Successful Project Management

SIXTH EDITION

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Successful Project Management, Sixth Edition

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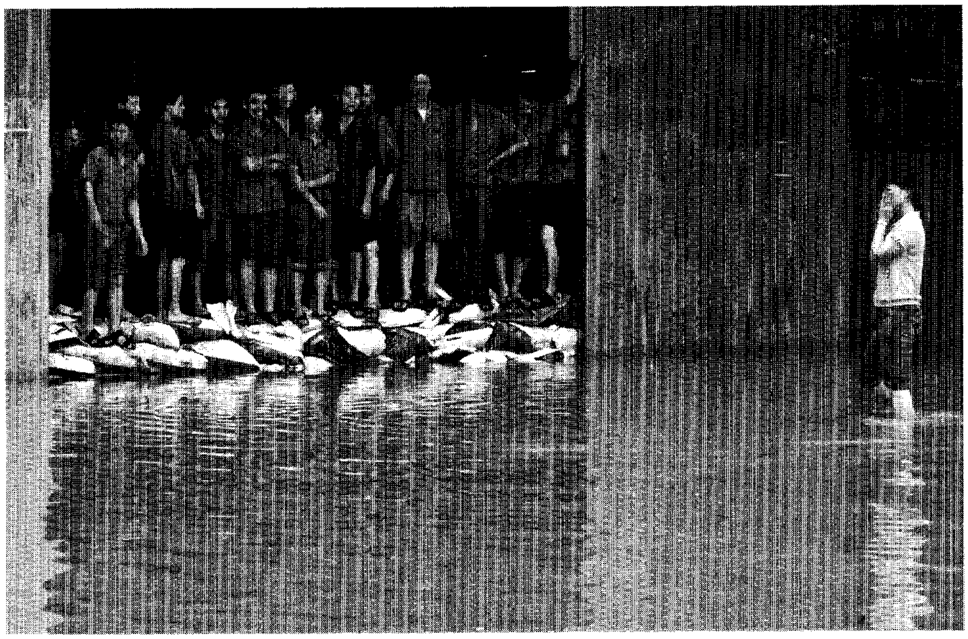
CHAPTER 5

Developing the Schedule

Earliest Start and Finish Times
Latest Start and Finish Times
Total Slack
Critical Path
Free Slack
Bar Chart Format

An Information System Example: Internet Applications Development for ABC Office Designs (Continued)



AP Photo

Concepts in this chapter support the following Project Management Knowledge Areas of *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*:

Project Time Management

More than Rain Delays Construction in Taiwan

Weather has always played a part in the scheduling of construction projects. Typhoons in Taiwan are known to suspend or extend project schedules. Delayed starts and extended durations have pushed activities on the critical paths to cause project delays on hundreds of construction projects in Taiwan. These scheduling delays are resulting in litigation, an average of 1.3 claims for each of the Taiwan Area National Expressway Engineering Bureau's 300 construction projects.

Project scheduling by experienced project managers and teams had taken into account potential causes for delays and had planned for predictable causes. The litigation claims in Taiwan are due to delays in precedent activities that impacted the work to be performed by contractors assigned to the delayed subsequent activities. These costly delays are a lesson for all who schedule the activities of any type of project and, in particular, construction projects.

Two main causes of critical path delays were identified—delayed start of the project and extended duration of activities. The challenges for the project delay causes were exclusive to each delay type.

Delayed starts were caused by public resistance, delayed site handover, change orders, government regulation changes, and delayed precedent activities. In addition to weather, extended duration delays were caused by changed site conditions, changed scope of work, shortages of materials, contractor financial difficulties, delayed inspections and acceptance by owner, inadequate construction approaches and methods, poor site management, and ambiguous definition and approval of calendar working days. A lesser extent of causes for extended duration of project activities include interference by the owner, contract issues, accidents, and price escalations.

A further examination into the causes reveals a common theme—change management. The team developing the schedule should use the lessons learned to include the expected impacts of changes to the orders and scope of work to limit the delays and the litigations. Even though the weather remains a leading cause for delays of the project's critical path, approaches to mitigate the other causes of delays in the project schedule are necessary to develop the most realistic schedule. Contingency inclusions within contracts are one method of mitigation, contingency scheduling is another.

Many lessons related to scheduling are to be learned from these 300 construction projects and their delays. A proactive approach to scheduling delay mitigation could offset the vast number of claims made in Taiwan and increase the probability of completing projects on time and within the planned schedule. Careful schedule planning to include the weather and expected changes are important to future planning efforts for successful project management in Taiwan or in your projects.

Based on information from Jyh-Bin, Y., C. Mei-Yi, and K. Huang (2013). "An Empirical Study of Schedule Delay Causes Based on Taiwan's Litigation Cases," *Project Management Journal, 44*(3), 21–31. doi:10.1002/pmj.21337.

The previous chapter discussed what work needs to be done in terms of scope and deliverables. It also discussed how that work will get done by defining specific activities and arranging them in a sequence of dependent relationships to create a network plan. This network plan is a roadmap for how all the activities fit together to accomplish the project work scope and objective. When network planning techniques are used, the scheduling function depends on the planning function. A *schedule* is a timetable for the plan and, therefore, cannot be established until the network-based plan has been created. In this chapter, we will develop a schedule for that plan. This chapter deals with estimating the resources and durations for all the specific activities, and developing a detailed project schedule that determines when each activity should start and finish.

This chapter also discusses monitoring and controlling the progress of the project, replanning, and updating the project schedule. Once a project actually starts, it is necessary to monitor progress to ensure that everything is going according to schedule. This involves measuring actual progress and comparing it to the schedule. If at any time during the project it is determined that the project is behind schedule, corrective action must be taken to get back on schedule, which may be very difficult if a project gets too far behind.

The key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking any needed corrective action immediately. A project manager cannot simply hope that a problem will go away without corrective intervention—it will not. Based on actual progress and on consideration of other changes that may occur, an updated project schedule can be generated regularly that forecasts whether the project will finish ahead of or behind its required completion time. You will become familiar with,

Estimating the resources required for each activity
Estimating the duration for each activity
Establishing the estimated start time and required completion time for the overall project
Calculating the earliest times at which each activity can start and finish, based on the project estimated start time
Calculating the latest times by which each activity must start and finish to complete the project by its required completion time
Determining the amount of positive or negative slack between the time each activity can start or finish and the time it must start or finish
Identifying the critical (longest) path of activities
Performing the steps in the project control process
Determining the effects of actual schedule performance on the project schedule
Incorporating changes into the schedule
Developing an updated project schedule
Determining approaches to controlling the project schedule
Implementing agile project management

After studying this chapter, the learner should be able to:

- Estimate the resources required for activities
- Estimate the duration for an activity
- Determine the earliest start and finish times for activities
- Determine the latest start and finish times for activities
- Explain and determine total slack
- Prepare a project schedule
- Identify and explain the critical path
- Discuss the project control process
- Develop updated schedules based on actual progress and changes
- Discuss and apply approaches to control the project schedule
- Explain agile project management

1. The estimated

____

for an activity will influence the

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to perform the activity and the

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of the activity.

2. When estimating resources for activities, the

____

of each resource has to be taken into account.

It is necessary to estimate the types and quantities of resources that will be required to perform each specific activity to subsequently estimate how long it will take to perform the activity. Resources include people, materials, equipment, facilities, and so forth. The **estimated resources** required for an activity will influence the estimated duration to perform the activity and the estimated cost of the activity.

When estimating resources for activities, the *availability* of each resource has to be taken into account. It is important to know what types of resources are available, in what quantities, and during what time periods to determine if the right types of resources will be available in sufficient quantities during the time periods that they are needed for specific activities. For example, a project for a new building requires architects and engineers during the design phase at the front end of the project, and then requires crafts and tradespeople during the construction phase. So the architect-engineering firm needs to have architects and engineers available when they will be needed to design the new office building. If they will not be available because they are assigned to work on other projects, it could delay the design of the office building or may require outsourcing the design activities to a subcontractor. When considering the availability of resources, it may be necessary to make some assumptions, such as the ability to hire additional individuals with the appropriate expertise in time for when they will be required to work on a project. For example, a project to develop a new information system to track product recalls may require more software developers than are currently available on staff. So when resources are estimated for specific software development activities, it may be determined that a certain quantity of software developers are required, along with the assumption that additional developers will be hired and available by the time they are required.

With an understanding of the availability of the types and quantities of various resources during the period the project will be performed, it is necessary to *estimate the types and quantities of resources required to perform each specific activity.* In many cases, especially for smaller projects, most activities involve people resources—that is, the members of the project team who may be utilized full time or part time during the project. For example, it is estimated that four painters are needed to paint the interior of a new house. If four painters are not available during the period they will be needed, then some of the painters may have to work extra hours or some of the work may have to be subcontracted. On the other hand, if too many painters are estimated, it would cause a problem of inefficiency because they would be bumping into each other, or they might have an excessive amount of idle time. In addition to people resources, specific activities may also require an estimate of equipment resources, such as the types and quantities of earth-moving equipment required to clear the land for an expansion of a school building. Similarly, there may be specific activities that require an estimate of materials or supplies needed for performing an activity, such as the lumber needed to frame a house, or the shingles needed to install a roof, or the furniture needed to be installed at a new day care center. Sometimes, estimating the types and quantities of materials that will be required for a specific activity provides an opportunity or reminder to include some related activities that may have been unintentionally forgotten when the specific activities were defined for a work package. In the case of the furniture, maybe the materials estimate was for the activity to install furniture, but then it was realized that several other preceding activities associated with the furniture had been left out, including requesting bids or quotes for the furniture, reviewing proposals, and ordering the furniture, as well as the supplier's task of making and/or delivering the furniture.

The estimated types and quantities of resources required for an activity together with the availability of those resources will influence the estimated duration for how long it will take to perform the activity.

When estimating the types and quantities of resources required for each specific activity, it is valuable to involve a person who has expertise or experience with the activity to help make the estimate. The estimated activity resources will also be used later for estimating activity costs and determining the project budget. See the section on estimating activity costs in Chapter 7 for further information.

See Chapter 6, Resource Utilization, for further discussion of this topic.

Reinforce Your Learning

3. It is necessary to estimate the ____________ and ____________ of resources required for each activity.

Estimate Activity Duration

Once the types and quantities of resources are estimated for each activity, estimates can be made for *how long* it will take to perform each activity. The **estimated duration** for each activity must be the *total elapsed time*—the time for the work to be done plus any associated waiting time. In Figure 5.1, for example, the estimated duration for activity 1, "Varnish Floors," is five days, which includes both the time to varnish the floors and the waiting time for the varnish to dry.

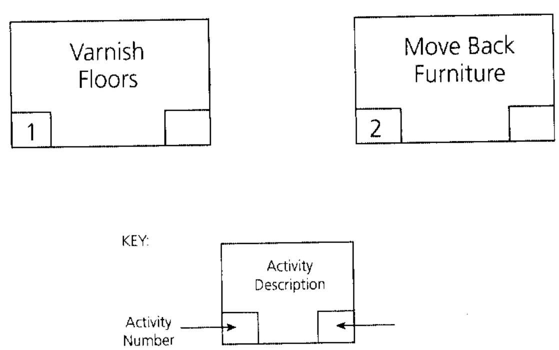
The activity's estimated duration is shown in the lower right-hand corner of the box.

It is a good practice to have the person who will be responsible for performing a specific activity estimate the duration for that activity. This generates a commitment from that person and avoids any bias that may be introduced by having one person estimate the durations for all of the activities. In some cases, though—such as for large projects that involve several hundred people performing various activities over several years—it may not be practical to have each person estimate activity durations at the beginning of the project. Rather, each organization or subcontractor responsible for a group or type of activities may designate an experienced individual to estimate the durations for all the activities for which the organization or subcontractor is responsible. If an organization or subcontractor has performed similar projects in the past and has kept records of how long specific activities actually took, these historical data can be used as a guide in estimating the durations of similar activities for future projects.

Reinforce Your Learning

4. True or false: The duration estimate for an activity should include the time required to perform the work plus any associated waiting time.

FIGURE 5.[illegible] **Activity Estimated Duration**



The estimated duration for an activity must be based on the estimated quantity of resources required to perform the activity. The estimated duration should be aggressive, yet realistic. It should not include time for a lot of things that could possibly go wrong. Nor should it be too optimistically short. It is generally better to be somewhat aggressive and estimate a duration for an activity at 5 days, say, and then actually finish it in 6 days, than to be overly conservative and estimate a duration at 10 days and then actually take 10 days. People sometimes perform to expectations—if an activity is estimated to take 10 days, their effort will expand to fill the whole 10 days allotted, even if the activity could have been performed in a shorter time.

5. The estimated ______________ for an activity must be based on the ______________ of ______________ required to perform the activity.

Playing the game of inflating estimated durations in anticipation of the project manager negotiating shorter durations is not a good practice. Nor is padding estimates with the vision of becoming a hero when the activities are completed in less time than estimated.

Throughout the performance of the project, some activities will take longer than their estimated duration, others will be done in less time than their estimated duration, and a few may conform to the estimated duration exactly. Over the life of a project that involves many activities, such delays and accelerations will tend to cancel one another out. For example, one activity may take two weeks longer than originally estimated, but this delay may be offset by two other activities that each takes a week less than originally estimated.

It should be noted that at the beginning of the project, it may not be possible to estimate the durations for all activities with a level of confidence regarding their accuracy. This is especially true for longer-term projects. It may be easier to estimate the durations for near-term activities, but as the project progresses, the project team can *progressively elaborate* the estimated durations as more information is known or becomes clear to allow for more accurate estimated durations.

Figure 5.2 shows the network diagram for a consumer market study, with the estimated durations in days for each activity. A consistent time base, such as hours or days or weeks, should be used for all the estimated durations of activities in a network diagram.

With projects for which there is a high degree of uncertainty about the estimated durations for activities, it is possible to use three time estimates: an optimistic estimate, a pessimistic estimate, and a most likely estimate. For a discussion of this probabilistic technique, see Appendix 1 at the end of this chapter.

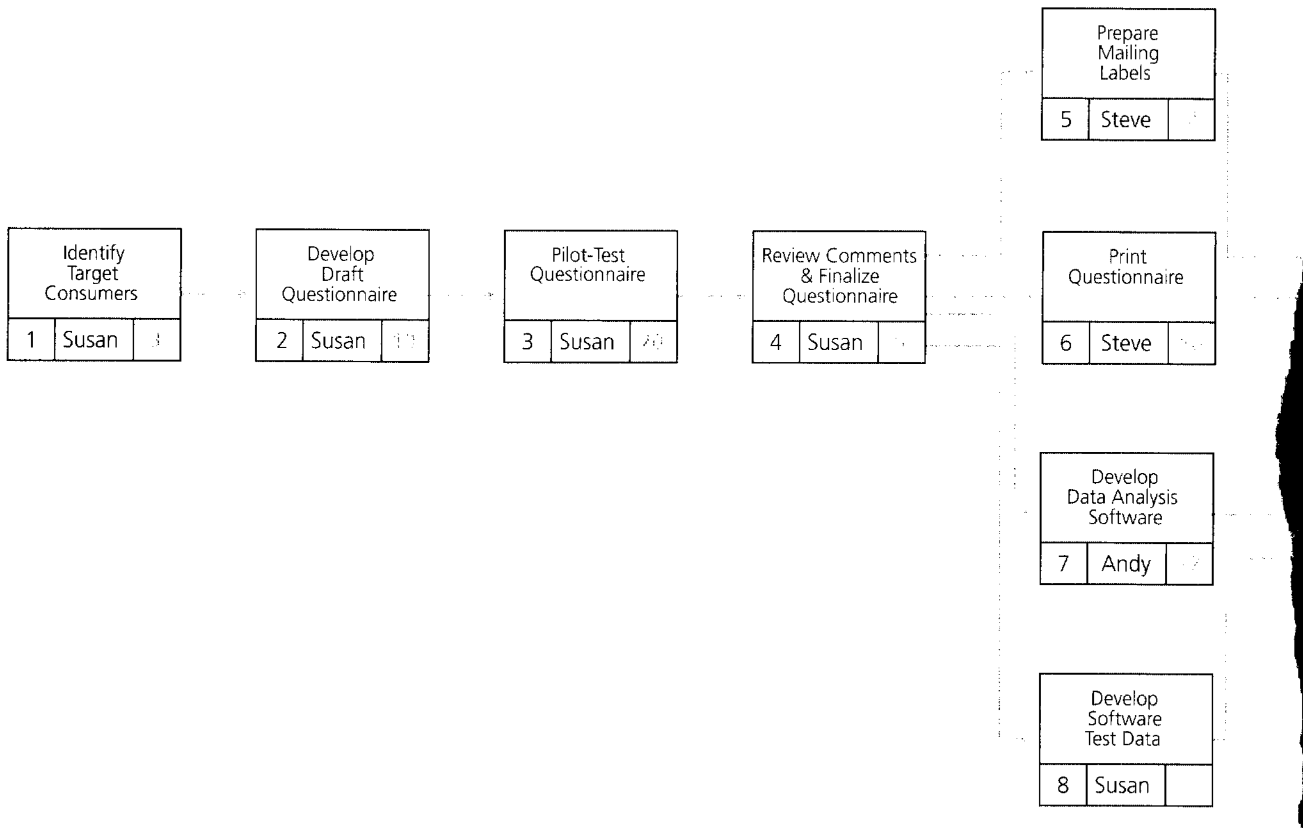
To establish a basis from which to calculate a schedule using the estimated durations for the activities, it is necessary to select an **estimated start time** for when the project is expected to begin and a **required completion time** for when the project must be done. These two times (or dates) define the overall window, or envelope, of time in which the project must be completed.

6. The overall window of time in which a project must be completed is defined by its ______________ ______________ time and ______________ ______________ time.

The sponsor or customer often states the project required completion time in the project charter, request for proposal (RFP), or contract—for example, the project must be finished by June 30, the feasibility study must be completed in time for the board meeting on September 30, or the annual reports must be in the mail by January 15.

The contractor, however, may not want to commit to completing the project by a specific date until the customer has approved the contract. In such cases, the contract may state, "The project will be completed within 90 days after signing of

Figure 5.2 Network Diagram for Consumer Market Study Project, Showing Estimated Durations



the contract." Here, the overall project time is stated in terms of a cycle time (90 days) rather than in terms of specific calendar dates.

Assume that the consumer market study project shown in Figure 5.2 must be completed in 130 working days. If we establish the project estimated start time as 0, then its required completion time is day 130.

