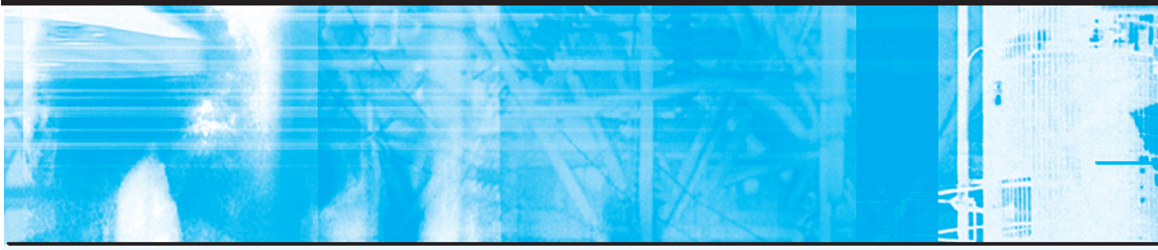


PART 5

Tools for Managing Services

Major operational decisions in service firms are often made on the basis of "gut feel." The instinct of grizzled veterans was often the only source consulted to make decisions such as granting a loan, locating a hotel, or determining employee requirements. The tide, however, is turning. As one executive of Southland Corporation (7-Eleven stores) put it: "Retailing used to be an art—now it's a science." The same can be said about services in general. In this section of the book we will look at some tools for aiding managerial intuition.

This section can add distinctive value to a business career. A business degree cannot confer the wisdom, connections, and practical know-how of 30 years' experience in a particular industry. What this section can deliver is new thinking and new methods those 30-year veterans have never seen—it brings new skills to old and important problems.

The business decisions discussed in this section represent high-impact and high-dollar decisions. Applying the methods discussed here to a business run primarily according to "gut feel" can create enormous benefits to both the business and an individual decision maker's career.

For example, deciding on the best location for a business (Chapter 16) can be THE key decision that forever limits or assists unit profitability, regardless of the unit's management. Likewise, developing a system for allocating resources to customers and determining which customer groups to target (Chapter 18) are not decisions made every day, but they profoundly affect a business.

The tools described here are quantitative in nature. This should not, however, be cause for alarm. None of the tools described here require higher-level mathematical preparation. Further, the chapters focus on using these tools, rather than creating them, leaving the mathematical complexities to more technical books. To a large extent, the purpose of Part 5 is to develop knowledge of when to use a tool, rather than attempting to create "mathematical masters." The goal is to give enough context so that, years from now, well after the details of this book recede from memory, a businessperson will know when to pick up the telephone and call for help.

CHAPTER

15

Real-World Project Management[1]

LEARNING OBJECTIVES *The material in this chapter prepares students to:*

- Understand and appreciate the characteristics and complexities of real-world project management.
- Identify factors that influence both success and failure in project management.
- Learn both qualitative and quantitative techniques critical to successful project management.
- Make qualified decisions related to time, cost, and performance trade-offs when managing projects.
- Develop, analyze, and interpret quantitative tools for managing uncertainty in project management.

In this chapter, we delve into the real world of project management not only to develop an understanding of leading-edge tools, methods, and techniques, but also to gain an understanding of what is required for success. The real world is complex, uncertain, messy, and often indeterminate with no clear right or wrong answer to the issues and problems organizations face. Perhaps nowhere is this reality more evident than in project management.

Characteristics of Project Management

Projects constitute the most pervasive process of business administration. Whether in finance, marketing, management information systems, or any other functional area, projects are part of everyday business life and represent a principal means for getting work done. A project consists of an interrelated set of activities designed to achieve a set of business objectives with defined resources and within a specified timeline. A well-planned project specifies what needs to be done, when it needs to be done, and the resources required to do so. Many times, however, things are not so well specified.

Typically, project objectives are defined in terms of deliverables. Deliverables are the work products that are created during the course of a project. Tangible deliverables include financial reports, remodeled homes, or a spacecraft. Deliverables can also be intangible, nonphysical items that are nevertheless clearly defined achievements. Examples of intangible deliverables include software programs, user training,

1. This chapter was written by Michael Ketzenberg, Assistant Professor at the College of Business, Colorado State University.

and corporate mergers. The sheer plethora of deliverables and countless methods for producing them makes each project a unique undertaking. Even so, from small well-defined projects like painting a house to monumental endeavors like putting a man on the moon, many of the same methods and techniques for project management can be applied to achieve their disparate objectives. In fact, although projects clearly vary in degree with respect to their magnitude and complexity, they all share, to one extent or another, the following common characteristics.

Unique One-Time Focus

One of the difficulties inherent in successful project management results from its originality. It's a one-shot deal that has never been accomplished before. Whether a project is defined as the development of a new software program, as coordinating and planning the merger of two organizations, or as a project of any other type and size, a given project represents new challenges. Even though hundreds of thousands of software programs have been developed and a large number of corporations merged, each occurrence is distinct. There has only been one Windows 95 and only one R. J. Reynolds and Nabisco merger, for example. This important point helps clarify the common project characteristic in the following discussion.

Subject to Uncertainties

Often, unexplained and unplanned events arise during project implementation that can affect resources, objectives, and timelines. Because projects are unique and represent new business endeavors, they are subject to uncertainties. It may be unclear whether the project objectives can in fact be achieved. For example, most new product development projects fail. Even small-sized projects often require new combinations of skills and resources that create uncertainty with respect to project success.

Multiple Stakeholders

By stakeholder we refer to any person or entity with a vested interest in the outcome of a project. This vested interest can take the form of customers who use the project results, companies that pay for a project, and project team members themselves who are responsible for the outcome. Most projects answer to several stakeholders. Take, for example, a typical consulting engagement. A company (buyer) engages the consulting company to help implement a project. The consulting company forms a project team headed by a partner of the firm and comprised of various managers and associates. The same team formation occurs on the side of the purchasing company, meaning that often the two teams work together and take responsibility for the outcome. The set of stakeholders, however, is not necessarily limited to these two teams, the project managers, and the companies involved. Consider also that these companies may be publicly owned. Large-scale, highly visible projects that involve public companies also face stockholders as stakeholders in the project. A clear example came as the U.S. Defense Department awarded to Lockheed the largest-ever, $200 billion project to develop the Joint Strike Fighter.

The difficulty with multiple stakeholders arises from their different interests in both the processes and outcomes of a project. What a team member on a project values may be entirely different from what a stockholder values. As a consequence, multiple stakeholders induce an added level of complexity to project management.

Finite Lifetime and Limited Resources

A project is generally constrained by limited resources and a fixed period of time available for completion. As a result, mistakes, delays, poor communication, and problems with coordination seem more pronounced and may even be more difficult to overcome. Many times, second attempts are not an option.

No Clear Authority

In many projects, particularly those that involve people and other resources from multiple functional areas, or even those that span organizational boundaries, the chain of command in a project may conflict with the formal management structures of the participating organizational units. An often-heard expression is that project managers are "given all the responsibility, but none of the authority;" that is, the project manager is held accountable for project success, but is not necessarily in full control of project resources.

This type of situation often occurs in matrix organizational structures. A matrix structure arises when project teams are formed with individuals that span multiple functional areas (e.g., accounting, finance, marketing, and operations). Individuals in these functional areas typically report to an immediate boss or supervisor in their own area. As such, a project team member who works on a particular project may be responsible to a project manager who resides in another department, in addition to his or her immediate supervisor. In this type of situation, problems can arise, particularly when resources are tight and priorities conflict. What can the project manager do when a team member becomes unavailable due to the request of another supervisor? Difficulties are compounded when project team members work on multiple projects simultaneously. Not only is it clear that project managers do not fully control their resources, but it can be difficult for project team members to prioritize their work. Hence, when managers plan the timing of project activities, considerable uncertainty surrounds the availability of resources. Consider further the consulting engagement example discussed earlier. The consulting firm may be responsible for directing and coordinating the work of the client firm employees, but clearly issues arise over the authority of the consulting firm to direct the work of the client employees. Yet these instances are common and present a constant challenge to successful project management.

These characteristics, whether considered individually or collectively, help clarify impediments to success in real-world project management. Nevertheless, successful projects are completed all the time. Even when we talk about successful project management, however, the definition of success itself can prove elusive. How do we know a project is a success or failure? Sometimes the answer is self-evident. When a rocket explodes on the launch pad or an architectural firm wins a design competition for a new building, success or failure is palpable and clear. In many, if not most cases, however, the definition of success is considerably less clear.

Consider, for example, when a new computer operating system is introduced in the market place. Is success measured by a certain level of technological achievement, by revenues, by market share, by the level of critical acclaim, or perhaps by some combination of factors? If the definition of success itself is not clearly understood, then how will it be possible to be successful? In the next section, we provide a framework for qualifying success and failure in project management.

Measuring Project Success

Among other more notorious lies like, "the check is in the mail," is the adage that "successful projects are completed on time, within budget, and to specifications." Although it may seem reasonable on face value to make such a claim, by this definition of success, there would be no successful projects—certainly not for projects of any meaningful or significant size. Many, if not most projects, are delivered late, come in over budget, or do not satisfy all requirements specified at the project inception. Yet, many of these projects are still considered successful.

In the real world, with real project management, projects are fluid and dynamic processes, subject to change and uncertainty, such that (1) nothing goes as planned, and (2) nothing goes as planned. Implementing a project resembles a journey. The destination may be clear, but the process is uncertain. Detours and sidetrips are possible, and the destination itself may even change en route. With respect to project management, resource levels may change, so too requirements, along with timetables. Hence, when the actual and completed project is compared with what was planned, the inevitable and perhaps significant deviations would eliminate a determination of success according to the prior definition. Yet, even with changes, problems, and the uncertainties that arise in project management, there are many successful projects. Consider, for example, the release of Windows 95, which was not only delayed for several months but was shipped with several bugs, and many planned features were dropped from the initial release. Nevertheless, no one will deny that by obtaining a 90% share of the market for personal computer operating systems, the Windows 95 product launch (and its successors) proved to be a success. So, how do we know whether any given project is a success?

