APPENDIX B

Project Schedules with PERT/CPM Charts

Chapter 3 provides a brief introduction to project scheduling using PERT/CPM charts. This appendix expands on that background by first explaining the techniques to build a PERT/CPM chart manually. Then it demonstrates how to use Microsoft Project to develop PERT/CPM charts electronically, using the familiar Rocky Mountain Outfitters development project.

BUILDING PERT/CPM CHARTS

Developing a PERT/CPM chart is a four-step process:

1. Identify all the tasks for the project (that is, build a work breakdown structure—WBS).
2. Determine the amount of work necessary to complete each task.
3. For each task, identify the immediate predecessor tasks.
4. Enter the tasks on a PERT/CPM chart, with connecting arrows based on the task dependencies; calculate start and end times based on durations and resources.

Chapter 3 discussed the first three steps in building a work breakdown structure. Figure B-1 is the same as the work breakdown structure for the planning phase of the RMO CSS project that was shown in Figure 3-9.

The first step—identifying all the tasks—can be done using any of the approaches explained in Chapter 3. The second step—determining the amount of work for each task—is an estimate of both the duration in days and the number of resources (people) needed for the task. As shown in Figure B-1, the first task requires two days and the second one day, each with two people working. Thus, the first requires four person-days of work and the second two. Each of the last four tasks in the *Define the problem* activity requires half a person for a full day, or about one-half person-day. No duration is assigned to the summary categories, since their duration is the composite of the individual tasks.

Note that this example uses a hierarchical structure and numbers the tasks to show this hierarchy. By grouping individual tasks together into a larger activity, project managers can define summary activities and larger milestones that help to monitor the progress of the project. This capability will become apparent when the information is entered into MS Project.

As indicated in the text, PERT and CPM have essentially merged into a one-step scheduling technique. The basic difference between them was in the techniques used to estimate the effort for the tasks. CPM used a simple estimate of the effort required. PERT used the most probable effort for the task. With PERT, three estimates are made for the task: pessimistic, most likely, and optimistic. The three are combined, using a weighted averaging scheme, into a single value to give the expected effort required for the task. A weighted average simply ensures that any large deviation by either the optimistic or pessimistic estimates will not drastically move the most probable duration away from its expected duration. However, this technique is not used very often today, especially for software projects. Today, most managers simply make their best estimate for each task.

Phases, Activities, and Tasks	Duration in days	Number of resources	Predecessor task
1.0 Project Planning Phase			
1.1 Define the problem			
1.1.1 Meet with users	2	2	0.0.0
1.1.2 Determine scope	1	2	1.1.1
1.1.3 Write statement of business benefits	1	1/2	1.1.2
1.1.4 Write statement of need	1	1/2	1.1.2
1.1.5 Define statement of system capabilities	1	1/2	1.1.2
1.1.6 Develop context diagram	1	1/2	1.1.2
1.2 Produce the project schedule			
1.2.1 Develop work breakdown schedule	2	2	1.1.3, 1.1.4, 1.1.5, 1.1.6
1.2.2 Estimate resources, durations, and predecessors	1	2	1.2.1
1.2.3 Develop PERT chart and Gantt chart	2	2	1.2.2
1.3 Confirm project feasibility			
1.3.1 Identify intangible costs and benefits	1	2	1.2.3
1.3.2 Estimate tangible costs	1	2	1.2.3
1.3.3 Estimate tangible benefits and do cost/benefit	2	2	1.3.1, 1.3.2
1.3.4 Evaluate organizational and cultural feasibility	1	1	1.3.3
1.3.5 Evaluate technical feasibility	2	1	1.3.3
1.3.6 Evaluate schedule feasibility	1	2	1.3.3
1.3.7 Evaluate resource availability	1	1	1.3.3
1.4 Staff the project			
1.4.1 Develop a project resource plan	1	2	1.3.4, 1.3.5, 1.3.6, 1.3.7
1.4.2 Identify and request tech staff	1	1	1.4.1
1.4.3 Meet with users, identify staff	1	1	1.4.1
1.4.4 Organize project team	1	1	1.4.2, 1.4.3
1.4.5 Conduct team-building exercises	3	2	1.4.4, 1.5.4
1.5 Launch the project			
1.5.1 Prepare presentation materials	1	1	1.3.7
1.5.2 Make executive presentation	1	1	1.5.1
1.5.3 Set up project facilities and support resources	3	2	1.5.2
1.5.4 Conduct official kickoff meeting	1	1	1.4.4, 1.5.3

FIGURE B-1

Work breakdown structure (WBS) for the project planning phase for RMO.