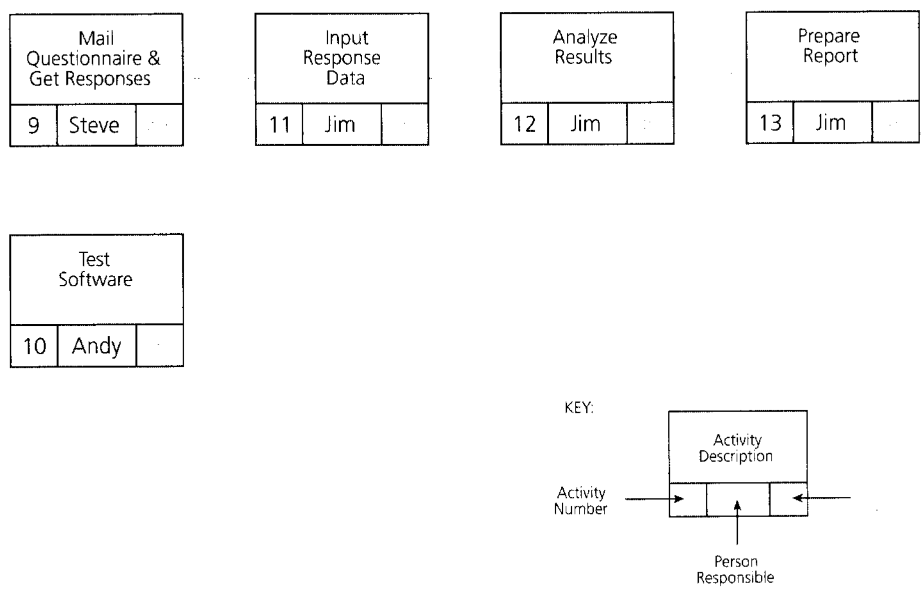
Develop Project Schedule

Once you have an estimated duration for each activity in the network and have established an overall window of time in which the project must be completed, you must determine (based on durations and sequence) whether the project can be done by the required completion time. To determine this, you can develop a project schedule that provides a timetable for each activity and shows:

1. The earliest times (or dates) at which each activity can start and finish, based on the project estimated start time (or date).
2. The latest times (or dates) by which each activity must start and finish to complete the project by its required completion time (or date).

EARLIEST START AND FINISH TIMES

Given an estimated duration for each activity in the network and using the project estimated start time as a reference, you can calculate the following two times for each activity:



1. **Earliest start (ES) time** is the earliest time at which a specific activity can begin, calculated on the basis of the project estimated start time and the estimated durations of preceding activities.
2. **Earliest finish (EF) time** is the earliest time by which a specific activity can be completed, calculated by adding the activity's estimated duration to the activity's earliest start time:

7. What is the equation for calculating an activity's earliest finish time?

$$EF = ES + \text{Estimated Duration}$$

The ES and EF times are determined by calculating *forward*—that is, by working through the network diagram from the beginning of the project to the end of the project. There is one rule that must be followed in making these forward calculations:

Rule 1: The earliest start time for a specific activity must be the same as or later than the latest of all the earliest finish times of all the activities leading directly into that specific activity.

8. The earliest start and earliest finish times for activities are determined by calculating ______ through the network diagram.

Figure 5.3 shows three activities leading directly into "Dress Rehearsal." "Practice Skit" has an EF of day 5, "Make Costumes" has an EF of day 10, and "Make Props" has an EF of day 4. "Dress Rehearsal" cannot start until all three of these activities are finished, so the latest of the EFs for these three activities determines the ES for "Dress Rehearsal." The latest of the three EFs is day 10—the EF time for "Make Costumes." Therefore, "Dress Rehearsal" cannot start any earlier than day 10. That is, its ES must be day 10 or later. Even though "Practice Skit" and "Make Props" may finish sooner than "Make Costumes," "Dress Rehearsal" cannot start because the network dependent relationships indicate that *all three activities* must be finished before "Dress Rehearsal" can start.

Earliest Start Times

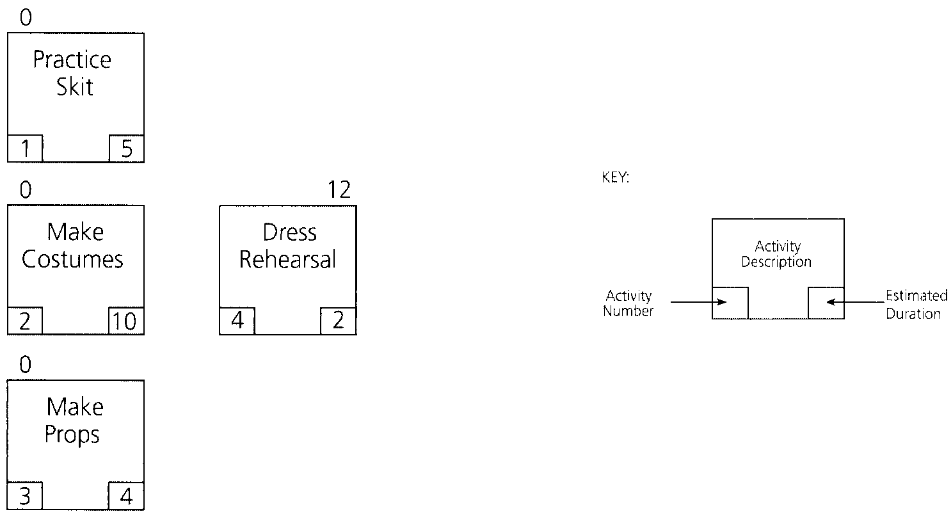
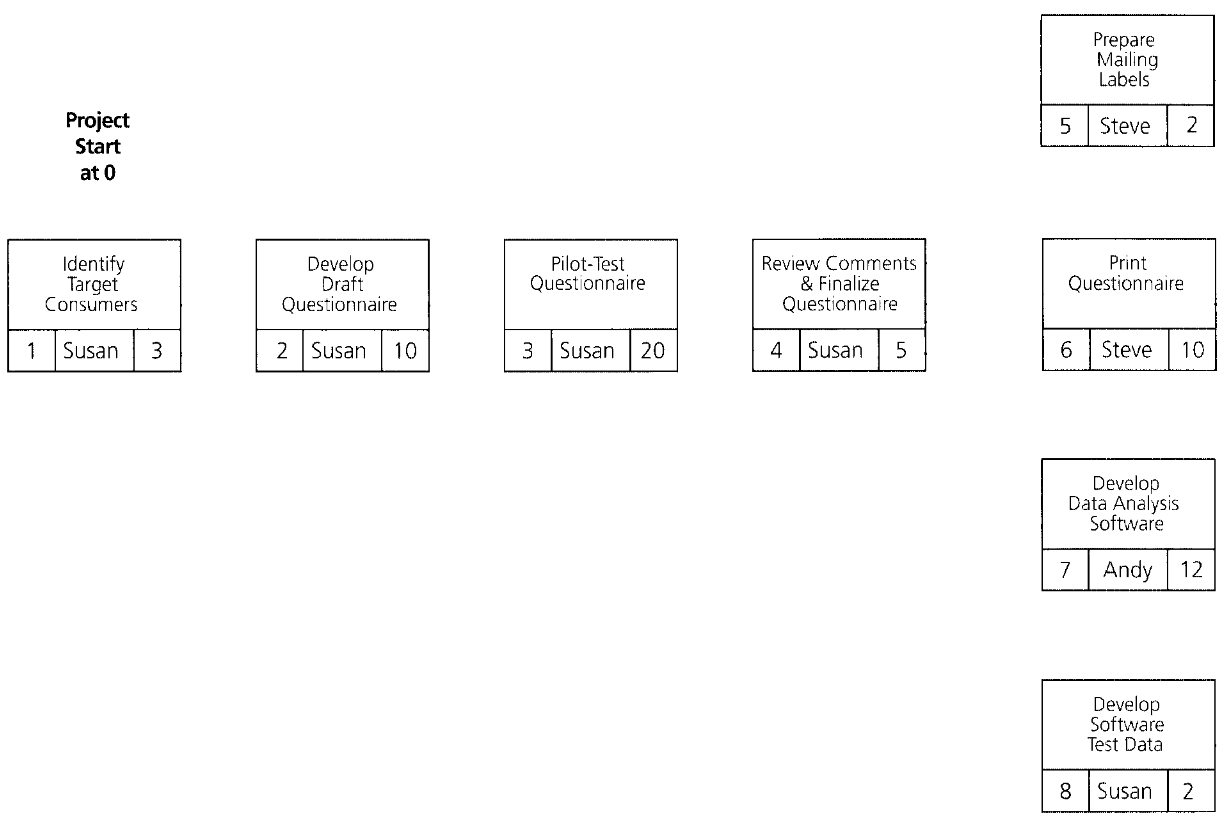


Figure 5.4 shows the forward calculations for the consumer market study project. The project estimated start time is 0. Therefore, the earliest "Identify Target Consumers" can start is time 0, and the earliest it can finish is 3 days later (because its estimated duration is 3 days). When "Identify Target Consumers"

Network Diagram for Consumer Market Study Project, Showing Earliest Start and Finish Times



is finished on day 3, "Develop Draft Questionnaire" can start. It has an estimated duration of 10 days, so its ES is day 3 and its EF is day 13. The calculations of ES and EF for subsequent activities are done similarly, continuing forward through the network diagram.

9. Refer to Figure 5.4. What are the earliest start and earliest finish times for "Pilot-Test Questionnaire"?

Look for a moment at "Test Software." It has an ES of day 50 because, according to Rule 1, it cannot start until the two activities leading directly into it are finished. "Develop Data Analysis Software" does not finish until day 50, and "Develop Software Test Data" does not finish until day 40. Because "Test Software" cannot start until both of these are finished, "Test Software" cannot start until day 50.

As a further illustration of Rule 1, refer once more to Figure 5.4. To start "Mail Questionnaire & Get Responses," the two activities immediately preceding it, "Prepare Mailing Labels" and "Print Questionnaire," must be finished. The EF of "Prepare Mailing Labels" is day 40, and the EF of "Print Questionnaire" is day 48. According to Rule 1, it is the later of the two EFs, which is day 48, that determines the ES of "Mail Questionnaire & Get Responses."

10. What determines a particular activity's earliest start time?

If you continue calculating the ES and the EF for each remaining activity in the network diagram in Figure 5.4, you will see that the very last activity, "Prepare Report," has an EF of day 138. That is 8 days beyond the project required completion time of 130 days. At this point, we know there is a problem.

It should be noted that although the ES and EF times for each activity are shown on the network diagram in Figure 5.4, this is *not* normally the case. Rather, the ES and EF times (and the LS and LF times, which are explained in

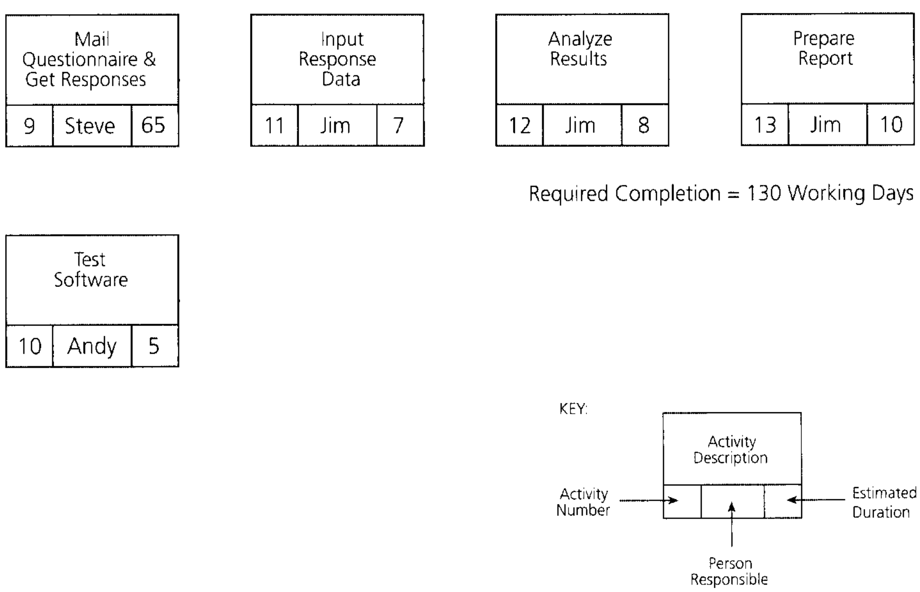


FIGURE 5.5 **Schedule for Consumer Market Study Project, Showing Earliest Start and Finish Times**

Consumer Market Study Project			[illegible]	[illegible]		[illegible]			
Activity		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	Identify Target Consumers	Susan	3	**0**	**3**				
2	Develop Draft Questionnaire	Susan	10	**3**	**13**				
3	Pilot-Test Questionnaire	Susan	20	**13**	**33**				
4	Review Comments & Finalize Questionnaire	Susan	5	**33**	**38**				
5	Prepare Mailing Labels	Steve	2	**38**	**40**				
6	Print Questionnaire	Steve	10	**38**	**48**				
7	Develop Data Analysis Software	Andy	12	**38**	**50**				
8	Develop Software Test Data	Susan	2	**38**	**40**				
9	Mail Questionnaire & Get Responses	Steve	65	**48**	**113**				
10	Test Software	Andy	5	**50**	**55**				
11	Input Response Data	Jim	7	**113**	**120**				
12	Analyze Results	Jim	8	**120**	**128**				
13	Prepare Report	Jim	10	**128**	**138**				

the following section) are listed in a separate schedule table, like the one in Figure 5.5. Separating the schedule table from the network logic diagram makes it easier to generate revised and updated schedules (perhaps using project management software), without continually making changes to the ES, EF, LS, and LF times on the network diagram itself.

LATEST START A[illegible]

Given an estimated duration for each activity in the network and using the project required completion time as a reference, you can calculate the following two times for each activity:

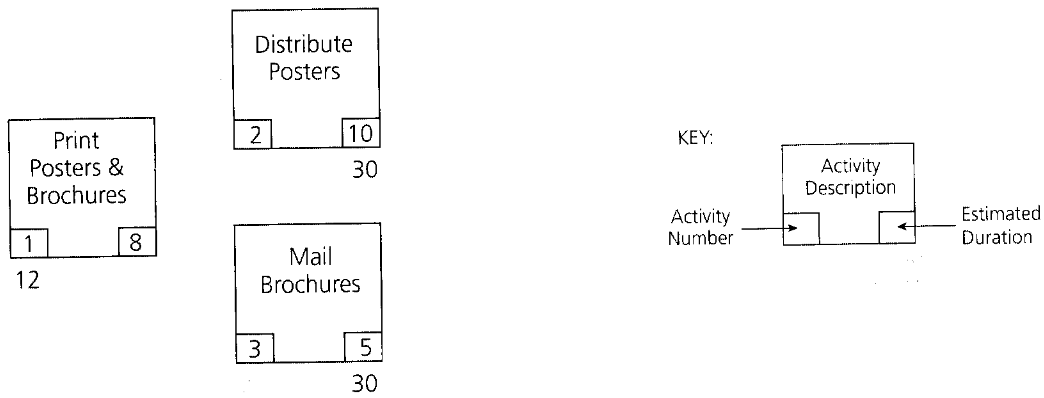
1. **Latest finish (LF) time** is the latest time by which a specific activity must be completed for the entire project to be finished by its required completion time. It is calculated on the basis of the project required completion time and the estimated durations of succeeding activities.
2. **Latest start (LS) time** is the latest time by which a specific activity must be started for the entire project to be finished by its required completion time. It is calculated by subtracting the activity's estimated duration from the activity's latest finish time:

$$LS = LF - \text{Estimated Duration}$$

[illegible] Your Learning

11. What is the equation for calculating an activity's latest start time?

Latest Finish Times



12. The latest finish and latest start times are determined by calculating __________ through the network diagram.

The LF and LS times are determined by calculating *backward*—that is, by working through the network diagram from the end of the project to its beginning. There is one rule that must be followed in making these backward calculations:

Rule 2: The latest finish time for a specific activity must be the same as or earlier than the earliest of all the latest start times of all the activities emerging directly from that specific activity.

Figure 5.6 shows two activities emerging directly from "Print Posters & Brochures." This project is required to be completed by day 30. Therefore, "Distribute Posters" must be started by day 20 because it has an estimated duration of 10 days, and "Mail Brochures" must be started by day 25 because it has an estimated duration of 5 days. The earlier of these two LSs is day 20. Therefore, the latest that "Print Posters & Brochures" must finish is day 20, so that "Distribute Posters" can start by day 20. Even though "Mail Brochures" does not have to start until day 25, "Print Posters & Brochures" must finish by day 20 or else the whole project will be delayed. If "Print Posters & Brochures" does not finish until day 25, then "Distribute Brochures" will not be able to start until day 25. Because "Distribute Brochures" has an estimated duration of 10 days, it will not finish until day 35, which is 5 days beyond the project required completion time.

Figure 5.7 shows the backward calculations for the consumer market study project. The required completion time for the project is 130 working days. Therefore, the latest that "Prepare Report," the last activity, can finish is day 130, and the latest that it can start is day 120 because its estimated duration is 10 days. For "Prepare Report" to start on day 120, the latest that "Analyze Results" must finish is day 120. If the LF for "Analyze Results" is day 120, then its LS is day 112 because its estimated duration is 8 days. The calculations of LF and LS for prior activities are done similarly, continuing backward through the network diagram.

