loaded Schedule—A CPM schedule in which each activity has a cost figure assigned to it. In some software packages, the user may assign resources (labor, equipment, materials) to each activity then the software calculates the cost using the cost of these resources given in the resource dictionary

Cost Performance Index (CPI)—The ratio of *Earned Value* of an activity to its *Actual Cost*. CPI = BCWP/ACWP or CPI = EV/AC.

Cost Ratio—A method of measuring percent complete for an activity (or a project) by distributing (linearly or using other curves) the cost over the duration of the activity (or project). Percent complete = Actual Cost/Total Cost. This method works well for activities with fixed budget and fixed duration such as a salary staff member.

Cost/Schedule Control System Criteria (C/SCSC)—A formal planning and control reporting system developed by the Department of Defense in the 1960s for its contractors to use. It is used for reporting project schedule and financial information. This system was later simplified and modified to what is currently known as *Earned Value Management*.

Cost This Period—see *Actual Cost This Period*.

Cost to Complete—see *Estimate to Complete (ETC)*.

Cost to Date—see *Actual Cost (AC)*.

Cost Variance (CV)—The difference between the *Earned Value* of an activity and its *Actual Cost*. CV = BCWP – ACWP or EV – AC.

CPM—See *Critical Path Method*

Crash Cost—Total cost of a construction project (direct and indirect), including the impact of crashing (maximum compression of) the schedule.

Crash Duration—The least possible duration for a construction project schedule. It is usually achieved by maximum *Schedule Compression*.

Critical Activity—An activity on the critical path. Any delay to a critical activity will result in a delay to the entire project.

Critical Path—The longest path in a network, from start to finish including any lags and constraints.

Critical Path Method (CPM)—A scheduling technique using networks for graphic display of the work plan. The method is used to determine the length of a project and to identify the activities that are critical to the completion of the project.

Cumulative Distribution Function—A function used to compute probabilities for a continuous random variable having values up to a certain value x : $F(x) = \Pr(X \leq x)$

Current Finish Date—The current (updated) estimate of the point in time when the project (or a specific activity) will be completed.

Damages—A measure of monetary compensation that a court or arbitrator awards to a plaintiff for loss or injury suffered by the plaintiff's person, property, or other legally recognizable rights.

Dangling Activity—An activity tied from only one end (start or finish). A dangling activity has only a predecessor(s) or successor(s), not both.

Data Date—The date as of which all progress on a project is reported.

Degressing—Degressing an in-progress Schedule is reversing all progress reflected on the schedule to go back to the starting point. This practice is used when there is no baseline schedule but there is a need to create one after construction has started.

Delay—An event or condition that results in work activity starting, or project completion, later than originally planned, or an interruption or a hindrance to planned progress.

Delay Claim—A claim for extension of time, monetary compensation, or both for a delay caused by actions of another party. Delay claims are classified into excusable, compensable and nonexcusable.

Dependency—see *Logic Relationship*.

Design-Bid-Build—Design-Bid-Build (also called traditional) contracting/project delivery method. The owner contracts with a design firm/consultant to complete the design of the contracted facility, and then selects the constructor through a competitive bidding process. The awarded bidder will become the contractor to build the facility.

Design-Build (DB) Contracting Method—Design-Build is a contracting/project delivery method whereby the owner contracts with a single entity (DB contractor) to do both the design and the construction of the contracted facility. The DB contractor may be a general contractor with the design services being subcontracted, a design firm with the construction services being subcontracted, or both design and construction being done in-house. Such contract may involve a variety of stipulations mostly deal with the amount and method of payment.

Design Development—The second phase of a designer's basic services (the first phase being schematic design), which includes developing all engineering and architectural drawings, specifications, and the cost estimate. This phase may come in stages; each stage is defined by a certain percent completion. For example, DD30 means design development at 30% complete. This indicates that about 30% of the information in

the design is determined. Potential contractors have to assume the remaining 70% information. Further stages follow with the percentage increasing, for example, DD60, DD90, indicating more design information determined. Final design is the third and final phase of the design process. It follows design development.

Direct Cost—Cost that is directly associated with a specific activity or work item. It typically includes labor, materials, equipment, and subcontracts.

Dispute Review Board (DRB)—A panel of three experienced, respected, and impartial reviewers organized before construction begins and meets at the jobsite periodically. The board is usually formed by the owner selecting a member for approval by the contractor, the contractor selecting a member for approval by the owner, with the two thus chosen selecting the DRB chair to be approved by both parties. The board becomes familiar with the project and its development. It helps prevent and resolve disputes between the contracting parties.

Dissolve an Activity—A function in Primavera software that deletes an activity but assigns its predecessors to its successors so that there won't be an interruption in the logic of the schedule.

Double-Restricted Float (in Precedence Networks)—The amount of time we have to delay the rest of work in an activity after it has started, then finish on time without delaying the entire project.