The third step, that of assigning task dependencies, is the one that lays the foundation for the development of the PERT/CPM chart. There are three types of dependencies between tasks: (1) project mandatory, (2) external mandatory, and (3) discretionary. Predecessors usually are easily assigned to project mandatory dependencies. One task depends on the completion or output of another task and thus is dependent on it. For example, running an acceptance test cannot begin until the acceptance test criteria and data have been defined (at least partially). External mandatory dependencies are caused by other, nonproject occurrences, such as the arrival of new hardware or the completion of an interface definition from another project. The most troublesome are the discretionary dependencies. They provide the most flexibility for building the schedule but also add the most complexity. For example, developers must determine which should be done first, designing input screens or output reports. Either will probably work. Complexity is added when the project manager tries to balance the scheduling of these tasks with the available resources (that is, the team members). Often several different tentative schedules must be built with different dependencies to determine a sequence that best utilizes team member skills. For now, let's assume all that juggling has been done and that Figure B-1 represents the final result. Note that the summary activities are not assigned predecessors and that scheduling activity is optional as long as the detailed tasks have predecessors assigned.

In the final step, the PERT/CPM chart is built based on detailed task, effort, and predecessor information provided in the table. Figure B-2 is a partial PERT/CPM chart showing these tasks. The summary activities have not been included since they do not participate directly in the dependency list. However, start and end "dummy" tasks have been added just for ease of understanding.