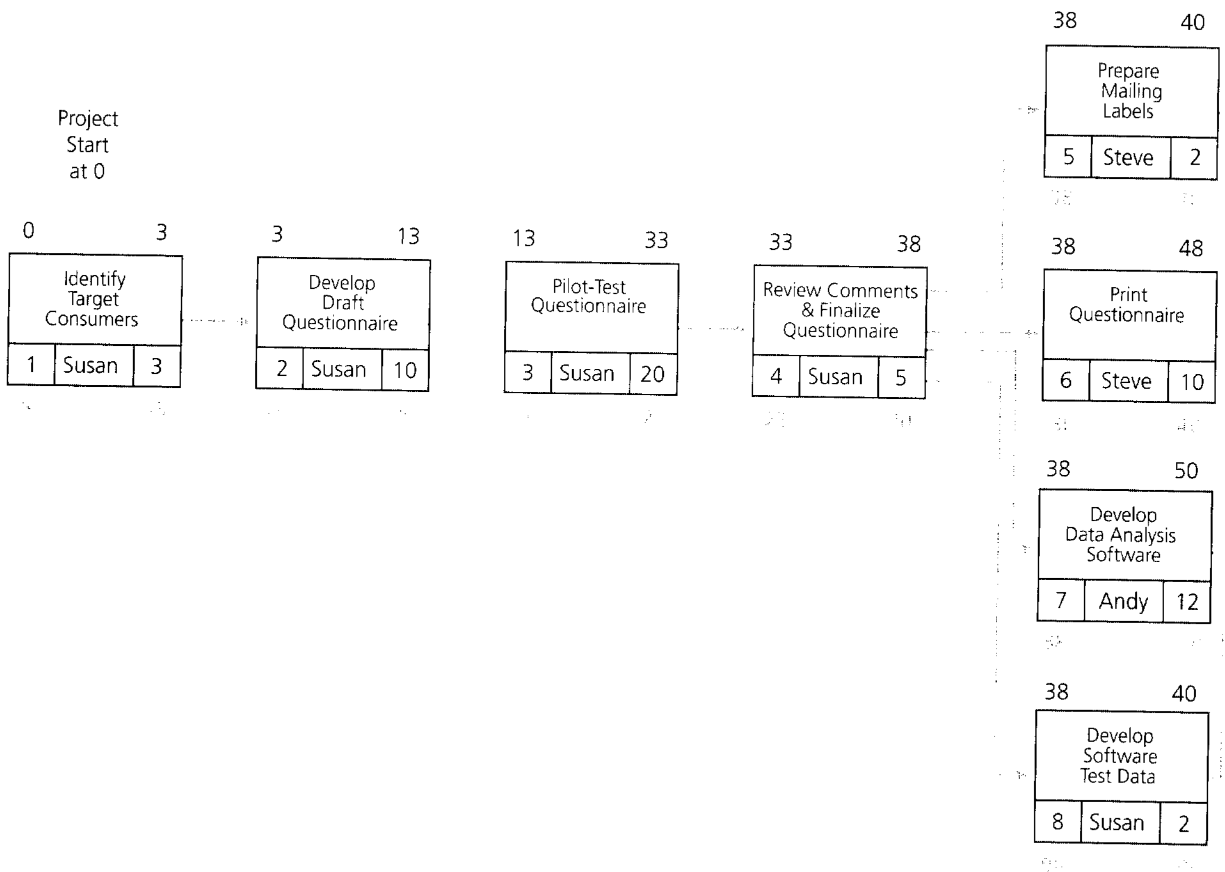
13. Refer to Figure 5.7. What are the latest finish and latest start times for "Input Response Data"?

14. What determines a particular activity's latest finish time?

Look at "Review Comments & Finalize Questionnaire." For the four activities emerging from this activity to start by their LS times (so that the project can finish by its required completion time of 130 days), "Review Comments & Finalize Questionnaire" must be finished by the earliest LS of all four activities, according to Rule 2. The earliest of the four LSs is day 30, the latest time by which "Print Questionnaire" must start. Therefore, the latest that "Review Comments & Finalize Questionnaire" must finish is day 30.

If you continue calculating the LF and the LS for each activity in the network diagram in Figure 5.7, you will see that the very first activity, "Identify Target

FIGURE 5.7 Network Diagram for Consumer Market Study Project, Showing Latest Start and Finish



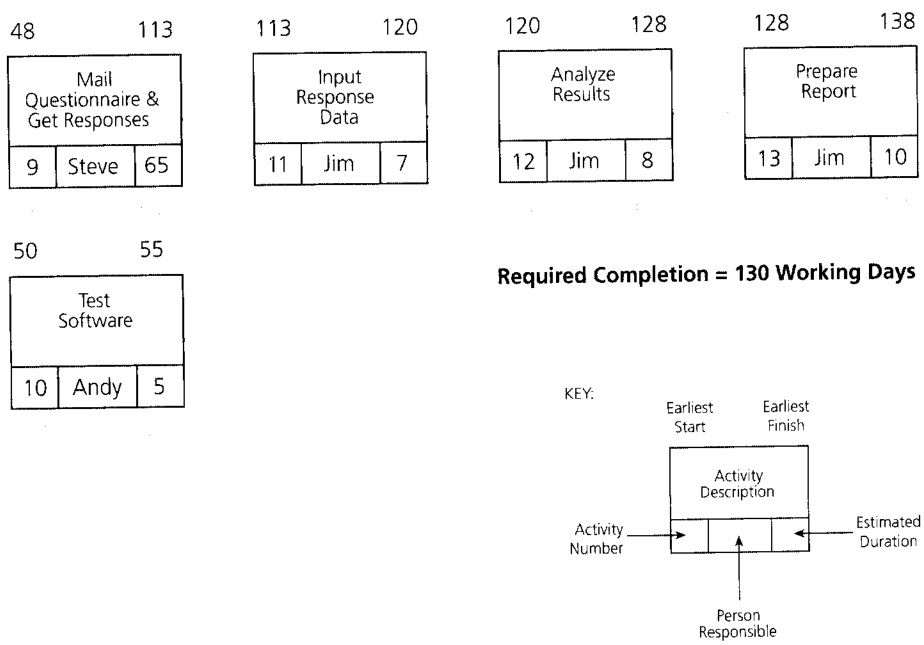
Consumers," has an LS of −8! This means that, in order to complete the entire project by its required completion time of 130 days, the project must start 8 days earlier than it is estimated to start. Note that this difference of 8 days is equal to the difference we got when calculating forward through the network diagram to obtain the ES and EF times. In essence, what we have found is that this project may take 138 days to complete, even though its required completion time is 130 days.

Like the ES and EF times, the LS and LF times are usually not shown on the network diagram itself, but rather in a separate schedule table as shown in Figure 5.8.

TOTAL SLACK

In the consumer market study project, there is a difference of eight days between the calculated EF time of the very last activity ("Prepare Report") and the project required completion time. This difference is the **total slack (TS)**, also referred to as *total float*. When the TS is a negative number, as in this example, it indicates a lack of slack over the entire project.

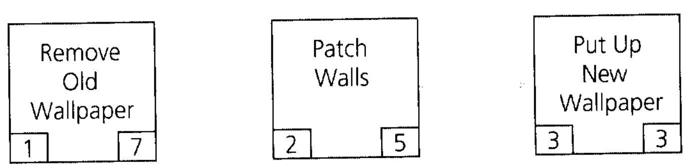
If TS is positive, it represents the maximum amount of time that the activities on a particular path can be delayed without jeopardizing completion of the project by its required completion time. On the other hand, if TS is negative, it represents



the amount of time that the activities on a particular path must be accelerated to complete the project by its required completion time. If TS is zero, the activities on the path do not need to be accelerated but cannot be delayed.

The total slack for a particular path of activities is common to and ***shared among all the activities on that path***. Consider the example below.

15. When a project has a positive total slack, some activities can be ________ without jeopardizing completion of the project by its required completion time. When a project has negative total slack, some activities need to be ________ to complete the project by its required completion time.



Required Completion = 20 Days

The earliest the project can finish is day 15 (the sum of the estimated durations of the three activities, 7 + 5 + 3). However, the required completion time for the project is 20 days. The three activities on this path can therefore be delayed up to 5 days without jeopardizing completion of the project by the required time. This does *not* mean that each activity on the path can be delayed 5 days (because this would create a total delay of 15 days); rather, it means that

Schedule for Consumer Market Study Project, Showing Latest Start and Finish Times

1	Identify Target Consumers	Susan	3	0	3	**−8**	**−5**		
2	Develop Draft Questionnaire	Susan	10	3	13	**−5**	**5**		
3	Pilot-Test Questionnaire	Susan	20	13	33	**5**	**25**		
4	Review Comments & Finalize Questionnaire	Susan	5	33	38	**25**	**30**		
5	Prepare Mailing Labels	Steve	2	38	40	**38**	**40**		
6	Print Questionnaire	Steve	10	38	48	**30**	**40**		
7	Develop Data Analysis Software	Andy	12	38	50	**88**	**100**		
8	Develop Software Test Data	Susan	2	38	40	**98**	**100**		
9	Mail Questionnaire & Get Responses	Steve	65	48	113	**40**	**105**		
10	Test Software	Andy	5	50	55	**100**	**105**		
11	Input Response Data	Jim	7	113	120	**105**	**112**		
12	Analyze Results	Jim	8	120	128	**112**	**120**		
13	Prepare Report	Jim	10	128	138	**120**	**130**		

16. The total slack for a path of ________ is common and ________ among ________ the ________ on the ________.

all the activities that make up the path can have a total delay of 5 days among them. For example, if "Remove Old Wallpaper" actually takes 10 days (3 days longer than the estimated duration of 7 days), then it will use up 3 of the 5 days of TS, and only 2 days of TS will remain.

TS is calculated by subtracting the activity's EF time from its LF time or its ES time from its LS time. That is, the slack is equal to either the latest finish time (LF) minus the earliest finish time (EF) for the activity, or the latest start time (LS) minus the earliest start time (ES) for that activity. The two calculations are equivalent.

$$\text{Total Slack} = LF - EF, \quad \text{or Total Slack} = LS - ES$$

Not all networks are as simple as the one just used to illustrate TS. In large network diagrams, there may be many paths of activities from the project start to the project completion, just as there are many routes you can choose from to get from New York City to Los Angeles. If 20 friends were going to leave at the same time from New York City and each was going to drive a different route to Los Angeles, they could not get together for a party in Los Angeles until the last person had arrived—the one who took the longest (most time-consuming) route. Similarly, a project cannot be completed until the longest (most time-consuming) path of

17. The longest path of activities from the beginning to the end of a project is called the

____________________ path.

activities is finished. This longest path in the overall network diagram is called the **critical path**.

One way to determine which activities make up the critical path is to find which ones have the least slack. Subtract the EF time from the LF time for each activity (or subtract the ES time from the LS time—both calculations will result in the same value), and then look for all the activities that have the lowest value (either least positive or most negative). All the activities with this value are on the critical path of activities.

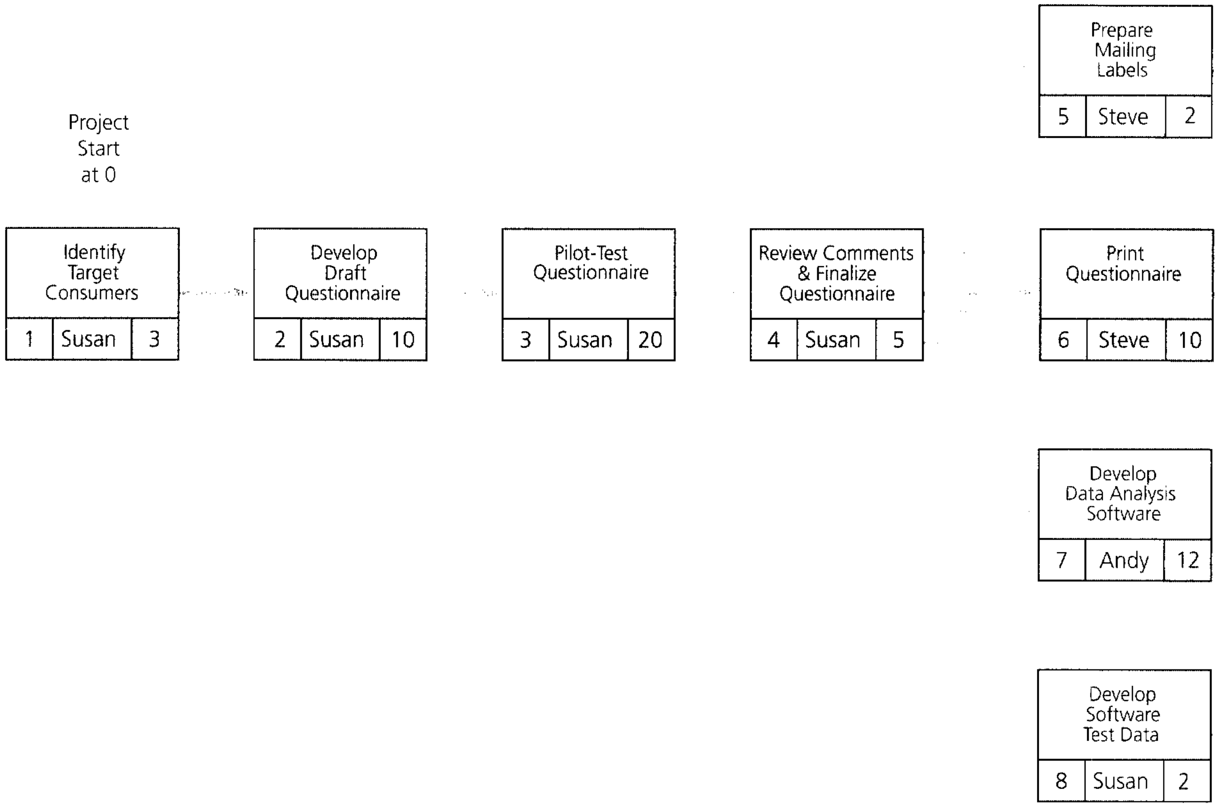
The values of TS for the consumer market study project are shown in Figure 5.9. The lowest value is −8 days. The activities that have this same value of TS make up the path 1–2–3–4–6–9–11–12–13. These nine activities comprise the critical, or most time-consuming, path. The estimated durations of the activities on this path add up to 138 days (3 + 10 + 20 + 5 + 10 + 65 + 7 + 8 + 10). Among them, these activities need to be accelerated 8 days to complete the project by its required completion time of 130 days. Figure 5.10 highlights the activities that make up the critical path.

To eliminate the −8 days of slack, the estimated durations of one or more activities on this critical path need to be reduced. Suppose we reduce the estimated duration of "Mail Questionnaire & Get Responses" from 65 days to 55 days by reducing the time respondents are given to return the questionnaire. Because the estimated duration of an activity on the critical path is being reduced

Schedule for Consumer Market Study Project, Showing Total Slack Values

1	Identify Target Consumers	Susan	3	0	3	–8	–5	–8	
2	Develop Draft Questionnaire	Susan	10	3	13	–5	5	–8	
3	Pilot-Test Questionnaire	Susan	20	13	33	5	25	–8	
4	Review Comments & Finalize Questionnaire	Susan	5	33	38	25	30	–8	
5	Prepare Mailing Labels	Steve	2	38	40	38	40	0	
6	Print Questionnaire	Steve	10	38	48	30	40	–8	
7	Develop Data Analysis Software	Andy	12	38	50	88	100	50	
8	Develop Software Test Data	Susan	2	38	40	98	100	60	
9	Mail Questionnaire & Get Responses	Steve	65	48	113	40	105	–8	
10	Test Software	Andy	5	50	55	100	105	50	
11	Input Response Data	Jim	7	113	120	105	112	–8	
12	Analyze Results	Jim	8	120	128	112	120	–8	
13	Prepare Report	Jim	10	128	138	120	130	–8	

FIGURE 5.10 Network Diagram for Consumer Market Study Project, Showing the Critical Path

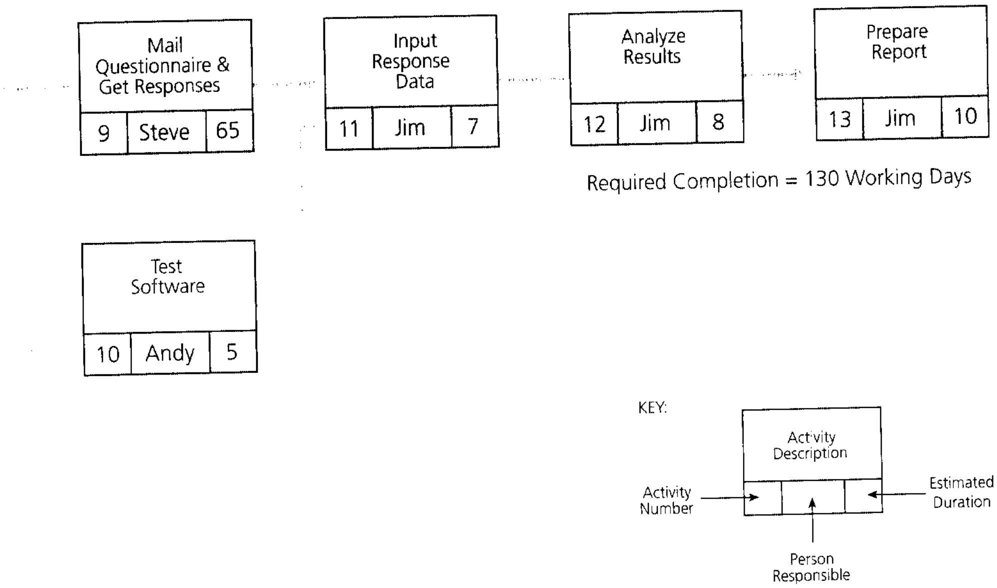


by 10 days, the TS changes from −8 days to +2 days. The revised estimated duration of 55 days can be used to prepare a revised project schedule, as shown in Figure 5.11. This schedule shows that the critical path now has a TS of +2 days, and the project is now estimated to finish in 128 days, which is 2 days earlier than the required completion time of 130 days.

As stated earlier, a large network diagram can have many paths or routes from its beginning to its end. Some of the paths may have positive values of TS; others may have negative values of TS. Those paths with positive values of TS are sometimes referred to as **noncritical paths**, whereas those paths with zero or negative values of TS are referred to as **critical paths**. The longest path is often referred to as the **most critical path**.

It is not unusual that the initial project schedule that is developed may have negative total slack, and it may then take several ***iterations*** *of revising the estimated resources and estimated durations of specific activities and/or changing the sequence or dependent relationships among activities to arrive at an acceptable baseline schedule.*

Sometimes the project team or contractor reacts to the project required completion date by force-fitting the schedule to meet the project required end date by arbitrarily reducing the estimated durations of specific activities and convincing themselves that somehow (by luck) the activities will get done in the reduced amount of time. Then, when the project does not get completed on time, they seem astonished! Instead, they should develop a realistic schedule, and then



determine how much negative TS there is based on the customer's required completion date. At that point, they can *rationally* determine how to reduce the negative slack to come up with an acceptable schedule that meets the project required completion date. This is done by making decisions about *how* to reduce the estimated durations of specific activities on the paths with negative slack. This may mean making trade-off decisions to add more resources; working overtime; subcontracting certain tasks; reducing scope/specifications; replacing some resources with higher-cost, more experienced resources; and so forth. As a last resort, it may mean going back to the sponsor or customer and asking for an extension of the project required completion date, for more money for the extra resources to accelerate the schedule, or for approval to reduce scope. It is better to inform the customer early in the project rather than surprising him or her later. It is important to manage the customer's expectations.