Driving Relationship—A relationship from a predecessor activity that controls the start or finish of a successor activity. For any activity with predecessors, there must be at least one driving relationship.

Dummy Activity—A fictitious activity with zero duration and no budget or resources assigned, used in *Activity on Arrow Networks* to maintain correct logic or distinguish activities' identities.

Duration—see *Activity Duration*.

Dynamic Minimum Lag—The Dynamic Minimum Lag (DML) is a new type of logical relationship in *Critical Path Method* (CPM) scheduling. DML relationship is dynamic; it moves along the activity in parallel to work progress to make sure the minimum lag is maintained at all times, not just at the start of finish.

Early Dates (for an activity)—The *Early Start* date and *Early Finish* date of that activity

Early Finish (for an activity) (EF)—The earliest date that activity can finish within project constraints.

Early Start (for an activity) (ES)—The earliest date that activity can start within project constraints.

Earned Value (EV)—see *Budgeted Cost for Work Performed (BCWP)*.

Earned Value Analysis—Analysis of project progress where the actual money budgeted and spent is compared to the value of the work achieved.

Earned Value Management—A method of integrating scope, schedule, and budget for measuring project performance. It compares the amount of work that was planned with what was actually earned and with what was actually spent to determine if cost and schedule performance are as planned.

Effort-Driven Activity—see *Resource-Driven Activity*.

End of Day Convention—A convention adopted by most scheduling books assuming that when a day (date) is mentioned, it implies the end of that day. An end of a day is equivalent to the beginning of the next day. For this reason, network calculations start on day 0 (i.e. end of day 0) which practically means the beginning of day 1. Using this convention, the duration of an activity is equal to the difference between its finish date and start date.

Estimate at Completion (EAC)—The expected total cost of an activity or project when the defined scope of work is completed. $EAC = Actual\ Cost\ (AC) + Estimate\ to\ Complete\ (ETC)$.

Estimate-Generated Schedule—A list of project activities along with their durations, generated by the cost estimating software. The list does not form a CPM schedule because it lacks logic links (relationships) and other schedule attributes. It may help form the foundation of a schedule.

Estimate to Complete (ETC)—The projected cost to complete the activity or project from its present state.

Event—A point in time marking a start or end of an activity. Contrary to an activity, an event does not consume time or resources and while statusing (updating) a project, an event can be statused as “not started” or “complete,” but not “in progress.” In computer software, events with significance can be created as “milestones,” and they are either “Start Milestones,” such as “Notice to Proceed,” or “Finish Milestones,” such as “Substantial Completion.”

Exculpatory Clauses—Disclaimer verbiage that is designed to shift risk

Excusable Delay—A delay that entitles the contractor to additional time for completing the contract work. Excusable delays usually stem from reasons beyond the contractor’s control.

Exemplary Damages—see *Punitive Damages*.

Expected Duration—The expected duration of an activity is the duration expected to take (in PERT calculations), taking into account the different possible values (optimistic, most likely, and pessimistic durations) and their weights. It is the mean (mathematical average) duration and is calculated using the equation:

$$T_e = \frac{T_o + 4T_m + T_p}{6}$$

which is a form of the general equation:

$$\mu = \frac{1}{n} \sum_{i=1}^n x_i$$

Fast-Track Projects—Starting the construction process on a project while design is still underway (i.e., overlapping design and construction of a project). The PMI (PMBOK, 4th ed) defines fast-tracking as a “schedule compression technique in which phases or activities normally performed in sequence are performed in parallel.”

Finish Milestone—An event marking the completion of an activity(s) with special significance such as *Substantial Completion* of construction.