The answer is at once simple and complicated. It is simple because the best determination of success is by those with a vested interest in it—the stakeholders. We say that project success lies in the eye of the stakeholder. A significant complication arises, however, when multiple stakeholders hold different interests, values, and objectives, which can and do change over time.

Take the consulting engagement example we discussed earlier. Success for the client may be measured, say, in how much operating costs are cut after project completion. For the consulting company, success may be measured in terms of the revenue generated by the engagement. Are the two linked? Perhaps, but there is no reason that a given project will be successful under both measures. The complication does not end there either. Consider the project manager from the consulting firm. It may be that the project manager is using the client engagement as a platform for promotion. Now, add in the project team members' different measures for success. Which measure or measures are valid or most important? Which measures are conflicting?

The answer depends on the project in question and the stakeholders involved, but it clearly brings up an important and significant consideration. Not all stakeholders are created equal. It is absolutely critical, in managing a project, that the stakeholders are identified, prioritized, and their measures of success well understood. Hence, a critical factor to successful project management is a thorough understanding and dissemination of project objectives so that project results can ultimately be measured in a manner that delineates and rationalizes the vested interests of the stakeholders. In this way, it is then possible to focus on the methods for achieving the specified results.

Understanding that success is in the eye of the stakeholder, and hence, "we will know it when we see it," is but a first step. The next logical step is realizing the processes necessary to achieve the desired success. Because any project includes far greater opportunities for things to go wrong than to go right, a good starting point for understanding the factors critical to success is to address the common causes for failure.

Qualitative Methods for Achieving Success

Experience is the great educator in life: Experience brings failure and through failure rises success. The United States did not launch a rocket to the moon on its first try. We might say mission control was very experienced. In a like manner, a successful project manager, unless extremely lucky, will have experienced prior failures and consequently perhaps knows more about what to do to avoid failure rather than what to do to generate success. From this perspective, we lay the groundwork for achieving success in project management as we discuss common causes for project failure and methods to avoid them.

Living in an Uncertain World

As we stated previously, the real world is subject to uncertainties, and real-world project management is no exception. The surest way to set a course for failure is to be unprepared for uncertainty. Stuff happens, problems arise, and plans must change. In other words, we can be absolutely 100% certain that the actual implementation of a project will *not* be done in accordance to the initial project plan. Hence, plans that do not account for uncertainty are considerably more likely to fail than those that do.

Uncertainty implies that the path to success lies in conservative planning. For example, resources should not be fully loaded at 100% utilization. If an employee is scheduled to work 40 hours a week, the project plan should not count on 40 hours of work. Although the precise number is hard to determine, a target of 80% for planned use of available hours is common, particularly in consulting. Lower utilization means flexibility to handle problems and issues as they arise during project implementation. It also means that planned work will take longer to complete, but it provides a conservative approach that also establishes the opportunity to exceed expectations—another critical issue to which we proceed.

Managing Expectations

Meeting the expectations of stakeholders is critical because the determination of project success resides with them. Managing expectations means monitoring and controlling them as they change over time. Hence, from the perspective of managing a project to success, it is important to not only understand those expectations, but to positively influence them over time as well.

To positively influence expectations means being positioned to exceed them. To do so requires a conservative approach to project planning. As we discussed, without conservative planning, the flexibility to handle problems or issues as they arise is absent. In turn, when problems do arise, the communication with stakeholders can only be negative—higher costs, extended deadlines, and other negative events. Conservative planning builds in a cushion to absorb issues and problems as they arise, which minimizes or eliminates negative communication. Furthermore, when things go right and problems are avoided, the project can be completed in less time, with fewer resources, and lower costs. Without conservative planning, the best that can be done is to meet expectations.

Conservative planning is but one example of managing expectations effectively. In fact, the need to manage expectations highlights a key set of skills required of project managers. Not only must a project manager be competent with respect to the technical skills and resources to do the project work and the managerial skills to plan and control the project implementation, she or he must demonstrate softer skills to effectively communicate and positively influence the variety of people who interact within the scope of a project. Certainly, the level of competence required in these three disparate areas of technical, managerial, and people skills is high, which explains why it is so difficult for organizations to find good project managers.

Scope Creep

Probably the most insidious and problematic issue to manage over the course of a project is scope creep. Scope creep refers to unplanned increases in project deliverables and hence increases in the workload of project activities. Scope creep arises from poor and inconsistent communication, fueled by mismanaged expectations. Generally, a natural tendency is for those who pay for a project or use the deliverables to want more than what is delivered. Without *clearly* defining work objectives in a written form that is communicated among everyone involved, it is possible for different people to form different expectations of the work to be completed and the objectives to be achieved. In other words, some people will be dissatisfied with the level of project work being accomplished. For consulting engagements in which these “some people” are paying clients, this expectation and failure to “meet” it can be particularly devastating.

Consider an example in which a software development firm is developing a computer system for a client company. The client company will have certain expectations about the functionality to be delivered, and so too will the developer. However, if the precise level of functionality is not written, communicated, and agreed upon, the client company may believe certain functionality is included where the developer does not. Virtually no good outcome is possible from this failure. Either the client will be disappointed when it becomes aware that desired functionality is missing or the developer, in order to placate the client, must do additional, unplanned work. Clearly, issues related to scope creep also tie in to effectively managing expectations of stakeholders.

In general, written communication and contracts that clearly spell out project scope and objectives will curtail scope creep and enable expectations to be managed appropriately. Probably just as important as it is to specify what is included in a project, is also to delineate specifically what is *not* included within the scope of a project. Because of the natural tendency for scope creep to occur over the course of a project, conservative planning (as already discussed) that allows for some scope creep also provides a way to positively influence expectations. In fact, planning for scope creep is similar to maintaining a capacity cushion that gives the project team flexibility to handle changes in project workload. In our software development example, even if the written scope and objectives document clearly shows that certain functionality is not included in the deliverables, the developer, with a capacity cushion, can include the additional functionality at no additional cost to the client and thereby exceed expectations.

So far, we have discussed qualitative factors that influence project success and failure. Although they are extremely important, so too are the more technical skills and methods needed to plan and manage projects to success. In the next section, we introduce quantitative tools for managing projects.

Quantitative Tools and Techniques for Project Management

Network diagramming offers one of the more versatile techniques for planning and managing projects. A network diagram is a graphic illustration of the activities in a project and the relationship among the activities. Recall that a project consists of a set of interrelated activities. The precedence relationships among activities identify which activities must be completed before other activities may start. A network diagram not only illustrates these precedence relationships, but is also useful for answering several questions important to effective project management. How long will the project take? What are the critical paths? What activities lie on the critical path?

Naturally, in order to draw a network diagram, it is essential to know the set of activities involved in the project to be diagrammed as well as the precedence relationship among those activities. Sometimes, however, projects are ill defined. Even with well-defined projects, it still may be unclear what activities are necessary to the project. For example, consider a project that involves buying a house. This project includes tasks such as viewing homes, preparing a contract, house inspection, obtaining a mortgage, and closing. Several other activities may or may not be included. Some activities such as surveys, engineering reports, or inspections can be conditional to any number of factors. Only during the course of such a project will the actual requirements become known. Alternatively, when not enough is known up front about the activities in a project, another project can be defined to better clarify the principal project requirements. It is important to note that omissions or errors concerning activities to be included or their relationships can significantly affect the likelihood of project success.

Once the activities for a project are clearly defined and their relationships determined, a work breakdown structure (WBS) can be developed. A WBS is simply a hierarchical organization of project tasks that decomposes project processes into subtasks and finally elemental activities at the lowest level. In Figure 15.1 we illustrate a WBS for the example project we use throughout the remainder of this chapter. The example project concerns the design, development, and implementation of an order/entry computer program.

Table 15.1 lists activities, their durations, and precedence for the nine activities displayed in the WBS. The labels A through I will be used to identify activities in the network diagram. Each label is associated with an activity description in the second column and an estimated duration, specified in weeks, is listed in the third column. Finally, the fourth column identifies activity relationships delineating the immediate predecessors for each activity. In our systems development example, activities A and B have no immediate predecessors. All other activities have at least one immediate predecessor and sometimes more. Consider activity C, Reports Design. This activity can begin only after the activities A and B are completed, where activities A and B are identified as immediate predecessors to C.

FIGURE 15.1: *Work Breakdown Structure for the Systems Development Project*

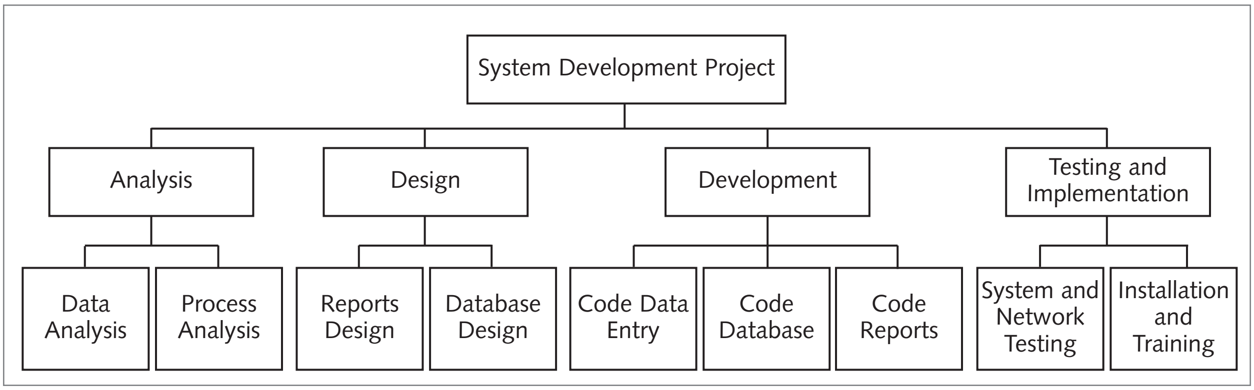


TABLE 15.1: *Activity Information for the Systems Development Project*

Activity	Description	Duration (weeks)	Immediate Predecessor(s)
A	Process analysis	4	—
B	Data analysis	3	—
C	Reports design	5	A, B
D	Database design	5	B
E	Code reports	4	C, D
F	Code data entry	3	D
G	Code database	4	D
H	System and network testing	3	F, G, H
I	Installation and training	1	H

Choosing a Project Network Diagramming Technique

Two commonly accepted approaches to diagramming project networks include (1) activity on node (AON) method, and (2) activity on arrow (AOA) method. With AON, nodes represent activities and arrows represent precedence relationships. With AOA, nodes represent events, such as the beginning or end of an activity, and arrows represent activities.