FREE SLACK

Another type of slack that is sometimes calculated is **free slack (FS)**, also referred to as *free float*, which is the amount of time a specific activity can be postponed without delaying the ES time of its immediately succeeding activities. It is the *relative difference* between the amounts of TS for activities entering into the same activity. FS is calculated by finding the lowest of the values of TS for all the activities entering into a specific activity and then subtracting it from the values of TS for the other activities also entering into that same activity. Because FS is the relative difference between values of

Revised Schedule for Consumer Market Study Project

1	Identify Target Consumers	Susan	3	0	3	2	5	2	
2	Develop Draft Questionnaire	Susan	10	3	13	5	15	2	
3	Pilot-Test Questionnaire	Susan	20	13	33	15	35	2	
4	Review Comments & Finalize Questionnaire	Susan	5	33	38	35	40	2	
5	Prepare Mailing Labels	Steve	2	38	40	48	50	10	
6	Print Questionnaire	Steve	10	38	48	40	50	2	
7	Develop Data Analysis Software	Andy	12	38	50	88	100	50	
8	Develop Software Test Data	Susan	2	38	40	98	100	60	
9	Mail Questionnaire & Get Responses	Steve	55	48	103	50	105	2	
10	Test Software	Andy	5	50	55	100	105	50	
11	Input Response Data	Jim	7	103	110	105	112	2	
12	Analyze Results	Jim	8	110	118	112	120	2	
13	Prepare Report	Jim	10	118	128	120	130	2	

TS for activities entering into the same activity, it will exist only when two or more activities enter into the same activity. Also, because FS is a relative difference between values of TS, *it is always a positive value.*

For an illustration of FS, consider Figures 5.9 and 5.10. In the network diagram in Figure 5.10, there are three instances where a particular activity has more than one activity entering into it:

Activity 9, "Mail Questionnaire & Get Responses," has activities 5 and 6 entering into it.
Activity 10, "Test Software," has activities 7 and 8 entering into it.
Activity 11, "Input Response Data," has activities 9 and 10 entering into it.

In the schedule in Figure 5.9, the values of TS for activities 5 and 6 are 0 and −8 days, respectively. The lesser of these two values is −8 days for activity 6. The FS for activity 5 is the relative difference between its TS, 0, and −8. This relative difference is 8 days: 0 − (−8) = 8 days. This means that activity 5, "Prepare Mailing Labels," already has a FS of 8 days and can slip by up to that amount without delaying the ES time of activity 9, "Mail Questionnaire & Get Responses."

18. Refer to Figures 5.9 and 5.10. Of the two activities entering into activity 11, "Input Response Data," which activity has free slack? What is its value?

Similarly, the values of TS for activities 7 and 8 are 50 and 60 days, respectively. The lesser of these two values is 50 days. Therefore, activity 8, "Develop Software Test Data," has an FS of 10 days (60 − 50 = 10) and can slip by up to that amount without delaying the ES time of activity 10, "Test Software."

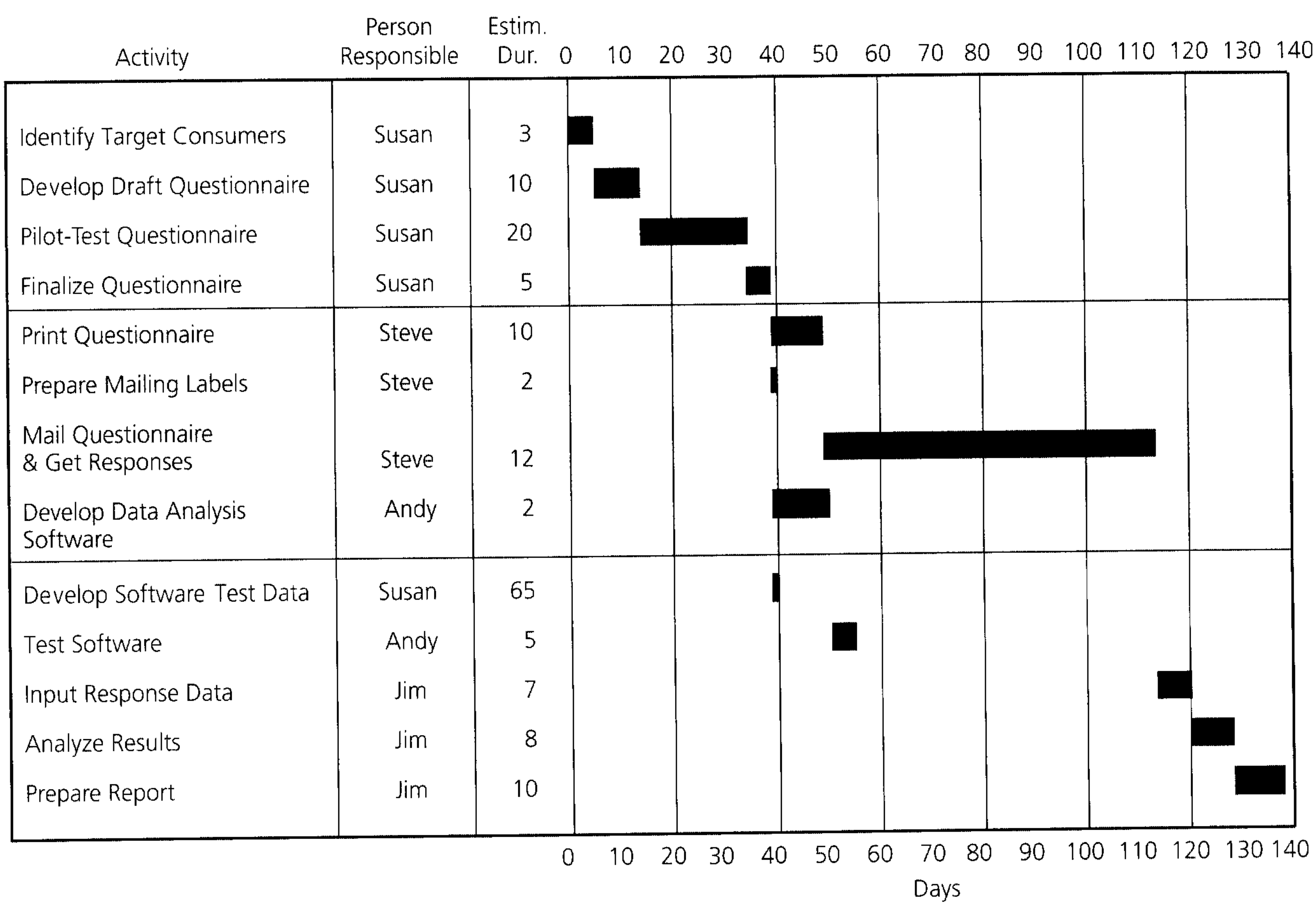
Network-based planning and scheduling techniques are often compared to another somewhat familiar tool known as a **bar chart**, sometimes referred to as a *Gantt chart*, that displays activities along a *time scale*. This is an older planning and scheduling tool; however, it remains popular because of its simplicity.

Figure 5.12 shows a bar chart for the consumer market study. Activities are listed on the left-hand side, and a *time scale* is shown along the bottom. The estimated duration for each activity is indicated by a bar spanning the period during which the activity is expected to be accomplished. A column that indicates who is responsible for each task can be added to the chart.

Project management software can automatically generate a time-scaled bar chart from the schedule table that is based on the network diagram. These bar charts can display arrows that connect the bars to show the dependent relationships among the activities. The bar chart can be based on the ES and EF times or on the LS and LF times. Figure 5.12 is a bar chart based on the ES and EF times in Figure 5.9.

However, bar charts are sometimes used *instead of* a network-based schedule. This has a shortcoming. When using *only* a bar chart for scheduling, without first creating a network-based schedule, the planning and scheduling of activities

Bar Chart for Consumer Market Study Project



is done simultaneously. The person draws the activity bars proportionate to the estimated durations for each activity and must be aware of the dependent relationships among the activities—that is, which activities must be finished before others can start and which activities can be performed concurrently. A major drawback of using only a traditional bar chart is that it does not graphically display those dependent relationships of activities. Therefore, it is not obvious which activities will be affected when a given activity is delayed.

Project Control Process

Figure 5.13 illustrates the steps in the project control process. It starts with establishing a baseline plan that shows how the project scope will be accomplished on schedule and within budget. Once this baseline plan is agreed upon by the customer and the contractor or project team, the project work can be performed. Then it is necessary to monitor the progress to ensure that everything is going according to the plan. The **project control process** involves regularly gathering data on project performance, comparing actual performance to planned performance, and taking corrective action immediately if actual performance is behind planned performance. This process must occur regularly throughout the project.

Reinforce Your Learning

19. If actual ______ is behind ______ performance, ______ ______ should be taken ______.

A regular **reporting period** (time interval) should be established for comparing actual progress with planned progress. Reporting may be daily, weekly, biweekly, or monthly, depending on the complexity or overall duration of the project. If a project is expected to have an overall duration of a month, the reporting period might be as short as a day. On the other hand, if a project is expected to run five years, the reporting period might be a month.

During each reporting period, two kinds of data or information need to be collected:

1. *Data on actual performance.* This includes
   - The actual time that activities were started and/or finished
   - The actual costs expended and committed
   - The earned value of the work completed
2. *Information on any changes to the project scope, schedule, and budget.* These changes could be initiated by the customer or the project team, or they could be the result of an unanticipated occurrence.

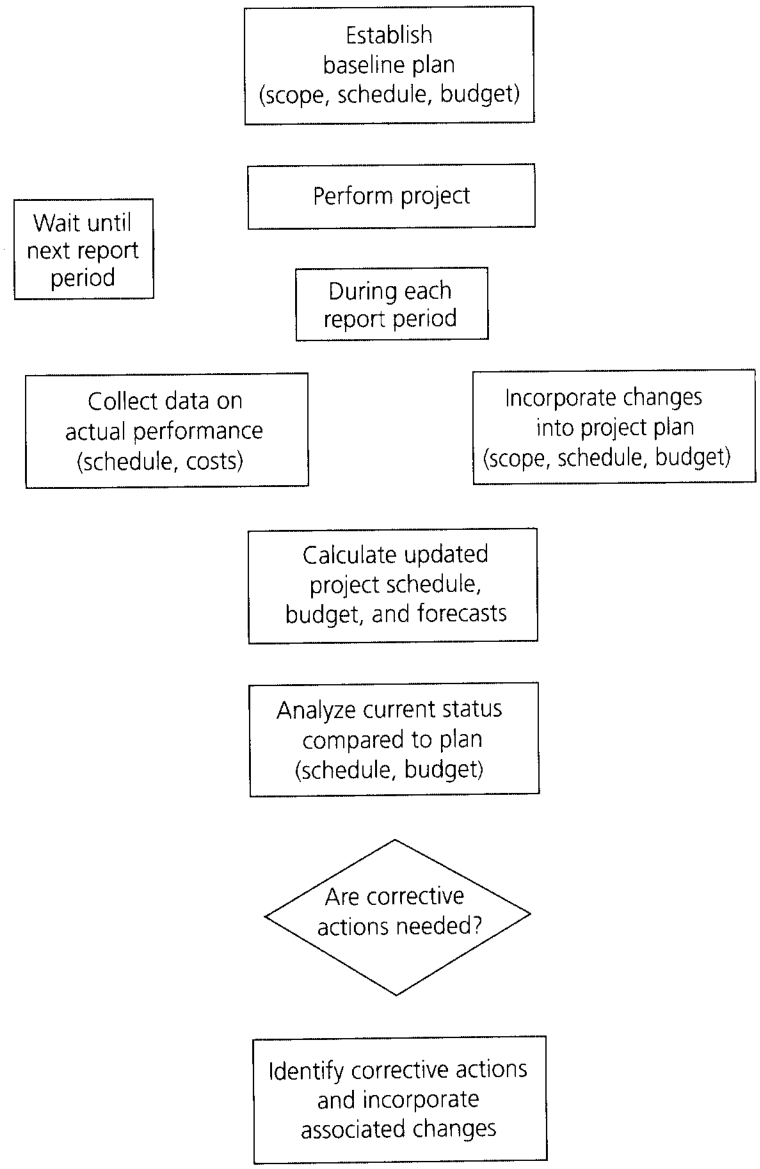
Reinforce Your Learning

20. What are the two kinds of data or information that need to be collected during each reporting period?

It should be noted that once changes are incorporated into the plan and agreed upon by the sponsor or customer, a new baseline plan has to be established. The scope, schedule, and budget of the new baseline plan may be different from those of the original baseline plan.

It is crucial that the data and information discussed above be collected in a timely manner and used to calculate an updated project schedule and budget. For example, if project reporting is done monthly, data and information should be obtained as late as possible in that monthly period so that when an updated schedule and budget are calculated, they are based on the latest possible information. In other words, a project manager should not gather data at the beginning of the month and then wait until the end of the month to use it to calculate an updated schedule and budget because the data will be outdated and may cause incorrect decisions to be made about the project status and corrective actions.

Project Control Process



Once an updated schedule and budget have been calculated, they need to be compared to the baseline schedule and budget and analyzed for variances to determine whether a project is ahead of or behind schedule and under or over budget. If the project status is okay, no corrective actions are needed; the status will be analyzed again for the next reporting period.

The key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking any needed corrective action immediately.

If it is determined that corrective actions are necessary, however, decisions must be made regarding how to revise the scope, schedule, or the budget. These

21. True or false: In general, it is better to have a shorter reporting period during a project.

22. Project ______________ is a ______________ approach to ______________ the project to accomplish the project ______________.

23. What three schedule elements will be affected by the actual finish times of completed activities?

decisions often involve a trade-off of scope, time, and cost. For example, reducing the estimated duration of an activity may require either increasing costs to pay for more resources or reducing the scope of the task (and possibly not meeting the customer's technical requirements). Similarly, reducing project costs may require using materials of a lower quality than originally planned. Once a decision is made on which corrective actions to take, they must be incorporated into the schedule and budget. It is then necessary to calculate a revised schedule and budget to determine whether the planned corrective measures result in an acceptable schedule and budget. If not, further revisions will be needed.

The project control process continues throughout the project. In general, the shorter the reporting period, the better the chances of identifying problems early and taking effective corrective actions. If a project gets too far out of control, it may be difficult to accomplish the project objective without sacrificing the scope, quality, schedule, or budget. There may be situations in which it is wise to increase the frequency of reporting until the project is back on track. For example, if a five-year project with monthly reporting is endangered by a slipping schedule or an increasing budget overrun, it may be prudent to reduce the reporting period to one week to monitor the project and the impact of corrective actions more closely.

The project control process is an important and necessary part of project management. Just establishing a sound baseline plan is not sufficient because even the best-laid plans do not always work out. *Project management is a proactive approach to controlling a project* to ensure that the project objective is accomplished, even when things do not go according to plan.

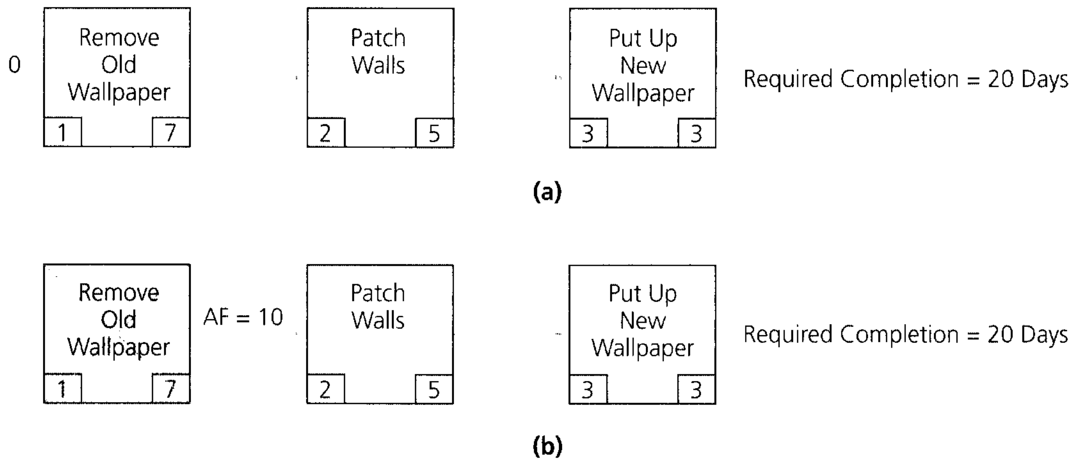
Effects of Actual Schedule Performance

Throughout a project, some activities will be completed on time, some will be finished ahead of schedule, and others will be finished later than scheduled. Actual progress—whether faster or slower than planned—will have an effect on the schedule of the remaining, uncompleted activities of the project. Specifically, the **actual finish (AF) times** at which activities are actually completed will determine the ES and EF times for the remaining activities in the network diagram, as well as the TS.

Part (a) of Figure 5.14 is a network diagram for a simple project. It shows that the earliest the project can finish is day 15 (the sum of the estimated durations of the three activities, $7 + 5 + 3$). Given that the required completion time is day 20, the project has a TS of $+5$ days.

Suppose that activity 1, "Remove Old Wallpaper," is *actually* finished on day 10, rather than on day 7 as planned, because it turns out to be more difficult than anticipated. See part (b) of Figure 5.14. This means that the ES and EF times for activities 2 and 3 will be 3 days later than on the original schedule. Because "Remove Old Wallpaper" is actually finished on day 10, the ES for "Patch Walls" will be day 10 and its EF will be day 15. Following through with the forward calculations, we find that "Put Up New Wallpaper" will have an ES of day 15 and an EF of day 18. Comparing this new EF of the last activity to the required completion time of day 20, we find a difference of 2 days. The TS got worse—it changed in a negative direction, from $+5$ days to $+2$ days. This example illustrates how the AF times of activities have a ripple effect, altering the remaining activities' ES and EF times and the TS.

Effect of Actual Finish Times



Crossed-out boxes indicate completed activities

It is helpful to indicate on the network diagram, in some manner, which activities have been completed. One method is to shade or crosshatch the activity box, as was done in part (b) of Figure 5.14.

Incorporate Changes into Schedule

Throughout a project, changes may occur that have an impact on the schedule. As was noted earlier, these changes might be initiated by the customer or the project team, or they might be the result of an unanticipated occurrence. Here are some examples of changes initiated by the customer:

- A home buyer tells the builder that the family room should be larger and the bedroom windows should be relocated.
- A customer tells the project team developing an information system that the system must have the capability to produce a previously unmentioned set of reports and graphics, which requires additional new elements in the database.

These types of changes represent revisions to the original project scope and will have an impact on the schedule and budget. The degree of impact, however, may depend on when the changes are requested. If they are requested early in the project, they may have less impact on schedule and budget than if they are requested later in the project. For example, changing the size of the family room and relocating the bedroom windows would be relatively easy if the house was still being designed and the drawings being prepared. However, if the changes are requested after the framing is put up and the windows are installed, the impact on schedule and budget will be much greater.

When the customer requests a change, the contractor or project team should estimate the impact on the project schedule and budget and then obtain customer approval *before* proceeding. If the customer approves the proposed revisions to the project schedule and budget, then any additional activities, revised estimated durations, and revised estimated resources and associated costs should be incorporated into the project schedule and budget.

An example of a change initiated by a project team is the decision by a team that is planning a community festival to eliminate all amusement rides for adults because of space limitations and insurance costs. The project plan would then have to be revised to delete or modify all those activities involving adult rides. An example of a change initiated by a project manager would be, rather than develop customized software for an automated invoicing component of a system, to use standard available software to reduce costs and accelerate the schedule.