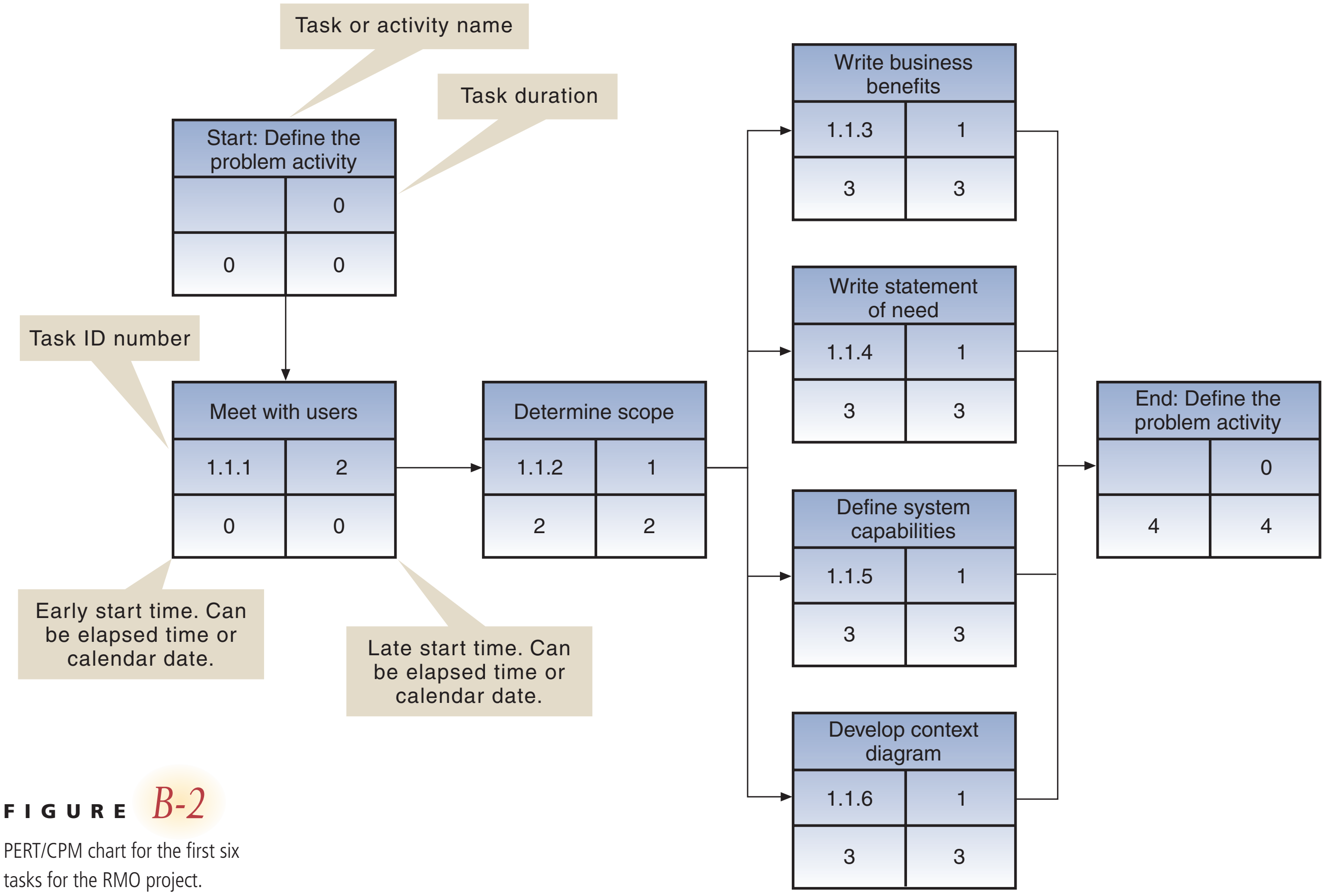


FIGURE B-2

PERT/CPM chart for the first six tasks for the RMO project.

The tasks are represented by the rectangles, and the predecessor relationships are indicated by the connecting arrows. The top compartment within the rectangle is the task name. The middle leftmost compartment is the task ID. The middle rightmost compartment is the duration, and the bottom-left corner is the start time for each task. To keep this example simple, the duration numbers are days, and the start date for each task is the number of days from the beginning of the project. Later, these days are translated into calendar dates. Note that a similar PERT/CPM chart generated by MS Project was shown in Figure 3-10, and another MS Project PERT/CPM example is shown later in Figure B-6.

early start time
the earliest time that a task can begin due to completion times of predecessor tasks

The start times in the bottom-left compartment are called the ***early start time*** for the task. These early start times represent the earliest time that the task can begin. In other words, based on all of the predecessor tasks, the given task cannot begin until the time indicated. Looking at Figure B-2, *Write statement of need* cannot begin until day three. These times are calculated with a forward pass through the chart, starting at the first task and moving sequentially following the arrows (that is, left to right) through the sequence of tasks. The start time of a given task is equal to the start time of the previous task plus the duration of the previous task.

In this example, the tasks numbered 1.1.3 through 1.1.6 can all occur concurrently. This illustrates some of the complexity of identifying dependencies among the tasks. As the project manager was building the dependencies, she noticed that these four tasks are interrelated and should be worked on at the same time. So each of these four tasks begins on day three and is finished by day four.

late start time
the latest time that a task can begin and still keep the project on schedule

The bottom-right compartments contain the times for the ***late start time***. Not all PERT/CPM diagrams show the late start time, but you need to understand the concept to understand some other, more advanced concepts. The late start time is the latest time that a given task can start and *still keep the project on schedule.* In this case, since we have such a simple chart, both the early start and the late start times are the same. A difference between early start and late start only occurs when tasks are scheduled in parallel and have different durations.

In Figure B-3 the individual tasks of the fourth activity on the WBS—*Staff the project*—are presented to illustrate a more complex situation with different early start and late start times and some additional characteristics of a PERT/CPM chart. In this figure two tasks are shown, 1.4.2 and 1.4.3, which are on parallel paths. Whenever there are two or more concurrent paths, it is possible that one will finish before the other. In fact, task 1.4.2 has duration of one day, while task 1.4.3 requires two days. Remember, the early start time is the earliest that a task can start since it depends on the completion of the prior task, and the late start time is the latest time that an activity can start and still keep everything on schedule. For example, as Figure B-3 shows, task 1.4.4 is scheduled to begin on day 18, so both tasks 1.4.2 and 1.4.3 must finish before day 18. Task 1.4.3 starts on day 16 and requires two days. However, task 1.4.2 is scheduled to begin on day 16 but only requires one day. Hence, if task 1.4.2 did not start until day 17, then it would still finish on time for task 1.4.4 to begin on schedule on day 18. Thus, task 1.4.2 has a late start of day 17. The difference between the early start and the late start is called ***slack time*** for the task, and in this case it is one day.