Figure 15.2 illustrates both techniques with a small example of three interrelated activities. In this example, Activity A is the immediate predecessor of activities B and C. Note that even though the two techniques can yield different-looking diagrams, they relate the same information. Hence, the selection of one method over another method is principally a matter of personal choice. An AOA diagram, however, becomes a little more complicated due to the inclusion of dummy activities. Dummy activities are used in an AOA diagram whenever two activities would otherwise share the same starting and ending nodes. In effect, only one arrow is allowed between any two nodes. Dummy arrows help preserve the precedence relationships of the work breakdown structure, without violating the single arrow rule. Figure 15.3 provides further illustration of ways to diagram common relationships using both techniques.

Constructing a Project Network

Using our example of the systems development project, we will proceed to construct a project network using the AON method. The steps for diagramming hinge on two

FIGURE 15.2: *Illustration of AOA and AON Diagramming Techniques*

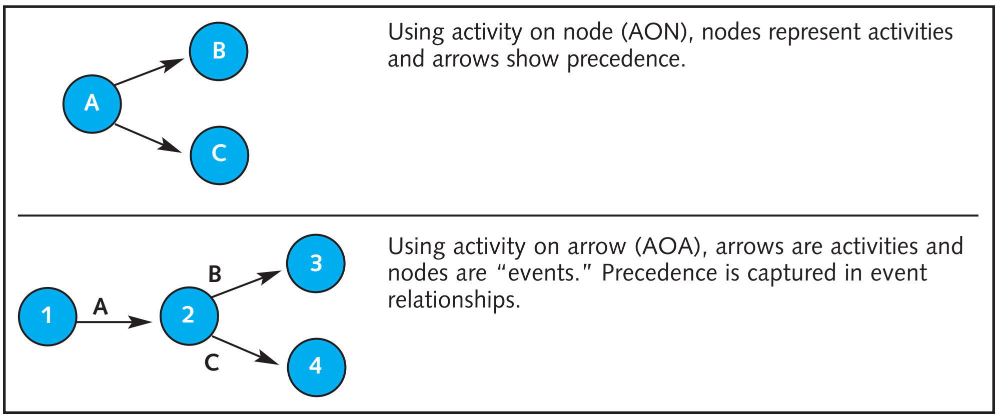
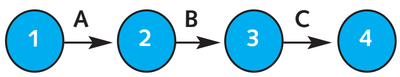
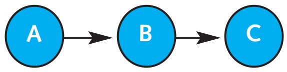
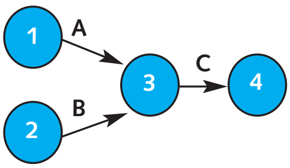
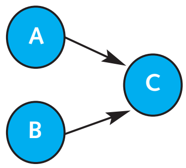
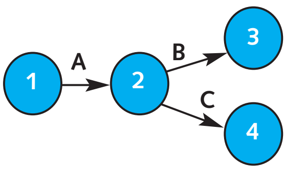
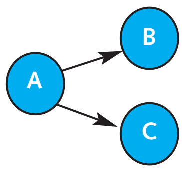
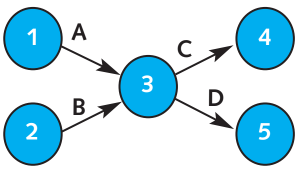
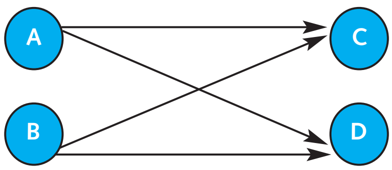
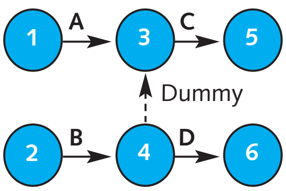
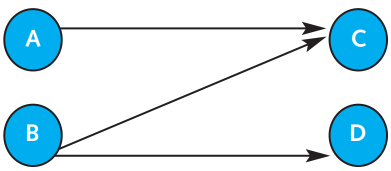
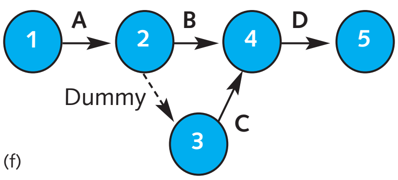
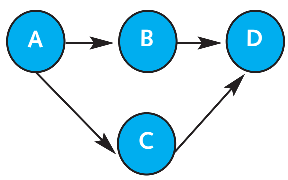


FIGURE 15.3: *Ways to Diagram Common Activity Relationships*

AOA	AON	Activity Relationships
 (a)		A precedes B, which precedes C.
 (b)		A and B must be completed before C can be started.
 (c)		B and C cannot begin until A has been completed.
 (d)		C and D cannot begin until both A and B have been completed.
 (e)		C cannot begin until both A and B have been completed; D cannot begin until B has been completed.
 (f)		B and C cannot begin until A has been completed; D cannot begin until both B and C have been completed.

rules: Each activity is represented by a single node and the arrows indicate the precedence relationships. To begin, start with a node to represent an activity with no precedents. If the project requires more than one such activity, as in our example, then create a dummy activity labeled "Start" to serve as the predecessor for all the activities without defined predecessors. The "Start" node has no duration and may be diagrammed as a square for clarity of representation.

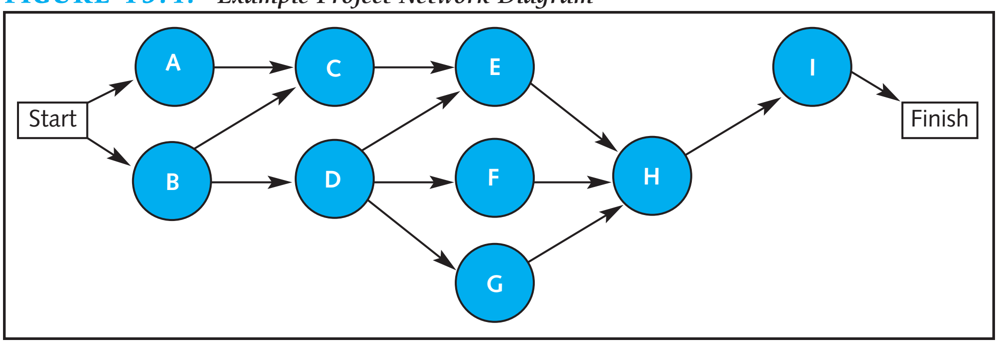
Build nodes and arrows as precedence relationships demand and continue in a logical fashion from starting node to ending node. If an activity is not a predecessor for any other activity, then it is an ending node. If more than one activity falls into this category, create a dummy activity for the ending node in the same fashion that we use a dummy "Start" node with multiple starting activities. Note that both dummy Start and End nodes may be desirable, if not required, to provide clear signals of the start and end of the project.

Diagramming the Systems Development Project

As indicated by the work breakdown structure in Table 15.1, this system development project consists of nine activities. The project deliverable is an installed computer system with user training. To proceed to this mark, both process and data analyses must first be conducted. These activities identify what the system must accomplish and the data that the resulting system must maintain and utilize. Once these tasks are completed, then the different system modules can be designed and afterwards coded. Only after all activities are coded can the system be tested, and only after successful system testing can the entire program be installed and the users trained on how to use it.

The AON network for the system development project is shown in Figure 15.4. In this diagram, activities are shown as circles, with arrows that capture precedence and indicate the order in which activities are to be completed. Note that activities A and B are linked to a start node because they have no immediate predecessors. Then, observe the arrows that link both activities A and B to activity C, thereby indicating that C cannot begin until A and B are completed. Activity B is the only immediate predecessor of Activity D. The diagram proceeds, essentially translating the information of the work breakdown structure into the visual representation of the project network. Note that activity I is not the predecessor of any other activity and links to an ending node. In this case, the ending node is not required, but visually helps to clarify the end point of the project.

FIGURE 15.4: *Example Project Network Diagram*



Of course, it (almost) goes without saying that there is a wide array of software and other technologies that can be used to facilitate project management. Microsoft (MS) Project ™ is one software tool that automates many tasks. Simply by entering tasks, task times, and precedence relationships, MS Project can generate a network diagram. Figure 15.5 shows the corresponding MS Project network diagram for our example project.

Developing a Project Schedule

A project network can be used to develop a project schedule or plan. The project schedule actually expands on the network by identifying the duration of the project and the start and end times for each activity in the project. A Gantt chart, like a network diagram, provides another way to develop and present a project schedule. In a Gantt chart, activities are listed vertically, and task times are denoted horizontally in bars that are mapped on a rolling calendar. The length of the bar corresponds to the length of the given task. Figure 15.6 shows the MS Project Gantt Chart for our example.