- Finish-Restricted Float (in Precedence Networks)**—The amount of time we can delay the start of work of an activity, or the rest of it if it has started, then finish on time without delaying the entire project.
- Finish-to-Finish (FF) Relationship**—A logic restraint that does not allow for the completion of one activity (the successor) until another activity (the predecessor) is completed.
- Finish-to-Start (FS) Relationship**—A logic restraint that does not allow for the start of one activity (the successor) until another activity (the predecessor) is completed.
- Float**—The maximum amount of time an activity can be delayed without violating certain conditions, depending on the type of float. See the specific type of float for exact definition. Float is sometimes called slack or leeway.
- Force Majeure**—An event or effect that cannot be reasonably anticipated or controlled, usually entitles the contractor for a relief from a contractual obligation, usually; an extension in time for the completion of the project.
- Forecast Cost Variance (FCV)**—The expected *Cost Variance (CV)* of an activity or a project after its completion, assuming the continuation of productivity and job conditions without change.
- Forecast Schedule Variance (FSV)**—The expected *Schedule Variance (SV)* of an activity or a project after its completion, assuming the continuation of productivity and job conditions without change.
- Forward Resource Leveling**—Leveling resources, starting from project start and going through all project activities, fulfilling their resource requirements and maintaining the total resource usage within the set limits. With such restrictions, some activities have to be delayed until resources are available and the project duration may be greater than planned, causing the finish date to occur later than originally scheduled.
- Forward Pass**—The process of going on a network from start to finish calculating the early dates for each activity and the project's completion date.
- Free Float**—The maximum amount of time an activity can be delayed from its *Early Start* date, without delaying the early start of the succeeding activities.
- Frequency of Updating**—The time interval between two regular schedule updates.
- Front-End Loading the Cost**—Overestimating early work activities and underestimating later work activities while maintaining the same overall contract sum. It is a practice done by some contractor to get early money. Owners dislike and often dispute this practice.
- Gantt Chart**—see *Bar Chart*.
- General Overhead**—see *Indirect Cost*.
- Graphical Evaluation and Review Technique (GERT)**—A network analysis technique that allows for conditional and probabilistic treatment of logical relationships (that is, some activities may not be performed).
- I-J Method**—see *Activity on Arrow (AOA) Network*
- Impact Schedule**—A schedule similar to the original (usually *As-Planned*) schedule but incorporating the causative factors (factors allegedly causing the schedule delays). By comparing the two schedules (original and impact), the contractor hopes to prove that the delay was caused by the alleged factors.

Imposed Finish Date—The project's completion date, as specified in the contract or stipulated by the owner.

Independent Float (Ind. F)—The maximum amount of time an activity can be delayed without delaying the early start of the succeeding activity(s), and without being impacted by the allowable delay of the preceding activities.

Indirect Cost—An expense that cannot be directly associated with a specific activity or work item such as overhead, profit, or insurance. If the expense can be attributed to a specific project, then it is job overhead; otherwise, it is general overhead.

Interfering Float (Int. F)—The maximum amount of time an activity can be delayed from its *early start* without delaying the entire project but causing delay to the *early start* of the succeeding activity(s). It represents the part of the Total Float that remains after deducting Free Float. Mathematically speaking, $\text{Int. F} = \text{TF} - \text{FF}$.

Interruptible Activity—An activity that can be performed in two or more separate segments. It is an activity that can be interrupted or paused.

Inventory Buffer—A theory in materials management that calls for all materials to be purchased, delivered, and stored on-site prior to installation.

Job Overhead—see *Indirect Cost*.

Just in Time—A theory in materials management that calls for delivering materials at time of installation only. Thus, not having any materials stored on-site.

Lag—A minimum waiting period between the finish (or start) of an activity and the start (or finish) of its successor.

Lane Rental Bidding/Contracting Method—The lane rental contracting method is an innovative contracting technique by which a contractor is charged a fee for occupying lanes or shoulders to do the work. Under this system, the owner (usually the public agency) assigns an hourly or daily charge for closing a lane or shoulder and charges the contractor for the closure. The objective of the method is to motivate contractors to minimize closures on high-volume roadways and/or during high volume time. This method is similar to the *A+B Bidding/Contracting Method*.

Late Dates (for an activity)—The *Late Start* date and *Late Finish* date of that activity.

Late Finish (for an activity) (LF)—The latest date that activity can finish without extending the project duration.

Late Start (for an activity) (LS)—The latest date that activity can start without extending the project duration.

Lead—A negative *Lag*.

Lean Construction—Lean construction is a holistic facility design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic, and continuous improvements in the contractual arrangements, the product design, the construction process design and methods selection, the supply chain, and the workflow reliability of site operations (Dr. T. Abdelhamid, https://www.msu.edu/user/tariq/Learn_Lean.html). Another definition by (Koskela et al. 2002): Lean construction is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value.

Least-Cost Duration—The duration of an activity associated with the *Least Cost Schedule*

Least-Cost Schedule—A CPM schedule accelerated to reach the point where the total cost of the project (direct and indirect) is minimum. If the duration of the schedule increases or decreases, the total cost will increase.

Linear Scheduling Method (LSM)—A scheduling method that consists of a simple diagram showing location and time at which a certain crew will be working on a given operation. It is most suited for construction projects with few linear activities (usually with large quantities) that have to be done in the same order or sequence but can, and do, overlap. For example, heavy construction projects such as roads, earthwork, or utility piping.

Line of Balance (LOB) Method—see *Linear Scheduling Method (LSM)*

Liquidated Damages—A stipulation in a contract of a monetary amount that must be paid by the contractor if the contractor fails to satisfactorily complete the project by the contract finish date. Liquidated damages are usually assessed per day of delay and they may increase after a certain amount of days, for example, \$1,000 per day for the first week, then \$1,500 per day for the second week, and on.

Litigation—The process of carrying on a legal contest by judicial process. The parties submit their disputes to the jurisdiction and procedures of federal or state courts for resolution.