Some changes involve the addition of activities that may have been overlooked when the original plan was developed. For example, the project team may have forgotten to include activities associated with developing training materials and conducting training for a new information system. Or the customer or contractor may have failed to include the installation of gutters and downspouts in the work scope for the construction of a restaurant.

Other changes become necessary because of unanticipated occurrences, such as a snowstorm that slows down construction of a building, the failure of a new product to pass quality tests, or the untimely resignation of a key member of a project team. These events will have an impact on the schedule and/or budget and will require that the project plan be modified.

Still other changes can result from progressive elaboration of adding more detail as the project moves forward. No matter what level of detail is used in the initial network diagram, there will be activities that can be broken down into greater detail as the project progresses.

Any type of change—whether initiated by the customer, the contractor, the project manager, a team member, or an unanticipated event—will require a modification to the plan in terms of scope, schedule, and/or budget. When such changes are agreed upon, a new baseline plan is established and used as the benchmark against which actual project performance will be compared.

24. Changes to the project can affect

________________,

________________,

and/or

________________.

With respect to the project schedule, changes can result in the addition or deletion of activities, resequencing of activities, changes to estimated durations for specific activities, or a new required completion time for the project.

See the section on managing changes in Chapter 10, and the section on track document changes in Chapter 12 for further discussion of managing and controlling changes.

Based on actual progress and on consideration of other changes that may occur, an updated project schedule can be generated regularly that forecasts whether the project will finish ahead of or behind its required completion time. Once data have been collected on the AF times of completed activities and the effects of any project changes, an updated project schedule can be calculated. These calculations are based on the methodology explained in this chapter:

The ES and EF times for the remaining, uncompleted activities are calculated by working forward through the network, but they are based on the *actual finish times* of completed activities and the estimated durations of the uncompleted activities.

The LS and LF times for the uncompleted activities are calculated by working backward through the network.

As an illustration of the calculation of an updated schedule, let us consider the network diagram shown in Figure 5.15 for the consumer market study project. Assume the following:

1. Completed activities:
  a. Activity 1, "Identify Target Consumers," actually finished on day 2.
  b. Activity 2, "Develop Draft Questionnaire," actually finished on day 11.
  c. Activity 3, "Pilot-Test Questionnaire," actually finished on day 30.

2. Project changes:
  a. It was discovered that the database to be used to prepare the mailing labels was not up to date. A new database needs to be purchased before the mailing labels can be prepared. This new database was ordered on day 23. It will take 21 days to get it from the supplier.
  b. A preliminary review of comments from the pilot test of the questionnaire indicates that substantial revisions to the questionnaire are required. Therefore, the duration estimate for activity 4 needs to be increased from 5 days to 15 days.

The network diagram in Figure 5.15 incorporates the above information. Figure 5.16 shows the updated schedule. Note that the TS for the critical path is now −5 days, instead of the +2 days in the baseline schedule in Figure 5.11. The anticipated project completion time is now day 135, which is beyond the required completion time of 130 days.

Schedule control involves four steps:

1. Analyzing the schedule to determine which areas may need corrective action
2. Deciding what specific corrective actions should be taken
3. Revising the plan to incorporate the chosen corrective actions
4. Recalculating the schedule to evaluate the effects of the planned corrective actions

If the planned corrective actions do not result in an acceptable schedule, these steps need to be repeated.

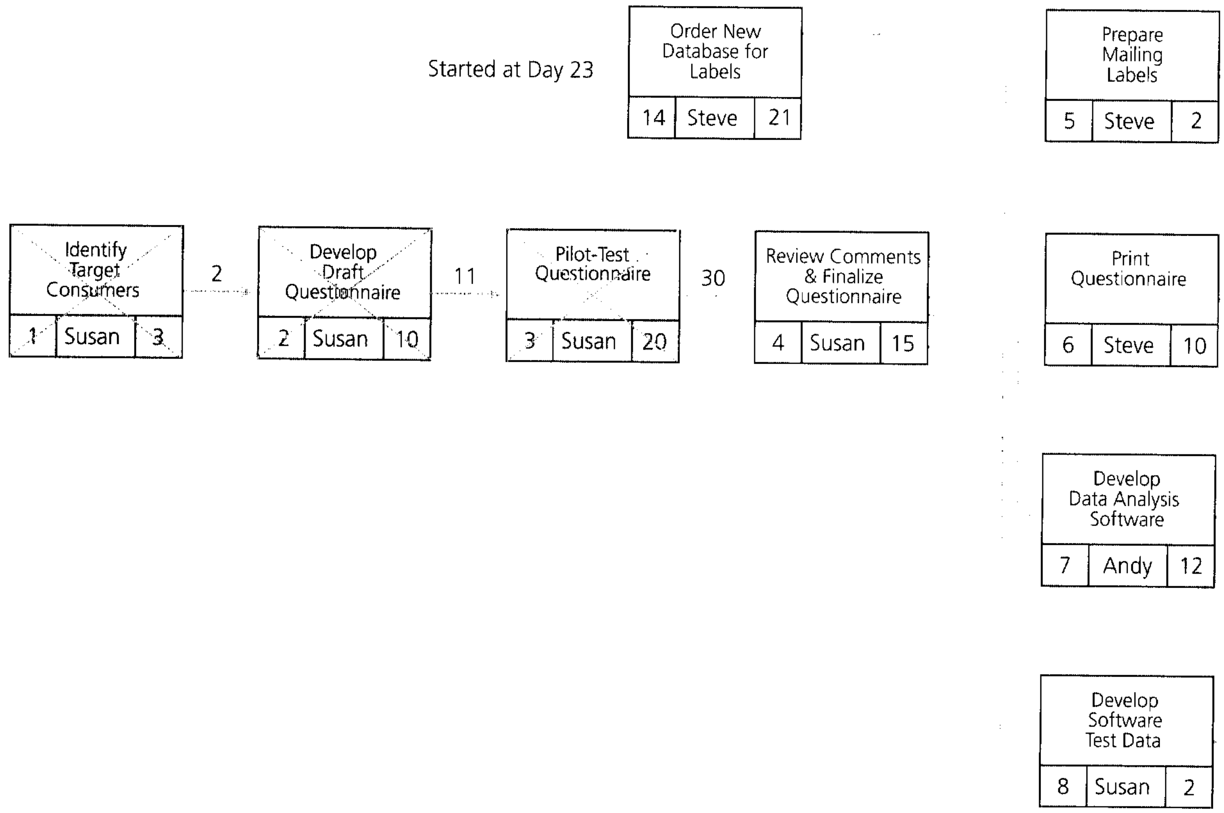
Throughout a project, each time a schedule is recalculated—whether it is after actual performance data or project changes are incorporated or after corrective actions are planned—it is necessary to analyze the newly calculated schedule to determine whether it needs further revision. The schedule analysis should include identifying the critical path and any paths of activities that have negative slack, as well as those paths where slippages have occurred (the slack got worse) compared with the previously calculated schedule.

25. In analyzing a project schedule, it is important to identify all the paths of activities that have ______________ slack.

A concentrated effort to accelerate project progress must be applied to the paths with negative slack. The amount of slack should determine the priority with which these concentrated efforts are applied. For example, the path with the most negative slack should be given top priority.

Corrective actions that will eliminate the negative slack from the project schedule must be identified. These corrective actions must reduce the estimated durations of activities on the negative-slack paths. Remember, the slack for a path of activities is shared among all the activities on that path. Therefore, *a change in the estimated duration of any activity on that path will cause a corresponding change in the slack for that path.*

Network Diagram for Consumer Market Study Project, Incorporating Actual Progress and Changes



When analyzing a path of activities that has negative slack, you should focus on two kinds of activities:

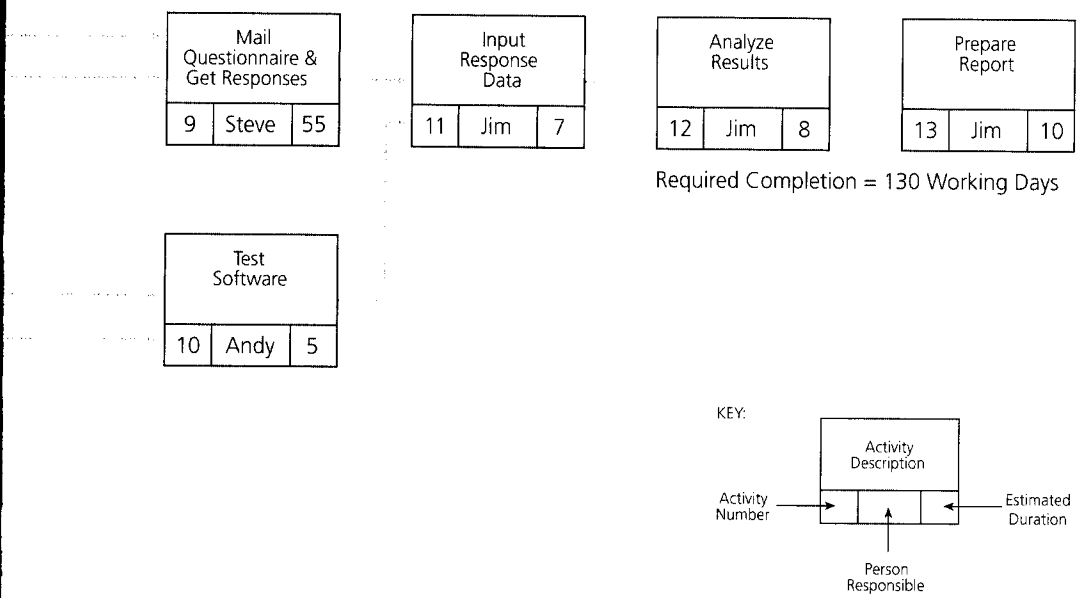
1. *Activities that are near term (that is, in progress or to be started in the immediate future).* It is much wiser to take aggressive corrective action to reduce the estimated durations of activities that will be done in the near term than to plan to reduce the estimated durations of activities that are scheduled sometime in the future. If you postpone until the distant future taking corrective action that will reduce the estimated durations of activities, you may find that the negative slack has deteriorated even further by that time. As the project progresses, there is always less time remaining in which corrective action can be taken.

   Looking at Figure 5.16, we can see that it would be better to try to reduce the durations of the near-term activities on the critical path, such as "Review Comments & Finalize Questionnaire" or "Print Questionnaire," than to put off corrective action until the last activity, "Prepare Report."
2. *Activities that have long estimated durations.* Taking corrective action that will reduce a 20-day activity by 20 percent (that is, by four days) has a greater impact than totally eliminating a 1-day activity. Usually, longer-duration activities present the opportunity for larger reductions.

   Look again at Figure 5.16. There may be more opportunity to reduce the 55-day duration estimate for "Mail Questionnaire & Get Responses" by five days (9 percent) than to reduce the shorter estimated durations of other activities on the critical path.

Reinforce Your Learning

26. When analyzing a path of activities that has negative slack, what two kinds of activities should you look at carefully?



Crossed-out boxes indicate completed activities

27. List four approaches to reducing the estimated durations of activities.

There are various approaches to reducing the estimated durations of activities. One obvious way is to apply more resources to accelerate an activity. This could be done by assigning more people to work on the activity or asking the people working on the activity to work more hours per day or more days per week. Additional appropriate resources might be transferred from concurrent activities that have positive slack. Sometimes, however, adding people to an activity may, in fact, result in the activity taking longer, because the people already assigned to the activity are diverted from their work to help the new people get up to speed. Another approach is to assign a person with greater expertise or more experience to perform or help with the activity, to get it done in a shorter time than was possible with the less experienced people originally assigned to it.

Reducing the scope or requirements for an activity is another way to reduce its estimated duration. For example, it might be acceptable to put only one coat of paint on a room rather than two coats, as originally planned. In some cases, a decision might be made to totally eliminate some activities, deleting them and their durations from the schedule, such as deciding not to install a fence around the property.

Increasing productivity through improved methods or technology is yet another approach to reducing the estimated durations of activities. For example, instead of having people keyboard data from patient medical forms into a computer database, optical scanning equipment might be used.

Once specific corrective actions to reduce the negative slack have been decided, the estimated durations for the appropriate activities must be revised

Updated Schedule for Consumer Market Study Project

1	Identify Target Consumers	Susan							2
2	Develop Draft Questionnaire	Susan							11
3	Pilot-Test Questionnaire	Susan							30
4	Review Comments & Finalize Questionnaire	Susan	15	30	45	25	40	–5	
5	Prepare Mailing Labels	Steve	2	45	47	48	50	3	
6	Print Questionnaire	Steve	10	45	55	40	50	–5	
7	Develop Data Analysis Software	Andy	12	45	57	88	100	43	
8	Develop Software Test Data	Susan	2	45	47	98	100	53	
9	Mail Questionnaire & Get Responses	Steve	55	55	110	50	105	–5	
10	Test Software	Andy	5	57	62	100	105	43	
11	Input Response Data	Jim	7	110	117	105	112	–5	
12	Analyze Results	Jim	8	117	125	112	120	–5	
13	Prepare Report	Jim	10	125	135	120	130	–5	
14	Order New Database for Labels	Steve	21	23	44	27	48	4	

in the network plan. Then a revised schedule needs to be calculated to evaluate whether the planned corrective actions reduce the negative slack as anticipated.

In most cases, eliminating negative slack by reducing durations of activities will involve a trade-off in the form of an increase in costs or a reduction in scope. (For a further discussion of this topic, see the appendix on Time–Cost Trade-Off at the end of Chapter 07.) If the project is way behind schedule (has substantial negative slack), a substantial increase in costs and/or reduction in work scope or quality may be required to get it back on schedule. This could jeopardize elements of the overall project objective, such as scope, schedule, budget, and/or quality. In some cases, the customer and the contractor or project team may have to acknowledge that one or more of these elements cannot be achieved; therefore, the customer may have to extend the required completion time for the entire project, or there may be a dispute over who should absorb any increased cost to accelerate the schedule—the contractor or the customer.

Some contracts include a bonus provision, whereby the customer will pay the contractor a bonus if the project is completed ahead of schedule. Conversely, some contracts include a penalty provision, whereby the customer can reduce the final payment to the contractor if the project is not completed on time. Some of these penalties can be substantial. In either of these situations, effective schedule control is crucial.

The key to effective schedule control is to aggressively address any paths with negative or deteriorating slack values as soon as they are identified, rather than hoping that things will improve as the project goes on. Addressing schedule problems early will minimize the negative impact on budget and scope. If a project falls too far behind, getting back on schedule becomes more difficult, and it does not come free. It requires spending more money or reducing the scope or quality.

On projects that do not have negative slack, it is important not to let the slack deteriorate by accepting delays and slippages. If a project is ahead of schedule, a concentrated effort should be made to *keep* it ahead of schedule.

Project meetings are a good forum for addressing schedule control issues. See the section on meetings in Chapter 12, and the section on problem solving in Chapter 11 for related information.

Big Delivery in Small Packages

Genesis Consulting had a portfolio of 10 projects to be completed. Their budget and time constraints allowed only 2 of those 10 projects to be scheduled to be completed in the next fiscal year. The team led by Jason Fair, CEO of Genesis Consulting in Glen Allen, Virginia, USA, knew they needed to do something different with their schedule. After a meeting with a colleague who had successfully implemented agile techniques into her company's projects and considering the potential payoffs and pitfalls, Fair decided to try.

With a schedule set to 15-day sprints instead of months, the team worked to address the most important deliverables at the front of the schedule to make sure they were completed first. As noted by Alan Campbell, PMP, senior consultant at ERP consultancy ArcherPoint, Atlanta, Georgia, USA, "Traditional projects will go along, then they'll start to run out of money, so they cut things out of the scope. What happens then is something at the very end of the project plan doesn't get delivered because of time and budget constraints, even though it was really important."

"With agile, you can visibly see what all the different pieces of work are, where they are, and who's working on what. You can very quickly identify where there are constraints, and that makes people very uncomfortable in the beginning," said Fair. Team meetings were limited to 15 minutes with a report by each member of the team stating, 'I did this yesterday, this is what I am doing today, and these are the obstacles that I need help with to complete my work.'

In addition to the quick meetings each day, communication with the stakeholders occurred at the end of each sprint instead of the more traditional quarterly update. Any miscommunications were handled in 15 days instead of waiting for 3 months; avoiding extensive cost and schedule delays to make changes or to clarify the miscommunication.

With each project, the potential benefits and pitfalls were evaluated to assess the risk of implementing agile project management techniques. Consideration of the best tools from the many techniques of project management was necessary to ensure implementation of the tools in the most appropriate situations to help increase the probability of successfully completing a project.

An evaluation of the projects' progress resulted in a productivity increase of 250 percent. The elimination of waste and increased collaboration allowed the team to complete two more projects the next year as they became more efficient. Jason Fair's decision to try agile project management techniques resulted in payoffs and avoided pitfalls to give Genesis Consulting big deliveries through the small packages completed during the 15-day sprints.

Based on information from Alderton, M. (2013), "Big Delivery in Small Packages," *PM Network, 27*(3), 60–65.

Chapter 4 defined an information system as a computer-based system that accepts data as input, processes the data, and produces information required by users. Scheduling the development of an information system is a challenging process. Such scheduling is often done in a haphazard manner, and, as a result, a large number of information system projects are finished much later than originally promised or never finished at all. One of the most important factors in effective scheduling is estimating activity durations that are as realistic as possible. This is not an easy task; however, it does become easier with experience.

Among the common problems that often push information system development projects beyond their required completion time are the following:

Failure to identify all user requirements
Failure to identify user requirements properly
Continuing growth of project scope
Underestimating learning curves for new software packages
Incompatible hardware
Logical design flaws
Poor selection of software
Failure to select the best design strategy
Data incompatibility issues
Failure to perform all phases of the systems development life cycle

Controlling the schedule for the development of an information system is a challenge. Numerous unexpected circumstances might arise that can push an information system development project well beyond its originally required completion date. However, just as with any other type of project, the key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking any necessary corrective action immediately.

Like other forms of project control, schedule control for information system development projects is carried out according to the steps discussed earlier in this chapter. A project control process such as the one illustrated in Figure 5.13 should be used for comparing actual performance with the schedule. Once the customer and the project team agree on changes, these changes should be recorded and the schedule should be revised.

Among the changes that commonly become necessary during information system development projects are the following:

Changes to the interface—such as added fields, different icons, different colors, different menu structures or buttons, or completely new screens.