The project schedule identifies the due dates and timing of events within the project timeline. The duration of a project is equal to the longest path in the project network, where a path is represented by a unique set of activities that link start and end nodes. The length of a path is determined by the sum of the durations for activities on the path. Table 15.2 identifies the five paths for the example system development project.

The longest path in a project is also known as the critical path. Since the longest path is the critical path, a project cannot be completed in any time shorter than indicated by the sum of activity times on the critical path. In our example, the critical path is A-C-E-H-I. Activities on the critical path are also known as critical activities. The idea behind the term *critical* is that any delay of these activities will delay the entire project. Hence, these activities require focused management attention.

FIGURE 15.5: *MS Project Network Diagram for the Systems Development Project*

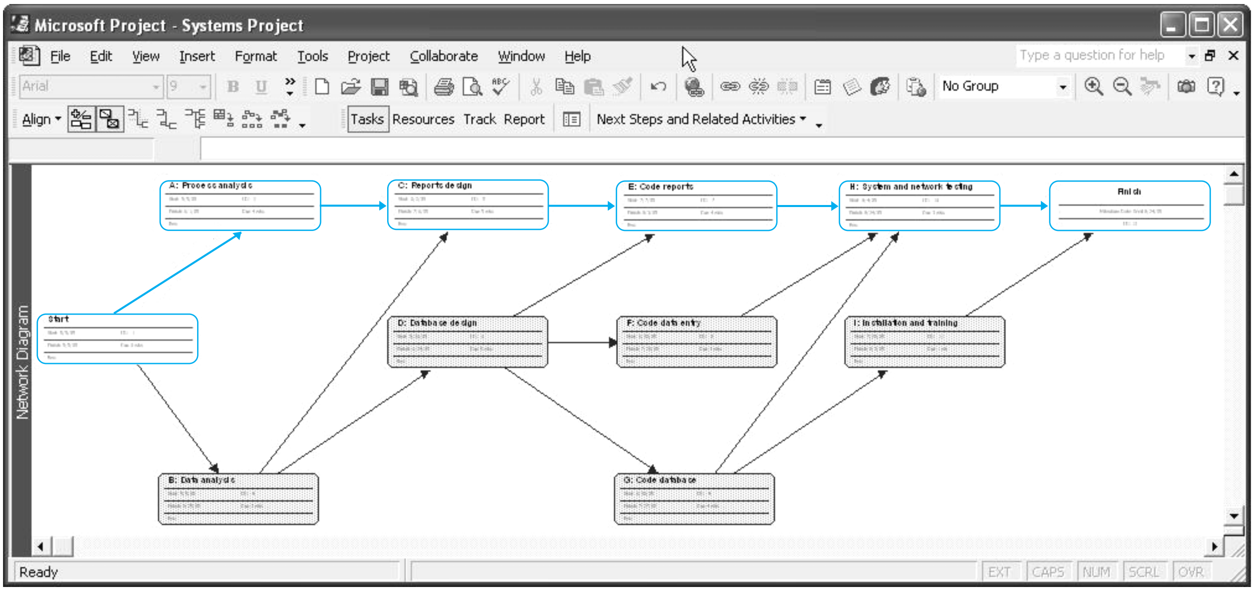
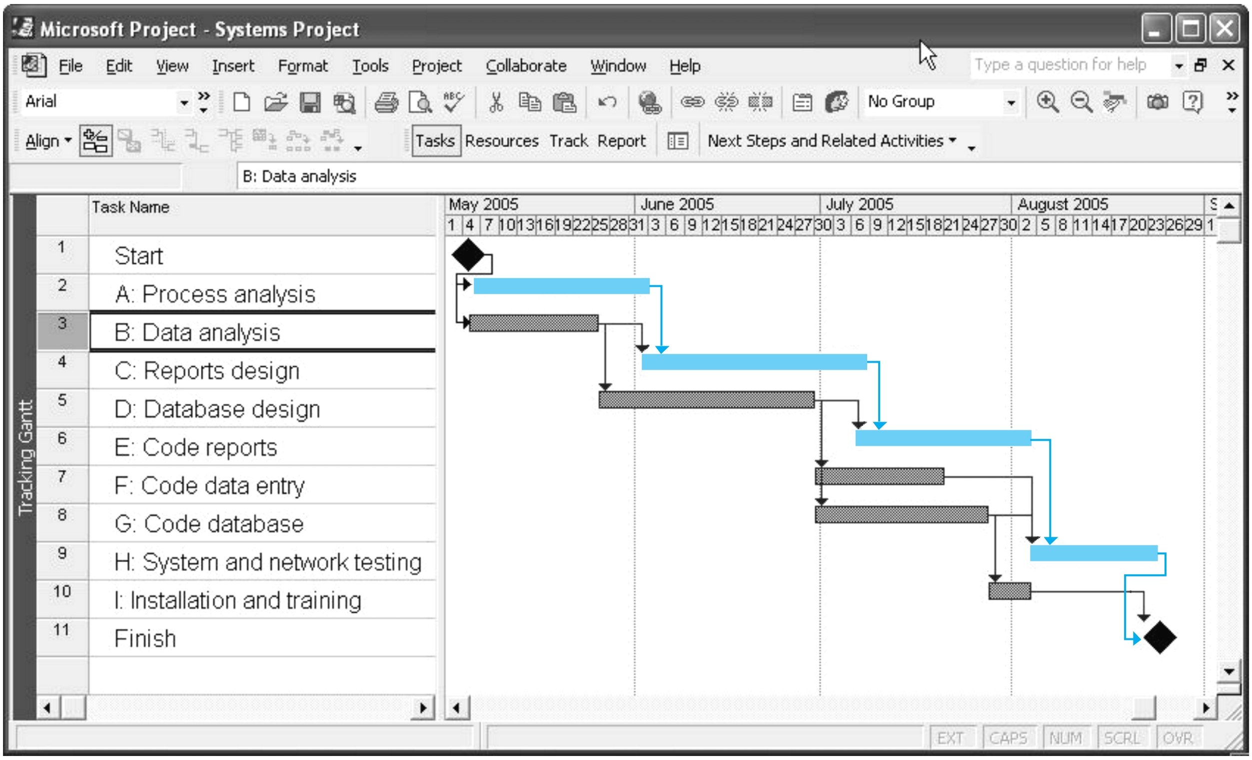


FIGURE 15.6: *MS Project with Gantt Chart for the Systems Development Project*



A project may include more than one critical path. This situation arises when two or more paths of the same length are also longer than any other paths. Our example contains only one critical path.

In small projects with only a few paths, it is a simple matter to manually identify each path and determine their lengths. Projects of any meaningful size may require hundreds if not thousands of paths. In these situations it is helpful to use any one of several available computer software programs like Microsoft Project™.

Even though careful management attention must be devoted to critical activities, noncritical activities should not be forgotten. Noncritical activities are, naturally, those activities that do not reside on a critical path and, as such, include activity slack. Activity slack is measured as the amount of time that an activity can be delayed before it becomes critical and delays the entire project. Because projects are plagued with uncertainty, activities with little and sometimes moderate levels of slack should also be carefully monitored. In fact, should delays occur, the critical path may shift

TABLE 15.2: *Paths in the Example Project*

	Path	Duration (weeks)
1	A-C-E-H-I	17
2	B-C-E-H-I	16
3	B-D-E-H-I	16
4	B-D-F-H-I	15
5	B-D-G-H-I	16

to one or more other paths in the project. This last point reemphasizes the notion the projects are dynamic, evolving processes that need to be managed.

Activity slack can be determined once the start times and end times for activities are determined. Four different time estimates are used: early start, early finish, late start, and late finish. The earliest start time denotes the earliest time that an activity can be started without violating any precedence relationship. The earliest finish time is equal to the earliest finish time plus the duration of the activity. The earliest finish time for the last activity in the project is also the length to completion of the project. The latest finish time is the latest time an activity can be completed without delaying one or more activities that follow it. The latest start time for an activity is equal to the latest finish time minus the duration. We now look at how to compute these four time estimates, beginning with earliest start and finish times.

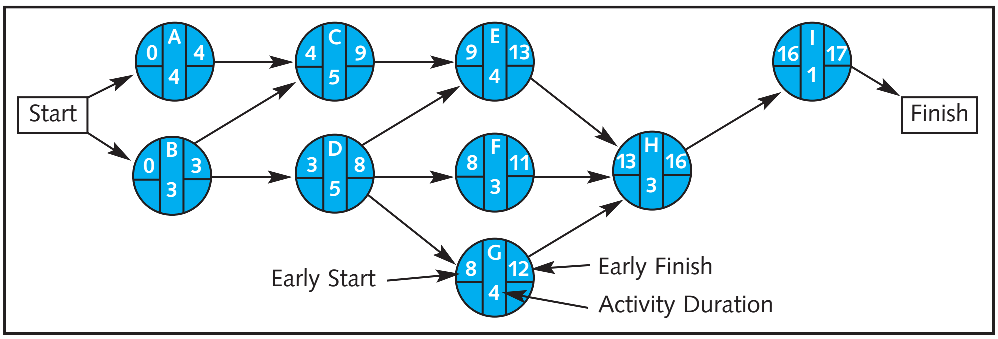
Computing Earliest Start and Earliest Finish Times

We demonstrate the task of computing earliest start and finish times with our example system development project. We use the abbreviation *ES* to denote early start time, *EF* to denote early finish time, and *D* to denote an activities duration. Using this notation, $EF = ES + D$. The earliest start time for any given activity is equal to the maximum earliest finish time of any predecessor activities. With no predecessor activities, the earliest start time is zero. Figure 15.7 identifies activity times and durations for our example project.