Logic Loop—A circular logical relationship between two activities in a network, that is, each one is a predecessor and a successor to the other one. A loop is an error that must be corrected or else CPM calculations (whether manually or by computer) will halt.

Logic Network—A diagram showing project activities and their logical relationships (interdependencies)

Logical Relationship—The interdependency of the activities in a network: One activity (the *Predecessor*) has to finish (or start) before another (the *Successor*) can start (or finish), with or without a *Lag*. There are four types of logic relationships: *finish-to-start, start-to-start, finish-to-finish, and start-to-finish*.

Look-Ahead Schedule—A segment of the overall schedule that includes only activities that have work planned during a certain period of time such as the next month or the next two weeks. Project managers may use *Look-Ahead Schedules* to focus on the immediate future activities.

Loop—see *Logic Loop*

Man-Hour Ratio—A method of measuring percent complete of an activity (or a project) by distributing (linearly or using other curves) the budgeted man-hours over the duration of the activity (or project). Percent complete = Actual Man-Hours/Total Man-Hours. This method is similar to *Cost Ratio* method except for using man-hours instead of money

Master Schedule—A CPM schedule that includes more than one *Subschedule*. Typically, a general contractor requires his subcontractors to submit their schedules then incorporate them as *Subschedules* in his *Master Schedule*, which shows all work items in the project. Relationships in a *Master Schedule* may be internal, that

is, within the same *Subschedule*, or external, that is, between activities from two different *Subschedules*.

Materials Management—The planning and controlling of all necessary efforts to ensure that the correct quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed.

Mediation—A method of trying to resolve a dispute by the use of an impartial intermediary to suggest ways to settle the dispute, rather than imposing a decision upon the parties.

Milestone—An event marking the start or completion of an activity with special significance. A milestone can be a *Start Milestone* or a *Finish Milestone*.

Monte Carlo Simulation—The technique used by project management applications to estimate the likely range of outcomes from a complex random process by simulating the process a large number of times.

Most Likely Duration—The duration believed to have more likelihood of occurring than any other duration

Negative Float—A situation occurs when performing an activity even on its early dates, fails to meet the project's imposed finish date or other constraint

Negotiation—When two or more parties with competing interests discuss an issue with the aim of reaching an agreement. It is the first step towards resolving claims.

Network—A graphical representation of the activities (and events) composing the project, in a logical and chronological depiction. Network diagrams are basically of two types: *arrow networks* and *node networks*. Arrow networks are also called *arrow diagramming method* (ADM), *activity on arrow* (AOA), or the *I-J method*. Node networks are also called *activity on node* (AON) or Node Diagramming Method. Precedence diagrams or *precedence diagramming method* (PDM) are an advanced form of node networks.

Non-Compensable Delay—A project delay beyond the control, and not the fault of, the owner such as unusual weather conditions, natural disasters (earthquakes, floods, hurricanes, etc.), wars or national crises, and labor strikes. Such delays usually do not entitle the contractor to monetary compensation but most likely entitles him to a time extension.

Nondriving Relationship—A relationship between a predecessor and a successor that does not affect the current activities dates. If a nondriving relationship is omitted, the CPM calculations—including all activities start and finish dates—should not change. However, a nondriving relationship may become driving if network conditions change such as activities' durations or logic, or if activities are added or deleted.

Nonexcusable Delay—A delay that does not entitle the contractor to either time extension or monetary compensation.

Nonworkdays—Days on which no work is/was performed, such as holidays, rain days, shutdowns, and the like. Nonworkdays are two types: known, such as holidays and scheduled shutdowns, and unknown, such as weather days and unscheduled shutdowns

Normal Cost—The cost of a project that is performed under *Normal Duration*.

Normal Distribution—A probability distribution forming a symmetrical bell-shaped curve.

Normal Duration—The amount of time it takes to finish the project under ordinary circumstances without any deliberate delay or acceleration.

Optimistic Duration—Optimistic duration is the amount of time an activity is expected to take if everything goes smoothly and efficiently within the realistic—even though may not be the likely—realm of expectations.

Original Duration—The number of time units (days, weeks, months, etc.) estimated to complete an activity that has not started yet.

Overhead—see *Indirect Cost*.

Overlapping Activities—Two activities are said to overlap when the successor starts while the predecessor is in progress. Mathematically speaking, the duration of the combination of the two activities is less than the summation of the two activities' durations

Payment Request (Pay Request, Payment Requisition)—A formal written request for payment by a contractor or subcontractor for work completed on a contract and—if allowed for in the contract—materials purchased and stored on the job site or in a warehouse, during a specified period of time. Subcontractors submit their payment requests to the general contractor, who combines them with his or her own in one total payment request to the owner. Typically, this process is done on a monthly basis.