List of Activities, Immediate Predecessors, and Estimated Durations

1. Gather Data	—	3
2. Study Feasibility	—	4
3. Prepare Problem Definition Report	1, 2	1
4. Interview Users	3	5
5. Study Existing System	3	8
6. Define User Requirements	4	5
7. Prepare System Analysis Report	5, 6	1
8. Input & Output	7	8
9. Processing & Database	7	10
10. Evaluation	8, 9	2
11. Prepare System Design Report	10	2
12. Software Development	11	15
13. Hardware Development	11	10
14. Network Development	11	6
15. Prepare System Development Report	12, 13, 14	2
16. Software Testing	15	6
17. Hardware Testing	15	4
18. Network Testing	15	4
19. Prepare Testing Report	16, 17, 18	1
20. Training	19	4
21. System Conversion	19	2
22. Prepare Implementation Report	20, 21	1

Changes to reports—such as added fields, different subtotals and totals, different sorts, different selection criteria, different order of fields, or completely new reports.

Changes to online queries—such as different ad hoc capabilities, access to different fields or databases, different query structures, or additional queries.

Changes to database structures—such as additional fields, different data field names, different data storage sizes, different relationships among the data, or completely new databases.

Changes to software processing routines—such as different algorithms, different interfaces with other subroutines, different internal logic, or new procedures.

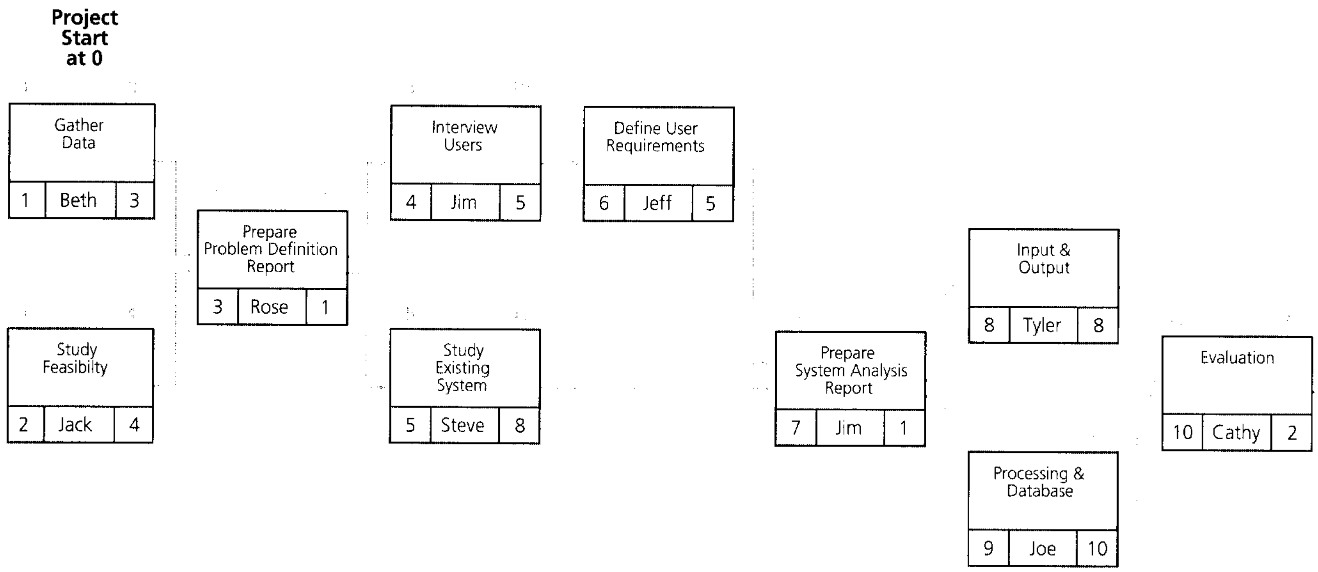
Changes to processing speeds—such as higher throughput rates or response times.

Changes to storage capacities—such as an increase in the maximum number of data records.

Changes to business processes—such as changes in work or data flow, addition of new clients that must have access, or completely new processes that must be supported.

Changes to software resulting from hardware upgrades or, conversely, *hardware upgrades resulting from the availability of more powerful software.*

FIGURE 5.18 Network Diagram for Web-based Reporting System Project, Showing Earliest Start and Finish Times



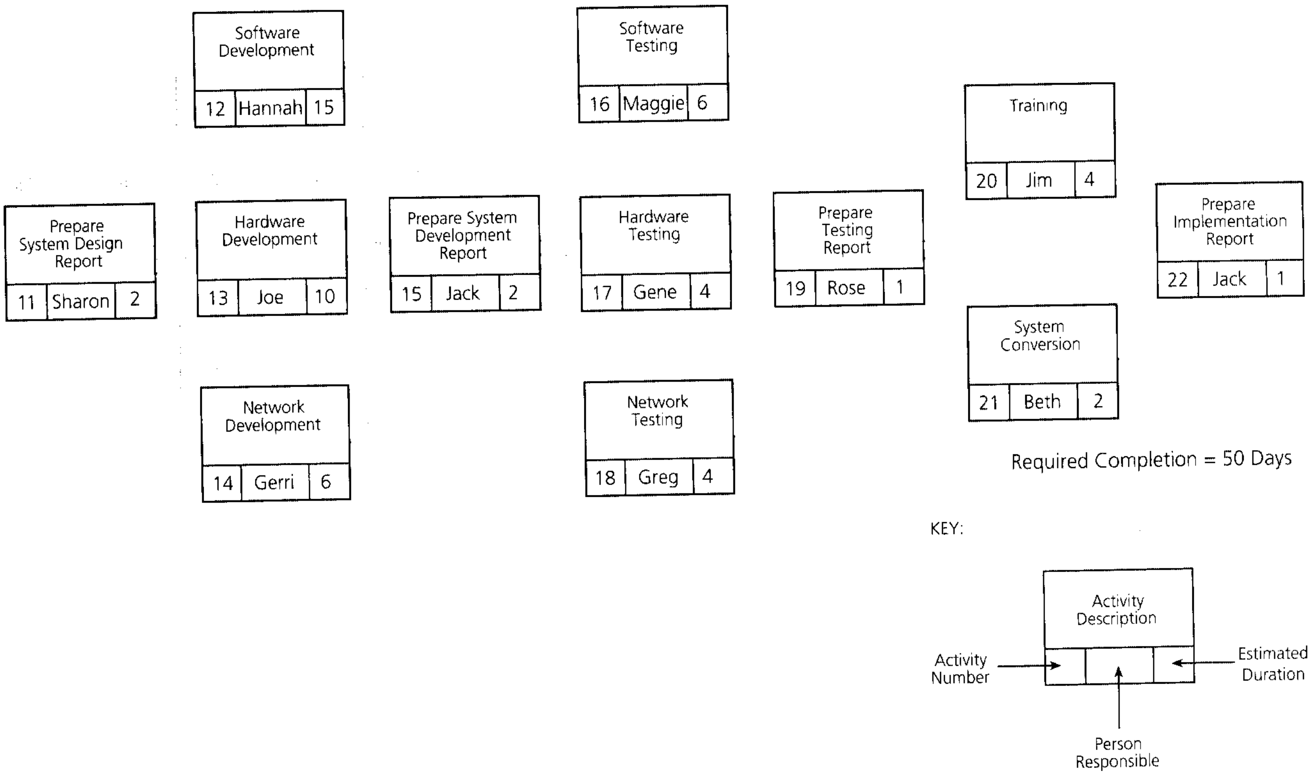
AN INFORMATION SYSTEM ENHANCEMENT PROJECT: APPLICATIONS DEVELOPMENT FOR ABC OFFICE DESIGNS (CONTINUED)

Recall from Chapter 4 that ABC Office Designs has a large number of sales representatives who sell office furniture to major corporations. Each sales representative is assigned to a specific state, and each state is part of one of four regions in the country. To enable management to monitor the number and amount of sales for each representative, for each state, and for each region, ABC has decided to build a Web-based information system. In addition, the information system needs to be able to track prices, inventory, and the competition.

The Information System department within the corporation assigned Beth Smith to be the project manager of the Web-based reporting system development project. Previously, Beth had identified all of the major tasks that needed to be accomplished and developed the work breakdown structure (WBS), responsibility assignment matrix, and network diagram. Her next step was to come up with estimated durations for the activities. After consulting extensively with the project team, she derived the estimates shown in Figure 5.17.

The project is required to be completed in 50 days, and it needs to be started as soon as possible. Having the estimated durations for each activity and the project required start and finish times, Beth was ready to perform the calculations for the ES and EF times for each activity. These values are shown above each activity in Figure 5.18.

Beth calculated the ES and EF times by going forward through the network. The first tasks, "Gather Data" and "Study Feasibility," have ES times of 0. Because "Gather Data" is estimated to take 3 days, its EF is 0 + 3 = 3 days. Because "Study Feasibility" is estimated to take 4 days, its EF is 0 + 4 = 4 days. Beth continued this process, moving forward through the network diagram until all activities had been assigned ES and EF times.



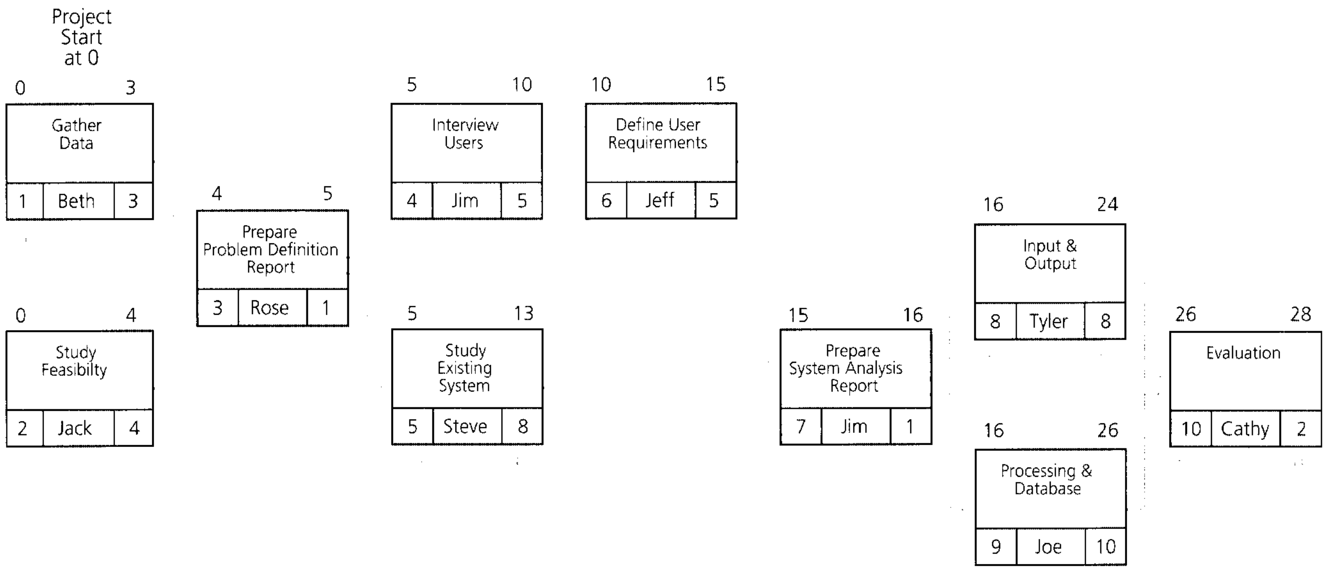
After the ES and EF times were calculated, Beth calculated the LS and LF times. The starting point here is the time by which the project must be completed—50 days. The LS and LF times are shown below each activity in Figure 5.19.

Beth calculated the LF and LS times by going backward through the network. The last task, "Prepare Implementation Report," has an LF time of 50—the time by which the project needs to be completed. Because "Prepare Implementation Report" is estimated to take 1 day to perform, its LS is 50 − 1 = 49 days. This means that "Prepare Implementation Report" must be started by day 49 at the latest, or the project will not finish by its required completion time. Beth continued this process, moving backward through the network diagram until all activities had been assigned LF and LS times.

After the ES, EF, LS, and LF times were calculated, Beth calculated the TS. These values are shown in Figure 5.20. Recall that the TS is calculated by either subtracting ES from LS or subtracting EF from LF for each activity.

After she calculated the TS for each activity, Beth had to identify the critical path. For the Web-based reporting system development project, any activity with a slack of −9 is on the critical path. Figure 5.21 shows the critical path for this

Network Diagram for Web-based Reporting System Project, Showing Latest Start and Finish Times



development project. At this point, Beth and her team must determine a way to reduce the development time by 9 days, request that the project completion date be extended from 50 to 59 days, or find some compromise.

However, after extensive discussions with upper management, in which she stressed the importance of developing the system right the first time and not having to rush through some critical phases of the SDLC, Beth convinced her superiors to extend the project completion time to 60 days.

Beth and her team proceeded with the project and completed activities 1 through 6:

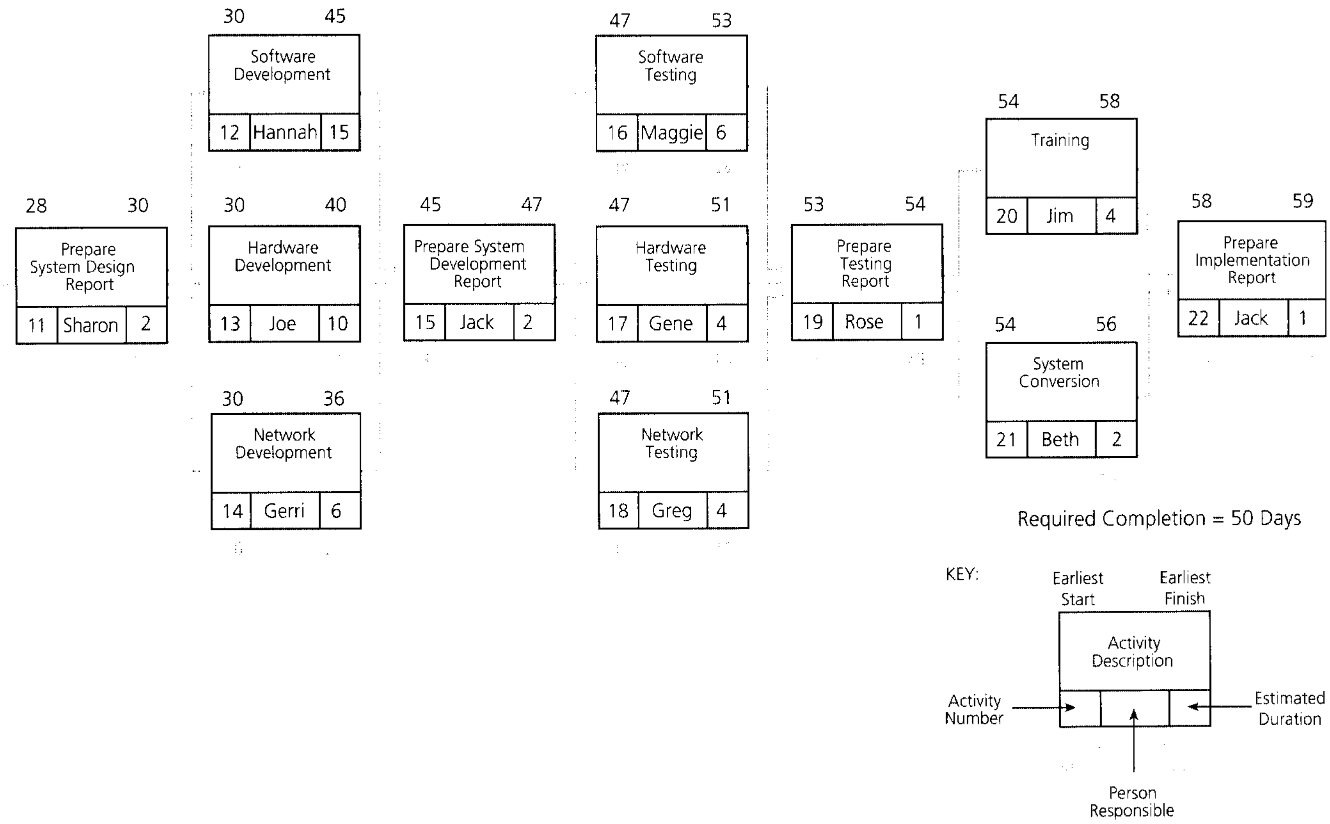
Activity 1, "Gather Data," actually finished on day 4.
Activity 2, "Study Feasibility," actually finished on day 4.
Activity 3, "Prepare Problem Definition Report," actually finished on day 5.
Activity 4, "Interview Users," actually finished on day 10.
Activity 5, "Study Existing System," actually finished on day 15.
Activity 6, "Define User Requirements," actually finished on day 18.

They then discovered that, by using some reusable software for the database, they could reduce the estimated duration of activity 9, "Processing & Database," from 10 days to 8 days.

Figures 5.22 and 5.23 show the updated network diagram and project schedule, respectively, after these changes have been incorporated. Notice that because of the above occurrences, the critical path now has a TS of 0.

Project Management Scheduling Features

Almost all project management information systems allow you to perform the scheduling functions identified in this chapter. Specifically, activity estimated durations can be in hours, days, weeks, months, or years, and with a click of



the mouse, time scales can easily be converted from days to weeks, weeks to days, and so on. The estimated durations can easily be updated and revised. In addition, calendaring systems provide the project manager with the ability to handle weekends, company holidays, and vacation days.

Project start and finish times can be entered as specific calendar dates (for example, June 1, 2015 or December 31, 2015), or an overall number of days (or weeks or months), without specific calendar dates assigned, can be entered (for example, the project needs to finish by week 50). Given the project required completion date and the list of activities with their estimated durations, the software will calculate the date by which a project needs to start. Similarly, it will calculate the earliest project completion date, based on the actual start date and the list of activities with their estimated durations.

The software will also calculate ES, EF, LS, and LF times, TS and FS, and the critical path, all with a click of the mouse. It is important, however, for the project manager to understand what these terms are and what the calculations mean.

Most project management information systems have the ability to provide Gantt or bar charts that display the dependencies among tasks by connecting

Schedule for Web-based Reporting System Project

1	Gather Data	Beth	3	0	3	–8	–5	–8	
2	Study Feasibility	Jack	4	0	4	–9	–5	–9	
3	Prepare Problem Definition Report	Rose	1	4	5	–5	–4	–9	
4	Interview Users	Jim	5	5	10	–4	1	–9	
5	Study Existing System	Steve	8	5	13	–2	6	–7	
6	Define User Requirements	Jeff	5	10	15	1	6	–9	
7	Prepare System Analysis Report	Jim	1	15	16	6	7	–9	
8	Input & Output	Tyler	8	16	24	9	17	–7	
9	Processing & Database	Joe	10	16	26	7	17	–9	
10	Evaluation	Cathy	2	26	28	17	19	–9	
11	Prepare System Design Report	Sharon	2	28	30	19	21	–9	
12	Software Development	Hannah	15	30	45	21	36	–9	
13	Hardware Development	Joe	10	30	40	26	36	–4	
14	Network Development	Gerri	6	30	36	30	36	0	
15	Prepare System Development Report	Jack	2	45	47	36	38	–9	
16	Software Testing	Maggie	6	47	53	38	44	–9	
17	Hardware Testing	Gene	4	47	51	40	44	–7	
18	Network Testing	Greg	4	47	51	40	44	–7	
19	Prepare Testing Report	Rose	1	53	54	44	45	–9	
20	Training	Jim	4	54	58	45	49	–9	
21	System Conversion	Beth	2	54	56	47	49	–7	
22	Prepare Implementation Report	Jack	1	58	59	49	50	–9	

tasks and their predecessors with lines and arrowheads. The user can click back and forth between the Gantt or bar charts and the network diagrams.