To obtain the solution for earliest start and earliest finish times, one must begin at the starting node at time zero. The starting node itself has zero duration, so in effect its $ES = D = EF = 0$. Hence, activities A and B, which emanate from the start node have earliest start times of zero. For activity A where $D = 4$, then $EF = 0 + 4 = 4$. Likewise, for activity B where $D = 3$, $EF = 0 + 3 = 3$. Now, activity C can only begin once the last predecessor activity is completed, activity A with $EF = 4$. Consequently, for activity C with duration 5, $ES = 4$ and $EF = 5 + 4 = 9$. For activity D with duration 5, $ES = 3$ because activity B is its only predecessor and $EF = 3 + 5 = 8$.

Moving forward to activity E, its earliest start time is the maximum of the earliest finish times of its two predecessors, activity C with $EF = 9$. Hence, *ES* for activity E is 9 and $EF = 9 + 4 = 13$. $ES = 8$ for both activities F and G since activity D is their sole predecessor. For activity F, $EF = 8 + 3 = 11$ and for activity G, $EF = 8 + 4 = 12$. *ES* for activity H is determined in a similar fashion to activities C and E because it has multiple predecessors. The maximum *EF* of either activities E, F, or G is 13, so *ES* for activity H is 13 and its $EF = 13 + 3 = 16$. Finally, activity I has an *ES* of 16 and an $EF = 16 + 1 = 17$.

FIGURE 15.7: *Early Start and Early Finish Times*



Computing Latest Finish and Latest Start Times

The process for computing latest finish and latest start times is the reverse of the process used for computing earliest start and earliest finish times. The latest finish time (*LF*) for any activity is equal to the minimum of the latest start times of any activities to which it is an immediate predecessor. The latest start time (*LS*) is simply the latest finish time minus the activity duration time, or, $LS = LF - D$. If an activity is not a predecessor of any other activity, and hence, is a final or ending node of the project, then the latest finish time is equal to the earliest finish time. Finishing any later than the earliest finish time would delay completion of the entire project.

We begin the process of determining latest start and latest finish times with the final or ending activity of the project. In our example, activity I is the final activity. Its earliest finish time is 17 weeks so its latest finish time must also be 17 weeks. Working backwards, $LS_I = 17 - 1 = 16$. Then, using the label of each activity as a subscript, the following computations can be made:

$$LF_H = LS_I = 16, \quad LS_H = LF_H - D_H = 16 - 3 = 13$$

$$LF_E = LS_H = 13, \quad LS_E = LF_E - D_E = 13 - 4 = 9$$

So far, we observed that the latest start and finish times are equal to the earliest start and finish times. This result will always be true for activities that reside on the critical path. Critical activities allow no slack and must be started and finished at the right time or the project as a whole will be delayed. Noncritical activities, however, may allow for slack. Slack is defined as the maximum amount of time that the latest start of an activity may be delayed beyond its earliest start time, without delaying the project. By definition then, slack $= LS - ES$. Because $LS - ES = LF - EF$, an equivalent measure of slack is latest finish time minus earliest finish time. Activities F and G contain slack because they are not on a critical path:

$$LF_F = LS_H = 13, LS_F = LF_F - D_F = 13 - 3 = 10, \text{slack} = LS - ES = 10 - 8 = 2$$

and

$$LF_G = LS_H = 13, LS_G = LF_G - D_G = 13 - 4 = 9, \text{slack} = LS - ES = 9 - 8 = 1$$

Activities C and A are on the critical path so we know that they have zero slack and that their latest finish and latest start times are equal to their earliest finish and earliest start times. Activity D is not a critical activity and to complicate matters, it is a predecessor activity to three other activities: E, F, and G. The rule applied here is that the latest finish time for activity D is equal to the minimum of the latest start times for the three activities. In this case, the minimum latest start time of activities {E, F, G} is 9. Hence, $LF_D = 9$ and $LS_D = 9 - 5 = 4$. The method for determining the latest finish time for activity B is the same as for activity D. Here, however, the latest finish time for each of the two activities that follow it {C, D} is the same. Hence, $LF_B = 4$ and $LS_B = 4 - 3 = 1$. Figure 15.8 shows the MS Project schedule for our example, with activity start and end times, as well as activity slack. The MS Project file for this example is on the Student CD.

Access your Student CD now for the Microsoft Project file for this example.

In summary, a project network serves as an effective tool for managing projects. Using a project network, we can determine when activities should be started, when they should be completed, and where in the project slack resides so that resources may be properly shifted if necessary. The project network can also identify critical activities and critical paths so that management attention will be focused on what is important.

FIGURE 15.8: *MS Project Schedule Table for the Systems Development Project Displaying Activity Slack Times*

	Task Name	Duration	Start	Finish	Late Start	Late Finish	Free Slack
1	Start	0 wks	Thu 5/5/05	Thu 5/5/05	Thu 5/5/05	Thu 5/5/05	0 wks
2	A: Process analysis	4 wks	Thu 5/5/05	Wed 6/1/05	Thu 5/5/05	Wed 6/1/05	0 wks
3	B: Data analysis	3 wks	Thu 5/5/05	Wed 5/25/05	Thu 5/12/05	Wed 6/1/05	0 wks
4	C: Reports design	5 wks	Thu 6/2/05	Wed 7/6/05	Thu 6/2/05	Wed 7/6/05	0 wks
5	D: Database design	5 wks	Thu 5/26/05	Wed 6/29/05	Thu 6/2/05	Wed 7/6/05	0 wks
6	E: Code reports	4 wks	Thu 7/7/05	Wed 8/3/05	Thu 7/7/05	Wed 8/3/05	0 wks
7	F: Code data entry	3 wks	Thu 6/30/05	Wed 7/20/05	Thu 7/14/05	Wed 8/3/05	2 wks
8	G: Code database	4 wks	Thu 6/30/05	Wed 7/27/05	Thu 7/7/05	Wed 8/3/05	0 wks
9	H: System and network testing	3 wks	Thu 8/4/05	Wed 8/24/05	Thu 8/4/05	Wed 8/24/05	0 wks
10	I: Installation and training	1 wk	Thu 7/28/05	Wed 8/3/05	Thu 8/18/05	Wed 8/24/05	3 wks
11	Finish	0 wks	Wed 8/24/05	Wed 8/24/05	Wed 8/24/05	Wed 8/24/05	0 wks

In addition, it should be noted that the process itself of putting together a project network before the project is scheduled to start facilitates learning about project details. At this time, project scope becomes clear, activity relationships are clarified, and resource requirements are established. In essence, it puts the project on the right track. One thing that any project manager can count on, however, is that the project plan as described by the initial project network is certainly not identical to what will be implemented.

As we discussed at the beginning of this chapter, projects are subject to risks and uncertainties such that what is planned will be changed, possibly many times over, before a project is completed. Project team members get sick, quit, or are required for (euphemistically, borrowed and never returned) other more critical projects. The work can take longer or shorter than planned. Additional work that was initially not considered may arise, the project deliverables can change, not to mention myriad other possibilities, all of which may affect the project. In other words, unplanned stuff happens, and usually not of the good variety. On any project of meaningful size and complexity, the project network that describes what actually happened on the project may show little resemblance to the project network as initially developed.

The importance of this last point is that projects and the networks that describe them are not static or frozen in time. They are dynamic and should be treated as such. Just because one project path is critical today does not mean that two other project paths will not be critical tomorrow. For this reason, the project network must be consistently updated to reflect its changing state. In the next section, we proceed with a statistical analysis approach to managing projects and show how project networks can be adapted to explicitly incorporate the elements of risk and uncertainty.

Probabilistic Project Management

The framework that we developed in the prior section for developing and using project networks can be adapted to consider the risks and uncertainties ever present in projects. Instead of treating activity durations as known, deterministic, and fixed, we can treat them probabilistically. With this approach, it is possible to answer questions such as, "What is the probability of completing the project in a certain amount of time?" In essence, we can treat activities as if they are random variables and assign probabilities to activity times to reflect the inherent uncertainties. Then, we can use these probabilities to calculate means and variances for activity times that, in turn, can be used to calculate project statistics.

The approach requires three time estimates for each activity. These include an optimistic time (*a*), a most likely time (*m*), and a pessimistic time (*b*). The optimistic time is the shortest time estimate and reflects the duration of an activity when everything goes nearly perfect. The most likely time estimate reflects the idea that bad stuff will happen (problems arise) and cause an activity to take longer than the optimistic time. The pessimistic time, the third time estimate, provides an activity time when just about everything that can go wrong does go wrong.

The statistical analysis approach assumes the probabilities for activity times are taken from the beta distribution. The choice of beta distribution arises because of its flexibility: The distribution can have any number of shapes that will allow the most likely time estimate to lie between the optimistic and pessimistic times. The most likely time estimate is the mode of the beta distribution with the highest associated probability. Because of its flexibility and ability to accommodate probability distributions of such variety and because projects and their activities themselves are so varied, the beta distribution is an ideal choice for accommodating uncertainty in project management.

The degree to which the three time estimates are close together or far apart is a direct measure of the uncertainty associated with an activity. It also presupposes that it is possible to assign three separate and reasonable time estimates. The three estimates may not be different values. For example, an activity may have the same optimistic time and most likely time, or the same pessimistic time and most likely time. In some cases, however, estimating activity times may prove difficult, particularly with new processes, methods, or techniques that provide no previous experience upon which to base those estimates. In essence, the activity times are a source of uncertainty. The task itself of estimating activity durations, then, is akin to forecasting. As such, judgmental forecasting methods may be particularly appropriate here, particularly those methods that can be used to generate a consensus forecast among all members of the project team.

With three time estimates, the mean time of an activity, denoted as t_e, can be estimated by

$$t_e = \frac{a + 4m = b}{6} \qquad (15.1)$$

Note that the formula for t_e is a weighted average of the three time estimates in which the most likely time (*m*) is weighted four times that of either the optimistic or pessimistic times. The variance of the beta distribution, denoted as σ^2 is the square of the standard deviation σ and is given by

$$\sigma^2 = \left(\frac{b - a}{6}\right)^2 \qquad (15.2)$$

The variance provides a direct measure of the uncertainty with respect to activity durations. Notice that the variance increases as the difference between the optimistic and pessimistic times increases. Alternatively, when the pessimistic and optimistic times are identical, the activity duration is assumed known with certainty and consequently the variance is zero.