Percent Complete—See *Activity Percent Complete* or *Project Percent Complete*

Pessimistic Duration—The duration under almost the worst case scenario within the realistic—even though it may not be the likely—realm of expectations.

Planned Value (PV)—see *Budgeted Cost for Work Scheduled (BCWS)*

Portfolio—A group of projects, not necessarily related or dependent, usually under one project manager or department. The PMI defines it as a collection of projects or programs, and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives.

Precedence Diagramming Method, PDM—A node network (see *Activity on Node Network*) that allows for the use of four types of relationships: finish-to-start (FS), start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF)

Precedence Network—See *Precedence Diagramming Method*

Predecessor Activity—An activity that has to finish (or start) in order for the succeeding activity(s) to start (or finish). It has been also defined as an activity that has some measurable portion of its duration logically restraining a subsequent activity or activities.¹

Probability Density Function (PDF)—A function used to compute probabilities for a continuous random variable at a certain value. The area under the curve of a probability density function over an interval represents probability (chance of occurrence): $f(x) = \Pr(X = x)$

¹ Theoretically, this portion can be zero, but practically it has to be greater than zero.

Probability Distribution—A function or mathematical model that describes all the values that the random variable can take and the probability (chance of occurrence) associated with each. Also called a probability function.

Probability Universe—The set of the values of all possible outcomes for a random variable.

Procurement—The process of acquiring materials, equipment, and/or services from external sources for use in the project. It is a process that usually starts long before the start of the construction process, and ends with project completion or closeout.

Professional Engineer (PE)—An engineer licensed by an authority (usually the government of the state) after fulfilling certain requirements (minimum experience and passing an exam).

Pro Forma—A projection or estimate of the cost/benefit ratio or rate of return on an investment. Project owners and investors usually use a pro forma to help them make a decision whether or not to carry out the project. Typically, a pro forma includes all expected costs (initial, recurring, and occasional) and expected revenues throughout the lifecycle of the project, then calculates the rate of return.

Program—A program is a group of related projects and/or services intended to meet a common objective and usually managed by one entity. A program could also indicate a large and complex project that is divided into several projects for more effective management. The PMI defines a program as a group of related projects managed in coordinated way to obtain benefits and control not available from managing them individually. Programs may include elements of related work outside of the scope of the discrete projects in the program.

Program Evaluation and Review Technique (PERT)—An event-oriented network analysis technique used to estimate project duration when there is a high degree of uncertainty with individual activity duration estimates. PERT applies the critical path method to a weighted average duration estimate. PERT is considered a probabilistic method. The name “PERT Diagram” is incorrectly used in the construction industry sometimes to denote a *Logic Network*.

Progress Override—An option used in Primavera scheduling software to ignore a logic relationship between two activities after actual work has violated this logic. For example, if activity A is a predecessor (with FS relationship) to activity B but activity B has started before activity A is completed, this option allows the remainder of B to proceed without regard to the completion of A. See also, *Retained Logic*.

Progress Payments—Periodic (usually monthly) payments made by the owner to the general contractor (and from the general contractor to the subcontractors) upon the approval of the *Payment Request*. Owners usually retain a portion of the *Progress Payment* (5–10% typically) till the successful completion of the project.

Progressive Elaboration—The continuous evolution of the project design documents along with its impact on the project’s cost estimate and schedule. Unlike *Scope Creep*, progressive elaboration is not considered a negative practice since it represents the changing in project’s attributes (cost, schedule) as project scope gets more clarified as a result of the development of the design documents.

Project—A temporary endeavor undertaken to create a unique product, service, or result (PMI PMBOK, 2008)

Project Breakdown Structure (PBS)—A task-oriented family tree of activities that organizes, defines, and displays the work to be accomplished. See *Work Breakdown Structure*

Project Charter—Project charter is a statement of the scope, objectives and participants in a project. It provides a preliminary delineation of roles and responsibilities, outlines the project objectives, identifies the main stakeholders, and defines the authority of the project manager. It serves as a reference of authority for the future of the project (Source: Wikipedia online).

Project Closeout—The full completion of a project signed off by all responsible parties and the finalization of all paperwork and payments.

Project Control—The continuous process of: Monitoring work progress, comparing it to *Baseline Schedule* and *Baseline Budget* (what was supposed to happen or what was planned), finding any variances (deviations from baselines), where and how much; analyzing the variances to find out the causes, and then taking corrective actions whenever and wherever necessary to bring the project back on schedule and within budget.

Project Cost Breakdown—see *Schedule of Values*

Project Management Office (PMO)—The Project Management Office in an organization is the department or group that defines and maintains the standards of process, generally related to project management, within the organization.

Project Management Plan—A formal, approved document used to guide both project execution and project control. The primary uses of the project plan are to document planning assumptions and decisions, facilitate communication among stakeholders, and document approved scope, cost, and schedule baselines. A project plan may be summary or detailed.