Virtually all project management information systems allow you to perform the control functions identified in this chapter. Specifically, while an activity is in progress or once an activity has been completed, current information can be entered into the system and the software will automatically revise the project schedule. Likewise, if the estimated durations for any future activities change, these changes can be entered into the system and the information system will automatically update the schedule. All network diagrams, tables, and reports produced by the software will be updated to reflect the most recent information.

See Appendix A in the back of the book for a thorough discussion of project management information systems.

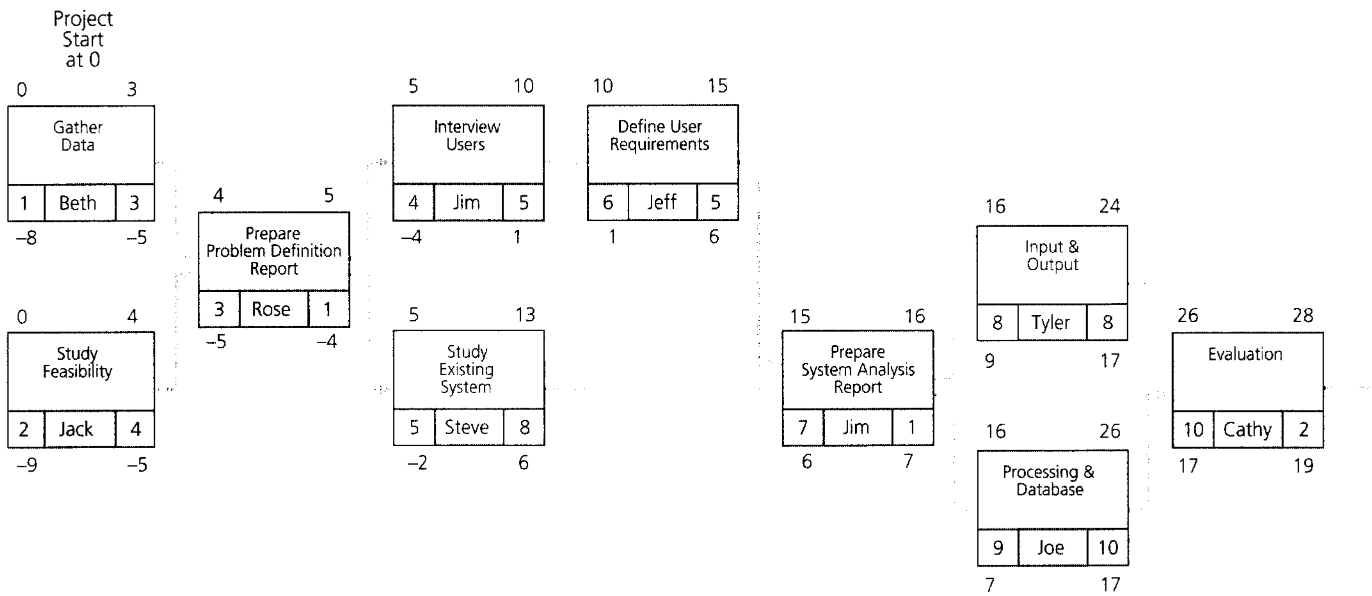
Agile project management is an approach to reduce product development time while minimizing risk through continuous interaction between the customer and small self-organized teams that produce increments of working product features in short time iterations while rapidly adapting to changes in requirements. It is applicable to projects for which the requirements are difficult to define at the beginning or may change quickly or often during the project. It emphasizes short term planning and intense work efforts in short fixed time cycles. Agile project management is sometimes used for software product development projects during which the final system product is completed in increments by developing sets or modules of specific product requirements and features in short timeframes.

There are various methodologies for implementing agile project management. One of the more popular methodologies is **Scrum**, a term derived from the game of rugby.

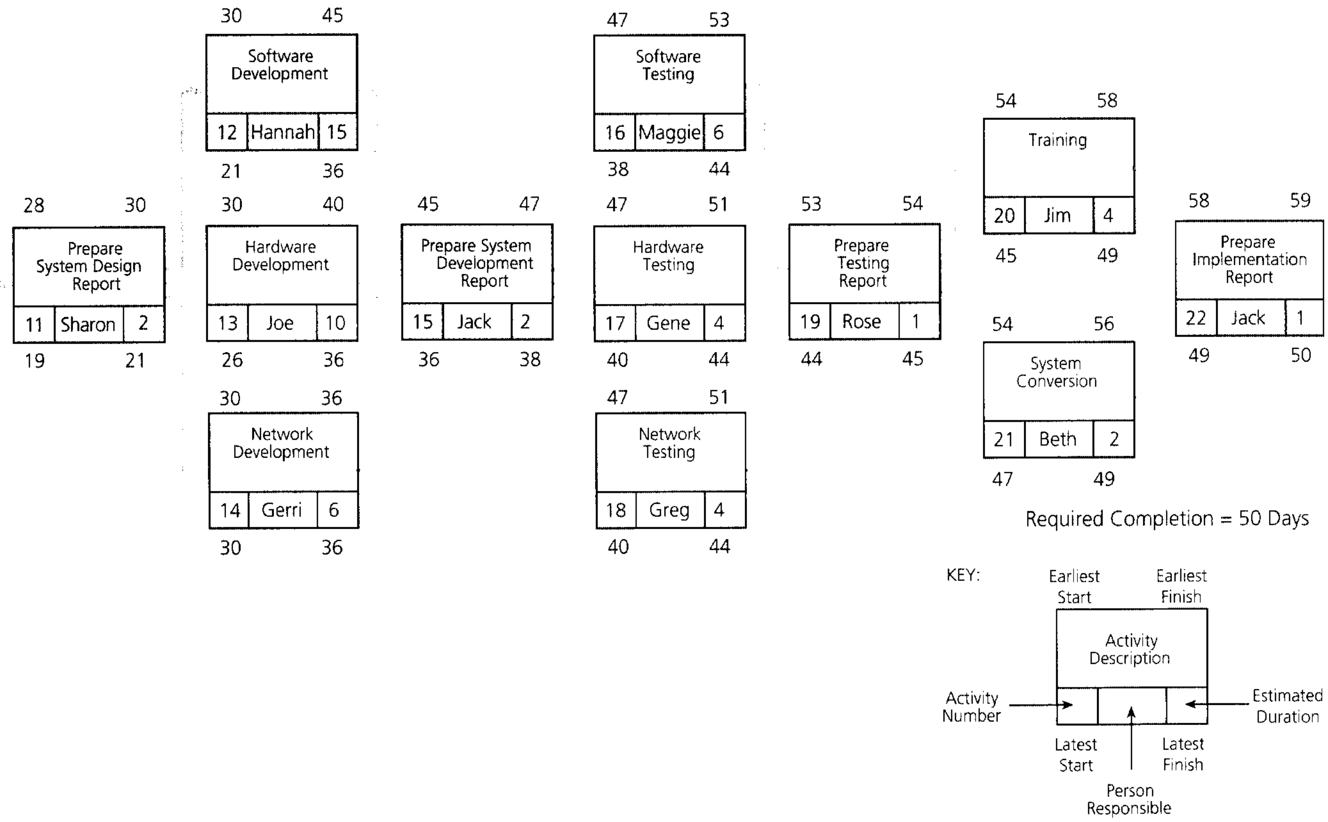
The roles of the participants involved in this approach include:

> A *product owner*, also referred to as the *customer representative*, is responsible for defining the customer requirements and product features and for ensuring that the development team delivers an end product with the required features. Sometimes product features may be defined by "stories" that are descriptions by end users of features they would like changed or added to an existing product or included in a new product. The product owner also prioritizes the requirements based on their value and dependent relationships or required sequence. She then creates a **product backlog** that is an ordered list of requirements or features from which the specific sets of items will be selected and released to the development team to produce and to demonstrate at the end of a fixed timeframe. These sets of features are referred to as a *releases* (similar to work packages) because the items are released from the product backlog to the team to produce a working product increment that is a portion of the overall end product that is being developed. The product owner is encouraged to collocate with the development team to enable regular discussions and clarifications of customer requirements, to review and provide comments and feedback on the work of the development team, and to specify any modifications that need to be made so the development team can adapt their work efforts during the remaining fixed time period to accommodate any changes; otherwise the changes will need to be incorporated in future releases.

Network Diagram for Web-based Reporting System Project, Showing the Critical Path



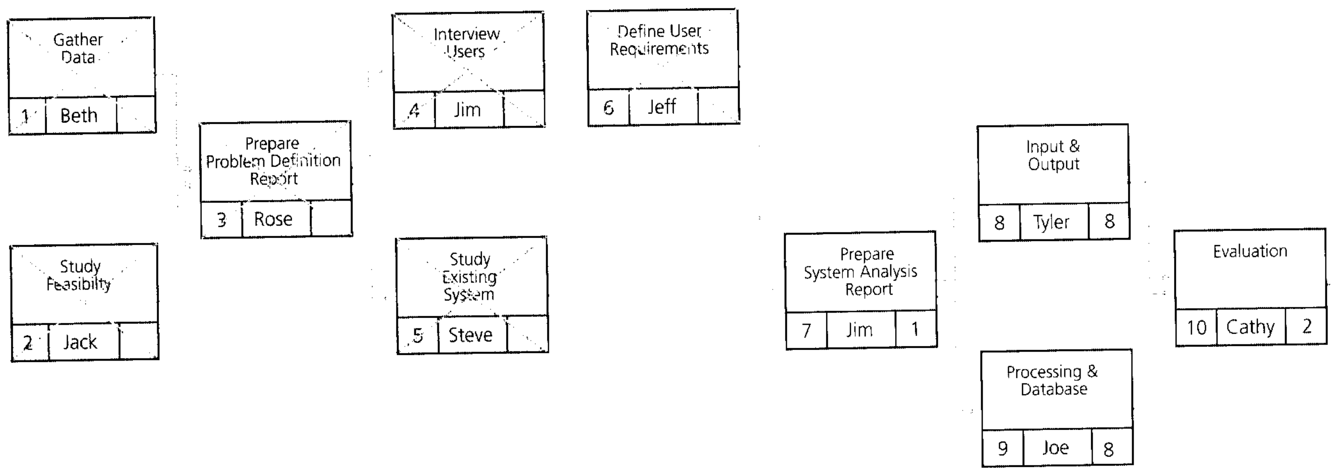
- The *development team* develops, delivers, and demonstrates working **product increments** (portions or modules of the overall end product that is being developed) for specific product features or requirements during a fixed timeframe, called a *sprint*, also referred to as an *iteration.* A sprint is usually one to four weeks. The development teams are cross-functional and include all the expertise and skills to produce the deliverable product increment by the end of the particular sprint. The goal for each sprint is to create and demonstrate a working product increment toward the completion of the final end product. The teams are also small, usually no more than about eight people, to ensure a high level of communication and collaboration. There is a strong emphasis on face-to-face communication and on an open office environment where people can readily interact with each other. Teams are self-organizing and do not have a leader. Rather they select and perform specific work tasks based on each person's skills and availability during the sprint.
- A *Scrum master* is a facilitator for the Scrum development process during a sprint whose primary job is to take actions to remove or reduce any obstacles, barriers, or constraints that are impeding progress of the development team toward accomplishing their work tasks and that may negatively impact the successful production and demonstration of a deliverable working product increment by the end of the sprint time. Sprint cycle times are fixed. If all the work is not completed within the fixed timeframe of a sprint, the uncompleted items are added back to the product backlog to be performed during a future sprint. The Scrum master is not the same as a project manager in that he does not have direct responsibility for the people on the development team. Team members do not work for the Scrum master; rather they are self-organized and self-directed.



The agile project management process includes:

1. Establishing the rationale, description, funding amount, and target completion date for the final end product (deliverable) and authorizing the project. This is similar to a project charter.
2. Defining the product requirements and creating an ordered product backlog of prioritized specific requirements and product features. This is similar to a project scope document.
3. At the beginning of each sprint the product owner and the development team have a *sprint planning meeting* to select a set of requirements or features from the top of the product backlog that will be released to the team and that can be produced and demonstrated by the team during the fixed timeframe for the sprint cycle. The development team then identifies the specific tasks, and estimates their durations, that it needs to perform to produce the product increment that demonstrates the features. Tasks are usually between four and twelve hours in duration. This sprint planning meeting usually takes one day or less. Once the team identifies the specific tasks to be

Network Diagram for Web-based Reporting System Project Incorporating Actual Progress and Changes



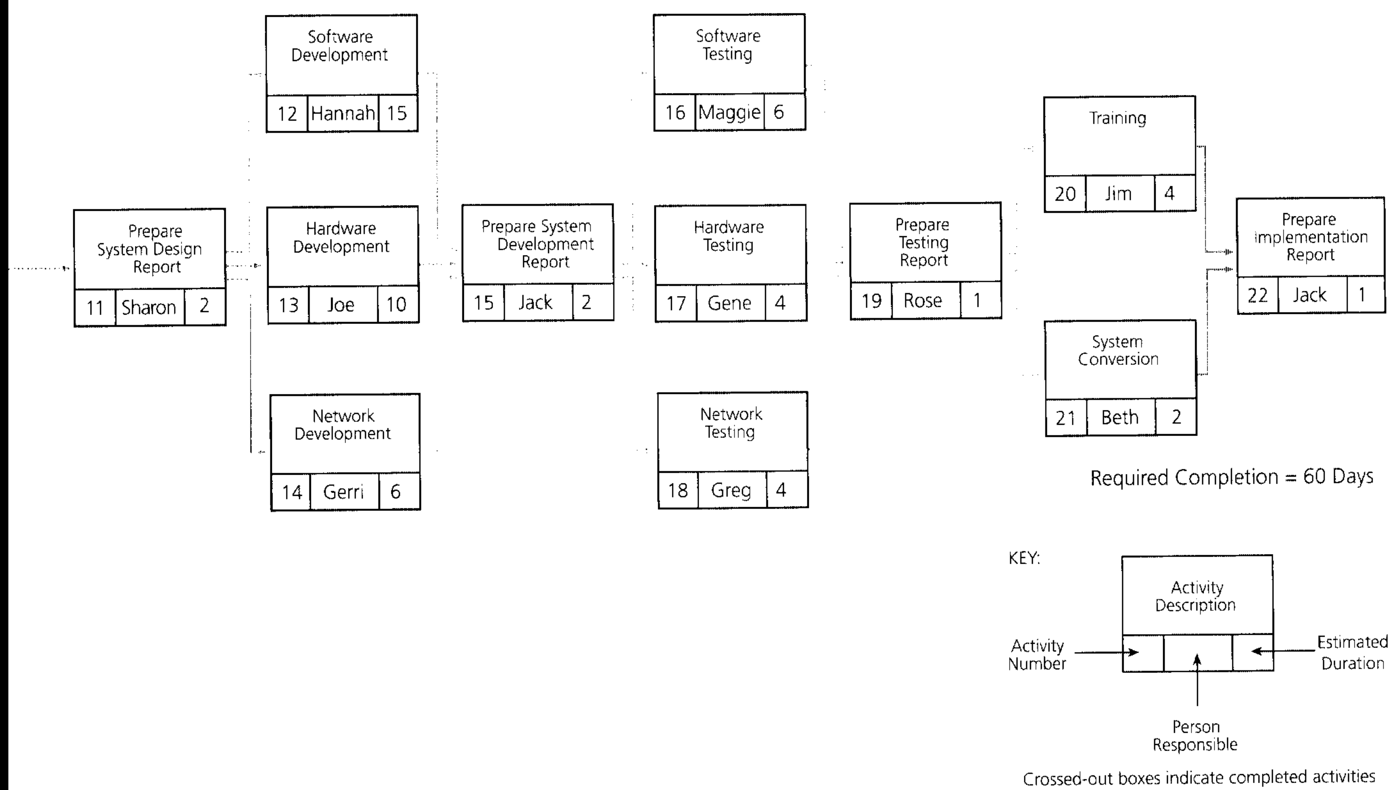
performed during the sprint, the list of tasks is referred to as the **sprint backlog**, which is used to monitor work progress. The Scrum master may create some project monitoring and control tools such as a *task board* that is used to display which tasks have been completed, are in-progress, or not yet started, and/or a *burn down chart* that shows the effort and work to date and the remaining effort in the sprint backlog. Often these tools are on large displays in the open office area and visible to the entire team to see their progress toward the completion of the sprint.

For large projects there may be multiple development teams working concurrently in different sprints on various releases from the product backlog to produce specific product increments. In such cases, it is important that the development teams communicate regularly to ensure there is appropriate integration among the product increments and also that there is no overlap or duplication of effort. The sprint Scrum masters should facilitate such efforts.

4. At the start of each day the development team has a *daily Scrum meeting*, also referred to as the *daily standup* as these meetings are usually limited to 15 minutes. During these meetings each team member is expected to come prepared to state

- what they did the previous day
- what they plan to do today
- any obstacles that are impeding their work. If impediments are identified, they are not solved at these Scrum meetings, rather the Scrum master and the appropriate team members will resolve those items during the workday. The Scrum meetings are not intended to be problem solving meetings.

During the daily Scrum meeting, if any team members state that they had completed a task, they then select another task from the sprint backlog of tasks on which they will work based on their skills.



These daily meetings provide a mechanism for accountability and motivation for the development team members.

Based on which tasks have been completed, the Scrum master will update the task board or burn down chart each day.

5. At the end of the sprint, there is a *sprint review meeting* at which the development team reviews the work that has been accomplished as well as which items were not completed. They also demonstrate their completed working product increment to the product owner and other appropriate stakeholders. If the product owner determines that changes need to be made to some features of the product increment, those changes are documented and added to the product backlog, along with any items that were not completed, and will be included in future releases and sprints. This meeting usually is no more than about four hours.
6. At the end of the sprint, there is also a *sprint retrospective meeting* during which the Scrum team, including the product owner, evaluates performance during the sprint regarding what went well and what could be improved in future sprints. This meeting is facilitated by the Scrum master and should take about two or three hours.