Calculating Means and Variances

Here, we use our example of the system development project to demonstrate how to calculate the mean and variance for an activity's time. For example, what would the mean and variance be for activity H if $a = 1$, $m = 2$, and $b = 9$? By plugging these values into the equations for t_e and σ^2 we find that

$$t_e = \frac{a + 4m + b}{6} = \frac{1 + 4(2) + 9}{6} = 3$$

and

$$\sigma^2 = \left(\frac{b - a}{6}\right)^2 = \left(\frac{9 - 1}{6}\right)^2 = 1.78$$

Note that the calculated mean for activity H is three weeks, while the most likely time estimate is two weeks. This example highlights the point that the mean and most likely time estimate will not necessarily be the same. The mode of a distribution and its mean will only be the same if the distribution is symmetric around the mean, such as the normal distribution. We show the calculated values t_e and σ^2 for all activities in the systems development project in Table 15.3.

Once activity statistics for a project are computed, they can be used to help determine where the greatest sources of uncertainty reside, and hence where management attention should be focused. The difference in time estimates for an activity are a measure of uncertainty, which can be captured in the variance of an activity. Therefore, it is a simple matter of finding those activities with the highest variances to indicate the highest level of uncertainty.

As shown in Table 15.3, activities B and H in the example project are associated with the highest level of uncertainty. The higher numbers for these activities do not necessarily mean that the level of uncertainty is out of line or that the uncertainty for the other activities is low enough. Management attention to the specific case can determine whether the uncertainty of a given activity is too significant and then focus efforts toward reducing that uncertainty or perhaps readjusting time estimates.

TABLE 15.3: *Time Estimates and Activity Statistics*

	Time Estimates (weeks)			Activity Statistics	
Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Mean (t_e)	Variance (σ^2)
A	3	4	5	4	0.11
B	1	2	9	3	1.78
C	3	5	7	5	0.44
D	2	5	8	5	1.00
E	1	4	7	4	1.00
F	2	3	4	3	0.11
G	1	4	7	4	1.00
H	1	2	9	3	1.78
I	1	1	1	1	0.00

Analyzing Probabilities

Uncertain activity times result in uncertain project duration. The main objective of the probabilistic approach to project management is to plan for uncertainty and to be able to assess those probabilities with respect to the project timeline. Evaluating the probability of meeting project due dates is an invaluable contribution of the probabilistic approach. To be able to calculate probabilities, however, we need to make a rather restrictive assumption about the relationship among activities.

We assume that the durations of all activities are independent of one another. Naturally, this assumption may not be valid. For example, if a specific project team member is assigned to multiple activities (a common occurrence), then activity durations are likely to be dependent. Nevertheless, the assumption allows us to draw upon the central limit theorem to compute project statistics. Recall that the central limit theorem holds that the sum of a group of independent, identically distributed random variables approaches a normal distribution as the number of random variables increases. With respect to project management, activity times are the random variables. By assuming activities times are independent, we can then use the sum of the expected times and sum of the variances for all activities that reside on a given path to assess the probability of completing the path by a desired completion time, where

$$T_E = \Sigma(\text{Activity times on the path}) \qquad (15.3)$$

and

$$\sigma^2 = \Sigma(\text{Variances of time on the path}) \qquad (15.4)$$

To illustrate how we can calculate the probability of completing a path by a given date, we return again to our example of the system development project. Here, we might ask the question, "If we assume the desired due date for the project is 19 weeks, what is the probability that the path with the longest expected completion time is finished within the desired time frame?" Before we begin, some additional notation is helpful. Let T = due date for the project and T_E = expected completion time for the path. With these values, then T, T_E, σ^2 can be used to compute a z-score, where the value of z is the number of standard deviations (of a standard normal distribution) that the project due date is from the expected completion time. Specifically,

$$z = \frac{T - T_E}{\sqrt{\sigma^2}} \qquad (15.5)$$

Now, in our example, T = 19. Because the path with the longest expected completion time is given by A–C–E–H–I, then

$$\begin{aligned} T_E &= \Sigma(\text{Activity times on the path}) \\ &= 4 + 5 + 4 + 3 + 1 = 17 \end{aligned}$$

and

$$\begin{aligned} \sigma^2 &= \Sigma(\text{Variances of activity times on the path}) \\ &= 0.11 + 0.44 + 1.00 + 1.78 + 0 \\ &= 3.33 \end{aligned}$$

so that

$$z = \frac{T - T_E}{\sqrt{\sigma^2}} = \frac{19 - 17}{\sqrt{3.33}} = 1.10$$

Using the Normal Distribution provided on the text's endsheet, the probability associated with a z-score of 1.10 is 0.8643. Hence, there is an 86.43% chance of completing the path on time. Note that we determined only the probability associated with the given path and not the entire project. Even though path A–C–E–H–I requires the longest expected completion time, due to the stochastic nature of activity times, any of the other four paths *may* take longer than 19 weeks. Hence the probability of completing the project within 19 weeks will be some value less than 0.8643.

To get a more accurate assessment of the probability for completing the project by a desired due date, we discuss two approaches. Our first alternative is to compute the probability that all paths are completed within 19 weeks. First, we calculate the probability that each of the other paths will be finished within 19 weeks, just as we did for path A–C–E–H–I. Then we obtain a joint probability by multiplying the individual probabilities. The joint probability provides an approximation of the probability for completing that project by the desired due date. Using the joint probability also depends on the assumption that path completion times are independent of one another. Naturally, if activities are common to more than one path, this assumption is no longer possible. Even so, path independence is generally an acceptable assumption when a project comprises a sufficiently large number of activities.

Alternatively, simulation can also be used to assess the probability of meeting project due dates. With this approach, a simulation software package such as SimQuick can be used to simulate project activity times and then compute statistics with respect to project completion times. The approach is akin to analyzing processes as we discussed in Chapter 9. Here, however, the project activities are the processes. For more specifics, please refer to Chapter 9.

The point of these exercises for any project is to determine the likelihood of meeting project due dates. If the resulting probabilities are unsatisfactory, the project manager can take action to increase the likelihood for success. Options available to do so include adding resources to reduce the project length, changing due dates, or changing project deliverables. In the next section we discuss these alternatives in more detail.

Making Time, Cost, and Performance Trade-Offs

Although a project network can be a useful tool for determining a project completion date, the date itself is generated in isolation of management expectations and may demonstrate virtually no relationship to what management or the various stakeholders desire for a given project. In the systems development project, the network we developed indicates an expected completion time within 17 weeks. However, management, or the customer who is purchasing the system, may want it much sooner than the date indicated by the project timeline. There is no magic here. Whenever a difference between expectations and the work required arises, either the amount of work must be adjusted or expectations changed. In effect, the project team will have to choose from several options that may include the following:

- Adding resources (people, money, equipment) to complete certain project activities in less time with more resources
- Reducing performance specifications of deliverables so that less work is required with the idea that the project duration should be shorter with fewer requirements
- Changing management expectations so that a later due date is acceptable, possibly by increasing performance specifications or perhaps by demonstrating problems associated with other alternatives
- Combining the previous alternatives

Making Time–Cost Trade-Offs

If a project falls behind schedule, or for that matter, whenever the planned completion date is later than a desired completion date, one alternative may be to add more resources to the project in order to increase the likelihood of achieving the desired date. Naturally, there may be the problem of too many cooks in the kitchen, such that adding more people to an activity may actually add complexity and increase project length. In many cases, however, project activities can be delegated among a larger group of people so that the work as a whole can be completed in less time. In effect, throwing more resources at a project to get things done more quickly essentially makes a trade-off between time and money: Spending more money (adding resources) will reduce the project length (buys time).

In this context, the cost of expediting certain activities to get a project done more quickly must be balanced against the potential benefits. For example, a firm may be penalized by delivering late on a project or may receive a bonus for coming in early. The process of making the time–cost trade-off is referred to as project crashing, and we discuss it next.

Crashing Costs

In order to make time–cost trade-offs, accurate estimates regarding the times and costs involved are necessary. From this perspective, two types of costs and two time estimates are needed for any activity that lies within the consideration set. These include

- Normal time (NT) = Expected activity duration without crashing
- Normal cost (NC) = Expected activity cost without crashing
- Crash time (CT) = Expected activity duration with crashing
- Crash cost (CC) = Expected activity cost with crashing

Although normal time is the longest expected duration for an activity, the crash time is the shortest possible expected duration. The difference, namely $NT - CT$, represents the time gained and traded for the cost: $CC - \sim C$. The basic idea is that the crash time for any activity will be less than normal time, but will come at a higher cost.

We make the assumption that costs are linear. Hence it costs proportionally the same to reduce an activity by one day as it does two days, or more. For example, consider an activity where $NT = 10$, $CT = 5$, $NC = \$1{,}000$, and $CC = \$5{,}000$. If a total of 5 crash days are possible for a total cost of $4,000 ($CC - NC$), each of the five days comes at a cost of $800. Therefore, reducing the activity's duration by two days will cost $1,600, by three days will cost $2,400, and so on. Another implicit assumption is that activities can be crashed any number of days between normal time and crash time. For any activity, the cost to crash an activity by one period is

$$\text{Per period crashing cost} = \frac{CC - NC}{NT - CT}$$

We also refer to the per period crashing cost as "bang for the buck." All else being equal, it is more desirable to crash activities with the biggest bang for the buck, which means reducing the greatest amount of time for the least amount of money. Nevertheless, we need to make a distinction between reducing a given activity's duration and reducing the duration of the entire project. Even though an activity's time may be reduced, the project duration may remain the same. In other words, a goal of crashing at minimum cost to achieve a shortened project timeline is more involved than simply selecting an activity with the biggest bang for the buck. Three factors must be considered.