Project Management Team—The individuals involved in the management of a project. This involvement can be in different capacities, at different levels, or at different times. The team is usually led by the *Project Manager (PM)*.

Project Manager (PM)—The individual responsible for managing a project and its completion within its scope, budget, and schedule.

Project Monitoring—A term sometimes used to mean project control. Technically, it includes the first three functions of *Project Control* (monitoring, comparing, finding).

Project Percent Complete—A completion percentage of the work in a project based on a chosen method of measuring work progress.

Project Plan—See *Project Management Plan*

Project Planning—The process of choosing the one method and order of work to be adopted for a project from all the various ways and sequences in which it could be done. Project planning serves as a foundation for several related functions such as cost estimating, scheduling, project control, quality control, safety management, and other.

Project Risk—“An uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective, such as time, cost, scope, or

quality. A risk may have one or more causes and, if it occurs, one or more impacts.” PMI’s PMBOK, 4th edition.

Project Scheduling—The determination of the timing and sequence of operations in the project and their assembly to give the overall completion time. Scheduling takes one part of the planning effort and zooms in on it.

Project Tracking—see *Project Control*.

Punch List—A list made near to the completion of a project showing the items of work remaining in order to complete the project scope.

Punitive Damages—Damages awarded by a judge to a plaintiff in excess of those required to compensate the plaintiff for losses incurred. Used to punish the defendant for wrongful conduct and to show the plight of the defendant as an example to potential wrongdoers.

Qualitative Analysis—The determination of the likelihood of a risk occurring on the project as well as assessing the severity of that risk should it occur, and prioritizing the resultant list of risks.

Quantitative Analysis—The assigning of a probability to the qualitative description of the risk, ranking the risks, and calculating the potential impact from both individual risks as well as the cumulative effect of all risks identified.

Rain Days—See *Nonworkdays*.

Recovery Schedule—A schedule prepared during the course of construction, after the project had fallen behind (either failed to meet an interim target or showed serious signs of failure to meet its expected completion date), with adjustments made by the contractor to expedite the remainder of the project to ensure a timely finish.

Redundancy—A duplication in depicting logical relationships. For example, if A and B are predecessors to C but A is a predecessor to B, then the relationship between A and C is redundant. Redundancies often happen when inserting activities after the logic network has been built. Unlike *Logic Loops*, a redundancy is not an error and it will not halt CPM calculations.

Relationship—See *Logic Relationship*

Remaining Duration—The number of time units (days, weeks, months, etc.) estimated to complete an in-progress activity.

Request for Change (RFC)—A request initiated by the owner, or the party representing the owner, authorizing the contractor for a change in the scope of the contract. The request is usually—but not always—preceded by an agreement on the impact of the change on the cost and schedule of the project.

Request for Information (RFI)—Solicitation issued to prospective bidders that is used to obtain information relative to how a prospective contractor proposes to perform certain work, its qualifications, and terms and conditions. Not used to obtain price information.

Request for Payment—see *Payment Request*.

Request for Proposal (RFP)—A formal invitation by the owner or its representative to potential bidders containing a scope of work that seeks a formal response (proposal) describing both methodology and compensation to form the basis of a contract.

- Request for Quotation (RFQ)**—A formal invitation to submit a price for goods and/or services as specified.
- Resource**—Any measurable effort or substance that is required or consumed by work activities in a project. In context of construction projects, resources are labor, materials, and equipment.
- Resource Allocation**—The assignment of the required resources to each activity, in the required amount and timing.
- Resource Constraint**—A type of constraint that subjects the start and continuity of an activity to the availability of required resources. See *Resource Allocation*, *Resource-Driven Activity*, *Resource-Driven Schedule*, and *Resource Leveling*.
- Resource-Driven Activity**—An activity where duration is calculated based on availability of required resources. Typically, several activities compete for limited resources and the scheduler has to set the priority rules among them.
- Resource-Driven Schedule**—A CPM schedule with some or all activities are *resource-driven*. Logic relationships still apply in addition to resource constraints.
- Resource Histogram**—A display of the number of units required (for future work) or consumed (for past work) of a specific resource during a specified period of time. The user can view the usage per unit of time or the cumulative usage. The user can compare the resource usage to the resource limit (availability). The histogram may plot the resource usage in terms of number of units or cost.
- Resource Leveling**—Minimizing the fluctuations in day-to-day resource usage throughout the project. It is usually done by shifting non-critical activities within their available float. It attempts to make the daily use of a certain resource as uniform as possible.
- Resource Loading**—See *Resource Allocation*
- Resource Usage Profile**—see *Resource Histogram*
- Restraint**—see *Constraint*
- Retainage**—A portion of the eligible *Progress Payment* that is held by the owner till the contractor fulfills his contractual obligations. The contract usually specifies the amount and conditions of the retainage. In large projects, it is customary to either reduce the retainage percentage or stop retaining any money by the owner after the project reaches certain completion stage such as 50% complete. Also called *Retention*.
- Retained Logic**—Maintaining a logic relationship between predecessor and successor activities even though the successor has violated this logic and started before the predecessor has finished. In other words, the rest of work in the successor activity will still have to wait till the rest of work in the predecessor activity is completed.
- Retention**—See *Retainage*
- Risk**—See *Project Risk*
- Risk Allocation**—A determination of how to respond to risks, which can include shifting risk, avoiding risks, preventing or eliminating risks, and incorporating risks into the schedule
- Risk Management**—Systematic process of identifying, analyzing, and responding to project risk (PMI's PMBOK, 4th Edition). A process designed to examine