FIGURE 5.23 **Updated Schedule for Web-based Reporting System Project**

Web-based Reporting System Project

Activity		[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]
				[illegible]	[illegible]	[illegible]	[illegible]		
1	Gather Data	Beth							4
2	Study Feasibility	Jack							4
3	Prepare Problem Definition Report	Rose							5
4	Interview Users	Jim							10
5	Study Existing System	Steve							15
6	Define User Requirements	Jeff							18
7	Prepare System Analysis Report	Jim	1	18	19	18	19	0	
8	Input & Output	Tyler	8	19	27	19	27	0	
9	Processing & Database	Joe	8	19	27	19	27	0	
10	Evaluation	Cathy	2	27	29	27	29	0	
11	Prepare System Design Report	Sharon	2	29	31	29	31	0	
12	Software Development	Hannah	15	31	46	31	46	0	
13	Hardware Development	Joe	10	31	41	36	46	5	
14	Network Development	Gerri	6	31	37	40	46	9	
15	Prepare System Development Report	Jack	2	46	48	46	48	0	
16	Software Testing	Maggie	6	48	54	48	54	0	
17	Hardware Testing	Gene	4	48	52	50	54	2	
18	Network Testing	Greg	4	48	52	50	54	2	
19	Prepare Testing Report	Rose	1	54	55	54	55	0	
20	Training	Jim	4	55	59	55	59	0	
21	System Conversion	Beth	2	55	57	57	59	2	
22	Prepare Implementation Report	Jack	1	59	60	59	60	0	

- The person who will be responsible for performing the activity should estimate the duration for that activity. This generates commitment from the person.
- The estimated duration for an activity must be based on the types and quantities of resources required to perform the activity.
- Activity estimated durations should be aggressive yet realistic.
- Activities should not be longer in estimated duration than the time intervals at which the actual progress will be reviewed and compared to planned progress.
- Project management involves a proactive approach to controlling a project to ensure that the project objective is accomplished, even when things do not go according to plan.
- Once the project starts, it is important to monitor progress to ensure that everything is going according to plan.
- The key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking any needed corrective action immediately.
- The key to effective schedule control is to address any paths with negative or deteriorating slack values aggressively as soon as they are identified. A concentrated effort to accelerate project progress must be applied to these paths. The amount of negative slack should determine the priority for applying these concentrated efforts.
- When attempting to reduce the duration of a path of activities that has negative slack, focus on activities that are near term and on activities that have long estimated durations.
- Addressing schedule problems early will minimize the negative impact on scope and budget. If a project falls too far behind, getting it back on schedule becomes more difficult and usually requires spending more money or reducing the scope or quality.
- If corrective actions are necessary, decisions must be made regarding a trade-off of scope, time, and cost.
- A regular reporting period should be established for comparing actual progress to planned progress.
- The shorter the reporting period, the better the chances of identifying problems early and taking corrective actions.
- During each reporting period, data on actual performance and information on changes to the project scope, schedule, and budget need to be collected in a timely manner and used to calculate an updated schedule and budget.

When network planning techniques are used, the scheduling function depends on the planning function. A schedule is a timetable for the plan and, therefore, cannot be established until the network-based plan has been created.

It is necessary to estimate the types and quantities of resources that will be required to perform each specific activity in the network diagram to subsequently estimate how long it will take to perform the activity. When estimating resources for activities, the availability of each resource has to be taken into account. The estimated types and quantities of resources required for an activity together with the availability of those resources will influence the estimated duration for how long it will take to perform the activity.

Once the types and quantities of resources are estimated for each activity, estimates can then be made for how long it will take to perform each activity. The estimated duration for each activity must be the total elapsed time—the time for the work to be done plus any associated waiting time. An activity's estimated duration must be based on the quantity of resources required to perform the activity. The estimate should be aggressive, yet realistic. At the beginning of the project, it may not be possible to estimate durations for all activities with a level of confidence regarding their accuracy. This is especially true for longer-term projects. It may be easier to estimate the durations for near-term activities, but as the project progresses, the project team can progressively elaborate the estimated durations as more information is known or becomes clear to allow for more accurate estimated durations.

To establish a basis from which to calculate a schedule using the estimated durations for the activities, it is necessary to select an estimated start time for when the project is expected to begin and a required completion time for when the project must be done. These two times define the overall window, or envelope, of time in which the project must be completed.

A project schedule provides a timetable for each activity and shows the earliest start (ES) and earliest finish (EF) times and the latest start (LS) and latest finish (LF) times for each activity. The ES and EF times are calculated by working forward through the network. The ES time for an activity is calculated on the basis of the project estimated start time and the estimated durations of preceding activities. The EF time for an activity is calculated by adding the activity's estimated duration to the activity's ES time. The ES time for a specific activity must be the same as or later than the latest of all the EF times of all the activities leading directly into that specific activity.

The LS and LF times are calculated by working backward through the network. The LF time for an activity is calculated on the basis of the project required completion time and the estimated durations of succeeding activities. The LS time is calculated by subtracting the activity's estimated duration from the activity's LF time. The LF time for a specific activity must be the same as or earlier than the earliest of all the LS times of all the activities emerging directly from that specific activity.

The TS for a particular path of activities through the network is common to and shared among all activities on that path. If it is positive, it represents the maximum amount of time that the activities on a particular path can be delayed without jeopardizing completion of the project by the required time. If TS is negative, it represents the amount of time that the activities on that path must be accelerated to complete the project by the required time. If it is zero, the activities on that path do not need to be accelerated but cannot be delayed. The critical path is the longest (most time-consuming) path of activities in the network diagram.

Once a project actually starts, it is necessary to monitor the progress to ensure that everything is going according to the plan. The key to effective project control is measuring actual progress and comparing it to planned progress on a timely and regular basis and taking any needed corrective action immediately. A regular reporting period should be established for comparing actual progress with planned progress. During each reporting period, two kinds of data or information need to be collected: data on actual performance and information on any changes to the project scope, schedule, and budget. The project control process continues throughout the project. In general, the shorter the reporting period, the better the chances of identifying problems early and taking effective corrective actions. If a project gets too far out of control, it may be difficult to achieve the project objective without sacrificing the scope, quality, schedule, or budget.

Throughout a project, some activities will be completed on time, some will be finished ahead of schedule, and others will be finished later than scheduled. Actual progress—whether faster or slower than planned—will have an effect on the schedule of the remaining, uncompleted activities of the project. Specifically, the AF times of completed activities will determine the ES and EF times for the remaining activities in the network diagram, as well as the TS.

Throughout a project, changes may occur that have an impact on the schedule. These changes might be initiated by the customer or the project team, or they might be the result of an unanticipated occurrence. Any type of change—whether initiated by the customer, the contractor, the project manager, a team member, or an unanticipated event—will require a modification to the plan in terms of scope, schedule, and/or budget. When such changes are agreed upon, a new baseline plan is established and used as the benchmark against which actual project performance will be compared.

Based on actual progress and on consideration of other changes that may occur, an updated project schedule can be generated regularly that forecasts whether the project will finish ahead of or behind its required completion time. Once data have been collected on the AF times of completed activities and the effects of any project changes, an updated project schedule can be calculated.

Schedule control involves four steps: analyzing the schedule to determine which areas may need corrective action, deciding what specific corrective actions should be taken, revising the plan to incorporate the chosen corrective actions, and recalculating the schedule to evaluate the effects of the planned corrective actions. Corrective actions that will eliminate the negative slack from the project schedule must be identified. These corrective actions must reduce the estimated durations of activities on the negative-slack paths. When analyzing a path of activities that has negative slack, the focus should be on two kinds of activities: activities that are near term and activities that have long estimated durations.

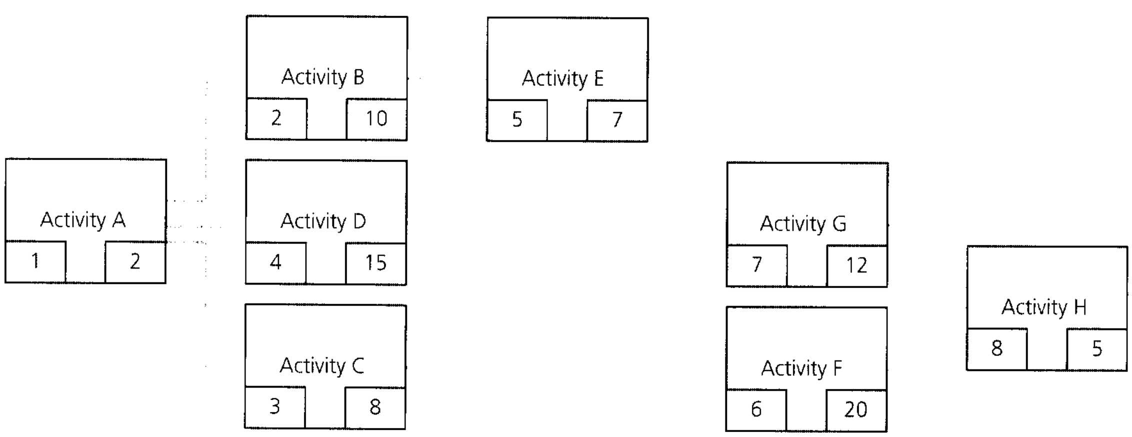
There are various approaches to reducing the estimated durations of activities. These include applying more resources to accelerate an activity, assigning individuals with greater expertise or more experience to work on the activity, reducing the scope or requirements for the activity, and increasing productivity through improved methods or technology.

Scheduling the development of an information system is a challenging process. Such scheduling is often done in a haphazard manner, and as a result, a large number of information system projects are finished much later than originally promised. One of the most important factors in effective scheduling is estimating activity durations that are as realistic as possible. The project manager should be aware of the common problems that often push information system development projects beyond their scheduled completion dates. Project management information systems can help with the scheduling process.

Agile project management is an approach to reduce product development time while minimizing risk through continuous interaction between the customer and small self-organized teams that produce increments of working product features in short time iterations while rapidly adapting to changes in requirements. It is applicable to projects for which the requirements are difficult to define at the beginning or may change quickly or often during the project. It emphasizes short term planning and intense work efforts in short fixed time cycles.

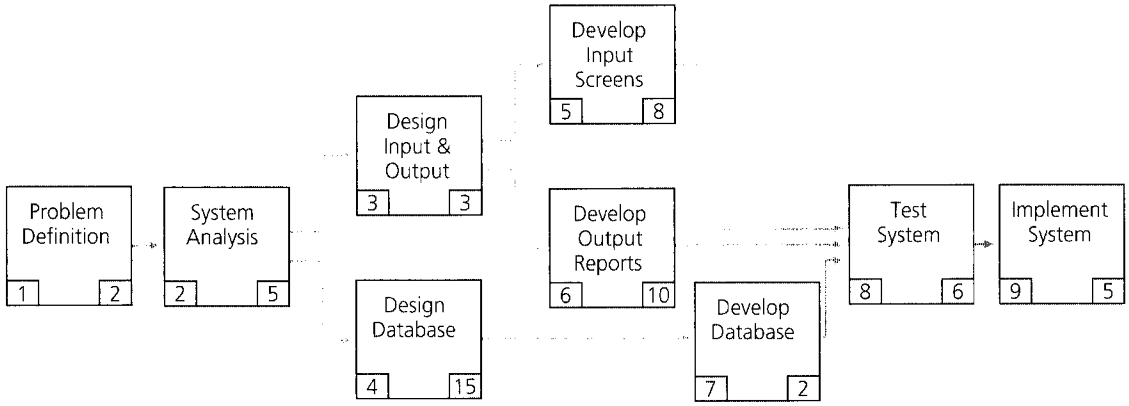
QUESTIONS

1. Why does the scheduling function depend on the planning function? Which one must be done first? Why?
2. Describe what an activity estimated duration is. How is it determined?
3. Why might a contractor prefer to state a project completion time in terms of number of days after the project starts rather than a specific date? Give some examples of instances when this would be appropriate.
4. Refer to Figure 5.4. Why is the earliest start time for "Review Comments & Finalize Questionnaire" day 33? Why is the earliest finish time day 38?
5. Refer to Figure 5.7. Why is the latest start time for "Mail Questionnaires & Get Responses" day 40? Why is the latest finish time day 105?
6. Describe the different types of project slack and how each is calculated.
7. Why is it important to determine the critical path of a project? What happens if activities on this path are delayed? What happens if activities on this path are accelerated?
8. From your experience, describe how you have used a project control process. If you did not use continual monitoring of the progress, how would it have helped improve the project's success if you did use it?
9. Why should a project have a regular reporting period? Should all projects have the same reporting period? Why or why not? What types of data should be collected during each reporting period?
10. Who can initiate changes to a project schedule? Describe why and when changes would occur in a project. How are the network diagram and schedule updated to reflect the changes?
11. Describe how you would apply the four steps of schedule control to a project. If the project needs to be accelerated, what kinds of activities would be the primary focus? Why?
12. Why is the scheduling of information system projects so challenging? What are some of the common problems that push information system projects beyond their due dates? How could using agile project management techniques help control a project's progression?
13. Calculate the ES, EF, LS, and LF times and the slack for each activity in the figure below, and identify the critical path for the project. Can the project be completed in 40 weeks? Assume that activity A actually finished at 3 weeks,

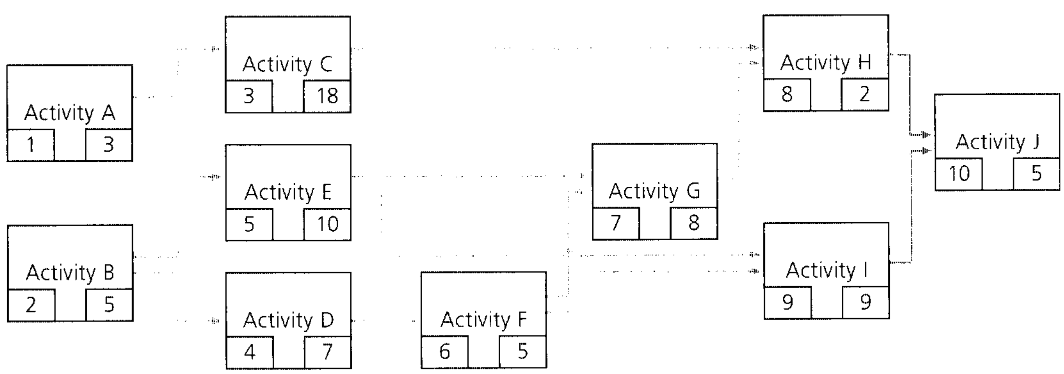


activity B actually finished at 12 weeks, and activity C actually finished at 13 weeks. Recalculate the expected project completion time. Which activities would you focus on to get the project back on schedule?

14. Calculate the ES, EF, LS, and LF times and the slack for each activity in the figure below, and identify the critical path for the project. Can the project be completed in 30 weeks? Assume that "Systems Analysis" actually finished at 8 weeks, "Design Input & Output" actually finished at 15 weeks, and "Design Database" actually finished at 19 weeks. Recalculate the expected project completion time. Which activities would you focus on to get the project back on schedule?



15. Calculate the ES, EF, LS, and LF times and the slack for each activity in the figure below, and identify the critical path for the project. Can the project be completed in 30 weeks? Assume that activity A actually finished at 5 weeks and activity B actually finished at 5 weeks. Recalculate the expected project completion time. Which activities would you focus on to get the project back on schedule?



INTERNET EXERCISES

For the website addresses of the organizations mentioned in these exercises, go to "Internet Exercises" at the book's companion website at www.cengagebrain.com. It is suggested that you save this website in your "Favorites" list for easy access in the future.

1. Search the Web for "project schedule." Describe at least three sites that you find. Search with additional terms such as "tools" and "control." List the terms that you have added, and describe at least three sites that you find.
2. For exercises 2 through 5, visit the website for the organization Mind Tools™. Explore the site. What kind of information does it provide?
3. On the "Home" page, explore the "Hot Tools and Resources" links. Describe what you find.
4. Explore the topics in the "Toolkit" link for Project Management. Read through a topic that interests you. Provide a one-page summary.
5. Click on the "News" link to subscribe to the free newsletter. In addition, under the "More Resources" link, click on "Videos," read an article and watch a video that interests you and provide a one-page summary.

CASE STUDY 1 A Not-for-Profit Medical Research Center

This case study is a continuation of the case study started in Chapter 4.

CASE QUESTIONS

1. Develop an estimated duration for each activity.
2. Using a project start time of 0 (or May 15) and a required project completion time of 180 days (or November 15), calculate the ES, EF, LS, and LF times and TS for each activity. If your calculations result in a project schedule with negative TS, revise the project scope, activity estimated durations, and/or sequence or dependent relationships among activities to arrive at an acceptable baseline schedule for completing the project within 180 days (or by November 15). Describe the revisions you made.
3. Determine the critical path, and identify the activities that make up the critical path.
4. Produce a bar chart (Gantt chart) based on the ES and EF times from the schedule in item 2.

Note: This case study will continue in Chapters 6 through 8, so save the results of your work.

GROUP ACTIVITY

Divide the course participants into the same groups as for the previous chapter's group activity. Then address each of the steps listed above.

CASE STUDY 2 The Wedding

This case study is a continuation of the case study started in Chapter 4.

CASE QUESTIONS

1. Develop an estimated duration for each activity.
2. Using a project start time of 0 (or January 1) and a required project completion time of 180 days (or June 30), calculate the ES, EF, LS, and LF times

and TS for each activity. If your calculations result in a project schedule with negative TS, revise the project scope, activity estimated durations, and/or sequence or dependent relationships among activities to arrive at an acceptable baseline schedule for completing the project within 180 days (or by June 30). Describe the revisions you made.

3. Determine the critical path, and identify the activities that make up the critical path.
4. Produce a bar chart (Gantt chart) based on the ES and EF times from the schedule in item 2.

Note: This case study will continue in Chapters 6 through 8, so save the results of your work.

GROUP ACTIVITY

Divide the course participants into the same groups as for the previous chapter's group activity. Then address each of the steps listed above.

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APPENDIX 1 Probabilistic Activity Durations

ESTIMATE ACTIVITY DURATIONS

Recall that the estimated duration for each activity is the estimated total elapsed time from when the activity is started until it is finished. With projects for which there is a high degree of uncertainty about the estimated duration for activities, it is possible to use three estimates for each activity:

1. ***Optimistic time (t_o)*** is the time in which a specific activity can be completed if everything goes perfectly well and there are no complications. A rule of thumb is that there should be only one chance in ten of completing the activity in less than the optimistic time estimate.
2. ***Most likely time (t_m)*** is the time in which a specific activity can most frequently be completed under normal conditions. If an activity has been repeated many times, the actual duration that occurs most frequently can be used as the most likely time estimate.
3. ***Pessimistic time (t_p)*** is the time in which a specific activity can be completed under adverse circumstances, such as in the presence of unusual or unforeseen