First, it makes sense only to crash activities that are on the critical path. Crashing noncritical activities does not affect project length. Second, even crashing an activity on a critical path may not reduce the project duration. This situation arises when the project contains more than one critical path. In these cases, it will be necessary to crash selected activities that reside on all critical paths simultaneously. Finally, it is important to realize that the process of crashing may cause the set of critical paths to change. We now introduce a three-step process for crashing that accommodates these considerations. Starting with the set of project paths in normal time (i.e., without crashing),

1. Identify critical path(s).
2. Find an activity or set of activities that will reduce the length of all critical paths by one time period for the biggest bang for the buck.
3. Stop if the desired project length is achieved or no more activities can be crashed. Otherwise, go to step 1.

As described, the three-step process of crashing is iterative. Because the critical path may change, crashing should be performed (to the extent possible) one time period per iteration. It only makes sense to crash activities on the critical path, and all critical paths must be reduced simultaneously. We illustrate the process of crashing with our example systems development project.

Crashing at Minimum Cost to Achieve a Desired Completion Date

In the systems development project, the expected completion date is 17 weeks. How would we crash the project if management wanted an expected completion date of 14 weeks? To begin, it is helpful to list the full set of paths in the project and the durations for each one of them. The example contains the following five paths:

- A–C–E–H–I with duration 17 weeks
- B–C–E–H–I with duration 16 weeks
- B–D–E–H–I with duration 16 weeks
- B–D–F–H–I with duration 15 weeks
- B–D–G–H–I with duration 16 weeks

Table 15.4 contains the necessary crashing information for each activity in our example. Beginning now with step 1, we look first at the only critical path at this time, namely path A–C–E–H–I at 17 weeks. Proceeding to step 2, of the critical activities A, C, E, H, and I, activity A has the least cost for crashing at $500 per week as identified in the last column of Table 15.4. Hence, we crash activity A one week, which

TABLE 15.4: *Crashing Information*

Activity	Normal Time (weeks)	Normal Cost	Crash Time (weeks)	Crash Cost	Crash Days Allowed	Cost per Crash Day
A	4	$2,000	3	$2,500	1	$ 500
B	3	$3,500	2	$4,000	1	$ 250
C	5	$5,000	3	$7,500	2	$1,250
D	5	$8,000	4	$9,500	1	$1,500
E	4	$4,000	2	$6,000	2	$1,000
F	3	$2,500	1	$3,000	2	$ 250
G	4	$6,000	3	$6,400	1	$ 400
H	3	$3,000	3	—	—	—
I	1	$1,000	1	—	—	—

reduces both the critical path and project duration by one week to 16 weeks. After crashing, the path durations are:

- A–C–E–H–I with duration 16 weeks
- B–C–E–H–I with duration 16 weeks
- B–D–E–H–I with duration 16 weeks
- B–D–F–H–I with duration 15 weeks
- B–D–G–H–I with duration 16 weeks

We have not reached 14 weeks, so we proceed back to step 1. Of the five paths in the project, four of them are now critical. In order to reduce the project length by one week, it will be necessary to reduce the lengths of all four paths simultaneously. The following combinations are possible {C,B}, {C,D}, {E,B}, {E,D}, and {E,G}. Note that {A,B} would be possible and in fact provide the biggest bang for the buck, or least cost per crash day, except that activity A was already crashed by its one allowable day. Of the remaining choices, the combination of crashing activities {E,B} costs the least at a total of $1,250 for both activities. After crashing, the path durations are:

- A–C–E–H–I with duration 15 weeks
- B–C–E–H–I with duration 14 weeks
- B–D–E–H–I with duration 14 weeks
- B–D–F–H–I with duration 14 weeks
- B–D–G–H–I with duration 15 weeks

Now, only two paths are critical, with a length of 15 weeks. We need to crash one more week to reduce the project duration down to 14 weeks. Only the following combinations will work: {C,D}, {C,G}, {E,D}, and {E,G}. Of these possibilities, the combination of {E,G} for $1,400 is the lowest.

In summary, we required three iterations of crashing activities one week at a time in order to crash the project down from 17 weeks to 14 weeks. The cost of crashing would be $3,150, increasing the total estimated project cost from $35,000 to $38,150.

The crashing technique for managing projects reduces their durations by making a trade-off between time and money. Because time and cost are the only considerations in the process, many important qualitative aspects will be ignored if they are not explicitly considered. For example, project crashing can increase stress levels, increase the use of overtime or extend working hours, and generally affect employee attitudes and morale in negative ways.

Reducing Performance Specifications and Other Alternatives

Making time–cost trade-offs is one way to expedite project activities and reduce the duration of the project. As previously mentioned, however, other alternatives may be more attractive to pursue and, interestingly, these other alternatives are often ignored or at best given limited consideration. One of these is making time–specifications trade-offs. The basic idea is similar to making time–cost trade-offs. Here, however, project specifications generally indicate the amount of work involved in a project, and because the work involved and the time required are directly related, it is possible to make a trade-off between time and specifications. In essence, the project duration can be reduced by simply eliminating certain project deliverables. For example, in the systems development project, it may be more attractive to simply drop or postpone a certain number of the reports the computer program automatically generates. By dropping these project deliverables, it may be possible to shift the resources originally intended for them onto other activities that could reduce the project duration without increasing costs. Naturally, the opportunity to eliminate deliverables on any project depends on a number of factors, particularly how critical a given deliverable is to the overall project. For example, activity B, Database Design in the systems development project, could not be dropped without effectively crippling the project. But, as mentioned, if certain reports are not critical, they could be dropped or postponed to a later date. In fact, one method of rapidly implementing computer programs is to quickly develop a core system with just basic features and only later, through a series of "enhancements" or future mini-projects, does the full system evolve.

It should be noted that if the planned project completion takes longer than desired, perhaps an approach may be to revisit the desired date of completion. Where did the date come from? Many times, a project team will find that the date is not set in stone. Perhaps it was originally decided because it seemed "reasonable" at the time. But most often, dates and durations are generally thought of first and the work requirements second. Hence, when the due dates of project deliverables are based on a good reason, the work should fit the schedule. Otherwise, it may be better to let the schedule (due dates) fit the work that is required.

Finally, it is important to realize that within the alternative set, individual alternatives are not mutually exclusive. It may be possible, even desirable, to implement a combination of these alternatives. For example, it may make sense to crash a project a few time periods and eliminate some of the deliverables. Alternatively, the desired due date might be put off until later, while simultaneously crashing a few activities on the project.

Summary

Projects are complex and dynamic processes and ever-present parts of business operations. Although projects vary in size and importance, they share certain characteristics that make them difficult to manage. Projects are subject to uncertainty, often involve multiple stakeholders, are subject to finite lifetimes and limited resources, and in many cases provide no clear authority within the project's structure. Each of these characteristics adds to a project's complexity and makes success difficult to achieve. Project success itself is often difficult to determine because of multiple stakeholders who effectively determine success. Consequently, it is important to manage the expectations of stakeholders and provide constant and consistent communication among everyone involved.

Successful project management means avoiding the common causes for failure and using state-of-the-art tools and methods to plan and control work as it proceeds. Common causes for failure include not proactively managing uncertainty, improperly managing expectations among stakeholders, and scope creep. A critical success factor that arises from these observations is conservative project planning.

An exceptional tool for project planning is a network diagram. A network diagram helps determine the project schedule and answer questions pertaining to when activities will start and end. The process of planning never ends until the project is completed. Because of the dynamic nature of projects, planning, in effect replanning, must be repeated periodically to update project status and allow management to make appropriate adjustments when necessary.

Review Questions

1. What are the common characteristics of projects? How do these characteristics increase the complexity and difficulty of achieving success in project management?
2. How should project success be determined?
3. What is meant by conservative project planning? Identify examples of conservative planning.
4. What are some of the common causes for project failure? Identify ways in which these causes can be circumvented or otherwise managed.

Problems

15.1. The following table outlines the activities, activity durations, and the precedence relationships of a project to be scheduled:

Activity	Duration (days)	Immediate Predecessors
A	3	—
B	2	—
C	6	A
D	4	A
E	5	A,B
F	2	C
G	8	D
H	2	E
I	5	F,G,H
J	10	E

a. Construct an activity-on-node network for the project.
b. Calculate the *ES*, *EF*, *LS*, and *LF* for each activity.
c. How long will it take to complete this project?
d. What is (are) the critical path(s)?
e. What is the slack for each activity not on a critical path?

15.2. The following table outlines the activities, activity durations, and the precedence relationships of a project to be scheduled:

Activity	Duration (weeks)	Immediate Predecessors
A	3	—
B	6	A
C	4	A
D	3	B
E	2	B,C
F	4	C
G	2	D,E,F

a. Draw the project network for the project.
b. Calculate the *ES*, *EF*, *LS*, and *LF* for each activity.
c. How long will it take to complete this project?
d. What is (are) the critical path(s)?
e. What is the slack for each activity not on a critical path?

15.3 You receive the following project information for each activity, the time (in weeks) it takes to complete, the possible weeks by which that time can be reduced, and the cost per week to decrease the activity time. The cost to complete the project in normal time is $10,000.

Activity	Duration (weeks)	Predecessor(s)	Crash Weeks Possible	Crashing Cost per Week
A	3	—	1	$1,500
B	2	—	—	—
C	7	A,B	3	$1,750
D	4	B	1	1,000
E	5	B	2	$1,250
F	1	C,D,E	—	—
G	2	E	1	$1,250

a. Draw the project network for this project.
b. What is the minimum time duration of the project?
c. What is the critical path of the project?
d. What is the slack time, if any, for activity D?
e. How much will it cost to complete the project in 10 weeks? 9 weeks?