uncertainties occurring during project delivery and to implement actions dealing with those uncertainties in order to achieve project objectives

Risk Register—A checklist of potential risks developed during the risk identification phase of risk management

Roll-up Schedule—see *Summary Schedule*.

S-Curve—A cumulative curve plotting work progress against time. Work progress may be expressed in terms of units of work, budget, man-hours, percent complete, or other. The curve loosely resembles the letter S because work typically starts at a light scale then intensifies towards the middle of the project, and finally lightens up again towards the end of the project. The curve is sometimes called “Lazy S-curve”.

Schedule—A display of project activities and events along with their timing plotted chronologically against a calendar. A schedule may or may not be based on the *critical path method*, CPM.

Schedule Acceleration—see *Schedule Compression*.

Schedule Compression—Shortening the project’s schedule without reducing the project’s scope to meet certain time and/or cost objectives. Schedule compression usually—but not always—increases project cost and often has physical limitation to how much it can be shortened

Schedule Contingency—An amount of time added to the base-estimated duration to allow for unknown impacts to the project schedule, or to achieve a certain level of confidence in the estimated duration.

Schedule Crashing—see *Schedule Compression*.

Schedule of Values—A listing of elements, systems, items, or other subdivisions of the work, establishing a value for each, the total of which equals the contract sum. The schedule of values is used for establishing the cash flow of a project and serves as the basis for payments requests (*R.S. Means Construction Dictionary*, 4th ed., 2010). Also called project cost breakdown or simply cost breakdown.

Schedule Performance Index (SPI)—The ratio of work performed to work scheduled. SPI = BCWP/BCWS or SPI = EV/PV.

Schedule Updating—Reflecting actual performance information on the schedule, in time of occurrence and amount (or percentage) of performed work, as well as implementing any changes to the future work on the schedule.

Schedule Variance (SV)—The difference between work performed and work scheduled. SV = BCWP – BCWS or SV = EV – PV.

Scheduler—A project scheduling professional in charge of preparing and updating a CPM schedule for a construction project. The scheduler is also responsible for producing reports required by the management, pertaining to the schedule.

Scheduling—See *Project Scheduling*.

Scope Creep—The continuous and gradual expansion of the scope of a project (size, area, design, materials, etc.) after the contract has been signed, as a result of multiple and successive owner-issued change orders. Scope creep usually results from the owner’s lack of scope vision, lack of appreciating the impact of changes on cost and schedule, unrealistic expectations, decentralized decision making,

and/or other factors. It usually results in negative consequences to the owner including the reduction of the value obtained in the project

Sequestering the Float—Eliminating or reducing the float of an activity or activities by inflating durations, inserting unnecessary logic relationships, inserting unnecessary lags, or a combination of these procedures. This is a technique practiced by some contractors in order to maintain inconspicuous ownership of the float. Most owners dislike this practice and disallow it by inserting a “no sequestering the float” clause in the contract.

Settlement—An agreement by which the parties consent to settle a dispute between them.

Single-Restricted Float—Activity float that is restricted from its start or finish, not both. See Start-Restricted Float and Finish-Restricted Float

Slack—see *Float*

Soft Logic—See *Resource Constraints*

Standard Normal Distribution—A normal distribution with the parameters mean, $\mu = 0$ and standard deviation, $\sigma = 1$. The random variable for this distribution is denoted by Z. The z-tables (values of the random variable Z and the corresponding probabilities) are widely used for normal distributions.

Start Milestone—An event marking the start of an activity with special significance such as Notice To Proceed (NTP).

Start-Restricted Float (in Precedence Networks)—The amount of time we can delay the rest of the work in an activity after it has started on its critical start date, without delaying the entire project.

Start-to-Finish (SF) Relationship—A logic restraint that does not allow for the start of one activity (the successor) until another activity (the predecessor) is completed.

Start-to-Start (SS) Relationship—A logic restraint that does not allow for the start of one activity (the successor) until another activity (the predecessor) has started.

Status date—see *Data Date*.