15.4 You receive the following project information for each activity, the time (in weeks) it takes to complete, the possible weeks by which that time can be reduced, and the cost per week to decrease the activity time. The cost to complete the project in normal time is $15,500.

Activity	Duration (weeks)	Predecessor(s)	Crash Weeks Possible	Crashing Cost per Week
A	4	—	1	$900
B	2	A	2	$500
C	4	A	2	$800
D	3	A	1	$250
E	4	B,C	1	$750
F	1	C,D,E	—	—

a. Draw the project network for this project.
b. What is the minimum time duration of the project?
c. What is the critical path of the project?
d. How much will it cost to complete the project in 12 weeks? 10 weeks?

15.5 If it is desirable to crash a project to shorten its time to completion, why not simply crash the activity with the lowest crash cost per period of time?

15.6 The following table outlines the activities, activity durations, and the precedence relationships of a project to be scheduled:

Activity	Duration (days)	Immediate Predecessors
A	3	—
B	2	—
C	6	—
D	4	A,B
E	5	B,C
F	2	A,D
G	8	D,E
H	2	F,G
I	5	G
J	10	F,H,I

a. Construct an activity-on-node network for the project.
b. Calculate the ES, EF, LS, and LF for each activity.
c. How long will it take to complete this project?
d. What is (are) the critical path(s)?
e. What is the slack for each activity not on a critical path?

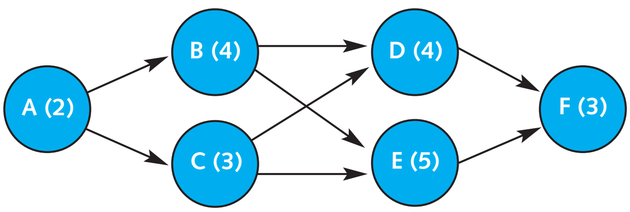
15.7 A project has an expected completion time of 16 weeks, yet the desired completion times is 14 weeks. If the variance of activities on the path with the longest expected completion time sums to 636, then
a. What is the probability of completing all activities on the path within the desired time frame?
b. If the project includes other paths, albeit with shorter expected completion times, why would the probability of completing the entire project be less than the answer to part (a)?

15.8 Management decided to implement the project described in the following table:

Activity	Predecessor(s)	Optimistic Time (weeks)	Most Likely Time (weeks)	Pessimistic Time (weeks)
A	—	2	3	5
B	—	1	2	4
C	A	3	3	5
D	A,B	2	6	9
E	C	2	4	5
F	B,D	1	2	3
G	E,F	2	3	4

a. Draw the project network.
b. What is the expected completion time of the project?
c. If the path A–D–F–G has the longest expected completion time, why is it not necessarily the critical path?
d. What are the variances for each activity?
e. Assuming that the path completion times are independent, what is the probability of completing the project in 15 weeks?
f. Given the same assumption as in part (e), what is the probability of completing the project in 12 weeks?

15.9 You are chosen to take over the following project and finish it four days ahead of the time indicated by the critical path. The following AON diagram describes the little remaining work to be done on this overdue project. Note that the activity durations, in days, are shown in parentheses.



The following table outlines information available regarding crash costs and times for the remaining activities.

Activity	Crash Cost ($/day)	Crash Days Possible
A	—	—
B	350	2
C	200	2
D	100	2
E	300	2
F	450	1

a. Use the critical path method to determine the duration for this project.
b. What is the most economical way to crash the project duration by four days? How much will it cost?
c. What is (are) the new critical path(s)?

CASE STUDY

The Quick Course Preparation Case

Tom and Harry sat dumbstruck as Dick, the Chair of the Management Department, asked them if they would co-teach the new MBA elective in Services Operations this fall. The slack jaws and waggling tongues were a little disconcerting. Dick then added, "Ok, I know it's asking a lot, given the additional teaching load and that there's only 30 days (not counting today) until the start of the semester, but we've got to have some motivation for this class and so there you have it. With both of you to split the effort, however, I don't think it should be too overwhelming."

"Dick, you know the students generally and intensely dislike it when there are two instructors teaching the same course. This does not bode well for the program or our teaching evaluations. Not to mention the last time this happened," replied Harry.

"Last time?" asked Dick.

"I told you not to mention that," said Harry.

Dick sighed. "Naturally, lines of communication and responsibility must be clearly defined so that the students know the score and expectations are properly managed. For that matter, I suggest breaking up the course into two modules, with each of you being the 'de facto' instructor for one of them."

Now Tom got into it. "Perhaps that might work, but I think preparation time is the bigger issue, what with only 30 days to prepare. You know it's a new course—a completely new preparation, and since it has a distance teaching component, all the materials need to be ready by the first day of class. How can we even get the course materials, including book and course pack to the bookstore in time? First, you have to select the course materials that include the textbook, cases, and reading materials—five days at least. Then, the order lead-time of the book itself is another 20 days alone. Actually, it could take anywhere from 15 to 25 days."

Dick responded, "That sounds like less than 30 days to me, but then math was never my strong point. Besides, I've heard that the new edition of *Successful Service Operations Management* is great. It even has a book chapter on Project Management. Surely, that should cut down the time devoted to selecting a book, and anyhow, I'm sure we can expedite book delivery via FedEx, if necessary, for about $500. That would save another three days if needed. Even with a fiscal budget that is, for the lack of a better metaphor, tighter than your ability to give A's, I'm sure I can loosen up a few dollars to make it happen if necessary."

Harry chimed in at that point, "Ok, but I think the cases and other reading materials are going to pose a bigger problem. It takes five days for our selections to go through the copyright department. Then it's another ten days to wait until they are delivered, and that's being more charitable than saying that this case is challenging. I mean, really, the materials could take anywhere from seven to fourteen days to be delivered. Only then can the course pack be put together, assuming we've put together all the other material—the lecture notes, homework sets, case assignments,

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and syllabus by that time. I mean, just putting the material together will take three days at least, then it's another five days until they are back from the printer and delivered to the bookstore."

"Ok, Ok, Ok," said Dick. "I realize you both did not expect this on your plate, particularly with the slack jaws, waggling tongues, and everything, but I have every confidence in the both of you to put together a bang-up course and save the day. I'm sure it won't go unnoticed by the Dean and it certainly won't by me. Moreover, I'll set aside some money so you have a graduate assistant that can help with the homework sets and the grading. I can also set aside some time to help. So why don't the both of you sit down, talk it through, and put together a plan. If there is something else you think of that I can do to help, just let me know."

Later, Tom and Harry met to discuss what they needed to do. Harry started. "Ok, as far as I can tell, the *very* first thing we need to do is figure out the course content. We should be able to hammer that out in about four days. Then we can select the course book, the cases, and supplementary reading materials as we discussed before. I think the estimate you stated earlier, five days, sounds about right. Although, if we get caught short on time, I know we can cut our search time for course materials via educational pay Web sites on the Internet. It would cost about $700, but then it should only take two days to select the materials."

"Well, that might be handy and as Dick mentioned, he can find some money if necessary," said Tom. "Once the materials are selected, we'll have to prep the lectures, create the case teaching plans, and of course, the syllabus. I'm sure we can draw on some material from our other courses, so I bet we can prep the lectures in about eight days, the case teaching plans should take about four days, and the syllabus two days at most. After we put together the lecture material, we can then put together the PowerPoint slides—say five days, and the lecture notes, afterwards, for the course pack in another day. What else?"

"Well, as I said before, the course pack should also contain both the case assignments and homework sets. Once the case teaching plans are completed, the case assignments should only take two days to put together. As for the homework sets, once we decide on the syllabus, I figure that should take another four days. I've got a lot of material already prepared that we can use."

"Since we will get a graduate assistant to help, we can have whoever that person is put together homework solution sets. I'd like to have it done before the start of the semester. That way, we can resolve any problems before they crop up during the course. But that means we have to hire the assistant and go through all that bother. Looking through a hundred resumes, well, I'd rather be a student assigned to this very case."

"Come on Tom, a graduate assistant will be a big help, and it won't be much of a bother," said Harry. "Look. It will take, say, five days to go through the hiring

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process, probably another five days of training and on-the-spot education, but then that person will be able to put together the solution sets for us. It will probably take ten days for whoever we hire, but I'd gladly trade the effort of creating solution sets with the effort on hiring and training—particularly given that we later have a resource to help with grading."

"Yeah, I'm sure you're right," said Tom. "We can actually get started on the hiring process at anytime, and I'm sure it won't hold us up. Anything else we've forgotten? That is, is there any other information we can impart on our readership to enhance the learning experience of this case?"

"The only thing I can think of is that we need to remember to leave five days lead time for the course pack to be printed and delivered to the bookstore, once we've put it together. Although, I know they can expedite for a fee of $400 that will cut it down to two days. Otherwise, I think we've covered everything."

Questions:

1. Viewing course management from the perspective of project management, what do Tom and Harry need to do to help ensure success of the course? That is, what issues must they address as co-teachers that they would not otherwise need to address? Will separating the course into modules address these issues appropriately? If not, what else do you recommend?
2. Put together a network diagram for this project assuming deterministic task times (use mean expected completion times). The network diagram should identify all activities, precedence relationships, and task times.
3. From your network diagram, list all paths, identify path lengths, and those that are critical.
4. Without crashing and without regard to whomever actually does the work, will the project be completed in normal time? If not, what, if anything, can be done in order to complete the course preparation within the allotted 30 days?
5. Using your answer to question 4 and the probabilistic time estimates, what is the probability of completing the project on time? What would be the best means of ensuring that this probability is greater than 95%. *Hint:* You first need to compute the probability of completing each path that contains activities with uncertain times.