Store Period Performance—A function in Primavera software that adds the latest “Cost this Period” to the “Cost to Date,” then makes “Cost this Period” zero. This is a practice the scheduler has to do every time there is a schedule update along with a *Payment Request*.

Stretchable Activity—An activity with flexible duration that increases or decreased to accommodate the amount of available resources or other restrictions. The activity duration of a *stretchable activity* is determined by the CPM calculations under user’s resource and/or other restrictions

Submittal—A sample, manufacturer’s data, shop drawing, or other such item submitted to the owner or the design professional by the contractor for the purpose of approval or other action, usually a requirement of the contract documents.

Subschedule—Generally, a subschedule is portion of a larger schedule based on certain criteria, such as responsibility, area, phase, period of time, or others. It is a common practice to refer to the schedule reflecting the work of one subcontractor or other single participant in the project as a subschedule. A subschedule may have

starting date, completion date, and/or duration usually different from the *Master Schedule*.

Substantial Completion—The point in time when the project is ready for use by the owner for the purpose intended and is so certified. See *Certificate of Substantial Completion*.

Successor Activity—An activity that cannot start (or finish) until another activity (predecessor) has finished (or started).

Summary Schedule—A schedule (usually *Bar Chart*) where activities are summarized (combined) by a certain criterion such as responsibility, phase, or area. If Work Breakdown Structure (WBS) is used, it is possible to summarize (roll up) the schedule at any level higher than the individual activity. Summary schedules are usually used to inform upper management about the overall project situation without too much detail.

Sunk Cost—Cost already incurred which could not be avoided even if the project were to be terminated. It cannot be recovered regardless of future events.

Target Schedule—see *Baseline Schedule*.

Task—see *Activity*.

Time Contingency—see *Schedule Contingency*.

Time Plus Cost Contracting Method—See *A+B Contracting Method*

Time Ratio—A method of measuring percent complete for an activity (or a project) by dividing actual duration by the total duration. This method works well for activities with uniform work over its duration. The method has also a variety of ways of calculations, mainly using actual or planned durations.

Time-Scaled Logic Diagrams (or Bar Charts with Relationships)—A bar chart with logic relationships (all or driving) depicted.

Total Float (TF)—The maximum amount of time an activity can be delayed from its early start without delaying the entire project.

Turn-Key Project—A turn-key project a project in which a builder/developer contracts to construct a completed facility that includes all items necessary for use and occupancy. All that is required of the buyer to begin using the facility is to turn a key in the new door lock and enter. (Source: <http://www.teachmefinance.com/>) The term turn-key does not indicate a specific contracting or delivery method, but in most cases, it implies a design-build (DB) contract.

Units Completed—A method of measuring percent complete for an activity that is made up of small, similar, and repetitive units of work. Percent complete = completed units/total units. This method can be applied to the entire project if the project can be divided into similar type of work such as road construction or earthmoving projects.

Unrestricted Float (in Precedence Networks)—The amount of time we can delay all or part of that activity from its early start without delaying the entire project.

Updated Impact Schedule—A method developed by the U.S. Corps of Engineers for helping resolve delay claims. The concept is to create an *As-Built Schedule* or updated schedule from the start of the project only to the point just before the delay occurred. The “original” or baseline schedule is updated with progress

information, and then compared to the impacted completion date on another schedule on which a delay is included.

Updated Schedule—A revised schedule reflecting project information at a given data date regarding completed activities, in-progress activities, and changes in the logic, cost, and resources required and allocated at any activity level (Popescu and Charoenngam, 1995, p. 566)

Value Engineering (VE)—A science that studies the relative value of various materials and construction techniques. Value engineering considers the initial cost of construction, coupled with the estimated cost of maintenance, energy use, life expectancy, and replacement cost.

Work Breakdown Structure (WBS)—A task-oriented detailed breakdown of activities that organizes, defines, and graphically displays the total work to be accomplished in order to achieve the final objectives of a project. The WBS breaks down the project into progressively detailed levels. Each descending level represents an increasingly detailed definition of a project component. In CPM scheduling, the components at the lowest WBS level are used as activities to build the project schedule.

Workdays—Days on which work was or can be performed.

Work Package—A well-defined scope of work that terminates in a deliverable product or completion of a service.

Zero Free Float—See *As Late As Possible*

Zero Total Float—A constraint in some computer scheduling programs that assigns a total float value of zero, causing the Early Dates to equal the Late Dates of the activity.

Z-function—see *Standard Normal Distribution*.

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an easy-to-follow guide to the theory and practice of project scheduling and control



NO MATTER HOW LARGE OR SMALL THE CONSTRUCTION PROJECT, an efficient, well-thought-out schedule is crucial to achieving success. The schedule manages all aspects of a job, such as adjusting staff requirements at various stages, overseeing materials deliveries and equipment needs, organizing inspections, and estimating time needs for curing and settling—all of which requires a deep understanding on the part of the scheduler.

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