slack time
the difference between the early start time and the late start time for a task; the amount of time a task can be delayed without delaying the project

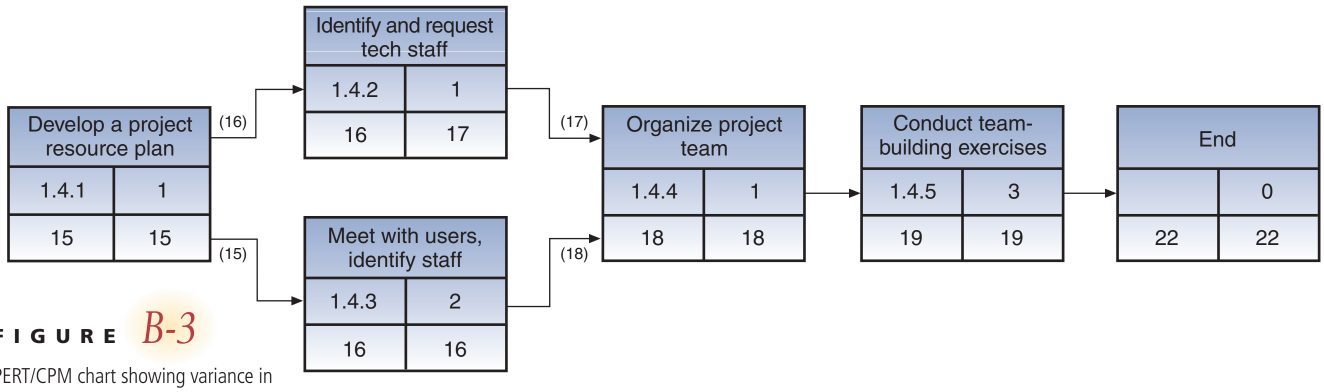


FIGURE B-3
PERT/CPM chart showing variance in early start and late start times.

Late start times are calculated with a backward pass through the chart, in other words, by going against the arrows. The ending task, in this case called End, assumes the project ends in 22 days, if the project is on schedule as shown by the early start times. So, the developer simply moves the 22 days from the early start time in the left compartment to the late start time in the right compartment. In this case, the project ends in 22 days, for both early and late dates. To find the late start dates, the developer then works backwards through the chart. The late start time of a given task is equal to the late start time of the successor task minus the duration of *that same* task. (Notice that to calculate the late start times, we use the duration of the same task, but in calculating early start times, in the forward pass, the duration we used was not the same as the one being calculated.) Proceeding backward upstream, all late start times are calculated.

Note that when there are tasks in parallel, the early start time has two predecessors that will influence its start time. The early start time is calculated using both predecessor tasks and the *latest* early start time that is shown. For example, the early start time for 1.4.4 based on task 1.4.2 is day 17. The early start time for 1.4.4 based on task 1.4.3 is day 18. Obviously, the task cannot begin before day 18 since one predecessor has not finished. Again, early start depends on the *latest* calculated time.

The late start of a task that has two (or more) successor tasks is the *earliest* of the late calculations. For example, observing task 1.4.1, the late start based on 1.4.2 is 17 minus 1, or day 16. The late start based on 1.4.3 is 16 minus 1, or day 15. Obviously, task 1.4.1 can start on day 15 no matter what, because it is not dependent on 1.4.2 or 1.4.3. In fact, it must start on day 15 to keep the project on schedule. Again, late start time takes the *earliest* of the late calculations.

Notice that some tasks in this diagram have an early start time and a late start time that are the same. In other words, the earliest and the latest that the task can begin is the same day. There is no slack time for that task. Tasks with no slack time are on the project's critical path. Chapter 3 defined the critical path as the longest path through the diagram that also represented the shortest possible time for the project to be completed. If any task on the critical path slips, then the entire project will slip. Looking at the PERT/CPM chart gives another, more precise definition of critical path: It consists of any task with an early start time and late start time that are equal. Every project has at least one critical path.

RMO PROJECT SCHEDULING WITH MICROSOFT PROJECT

It should be obvious that building a complex PERT/CPM chart by hand can be very tedious and complicated. Sometimes several iterations of the schedule may need to be done before it is complete and satisfactory. Projects also change as they progress, so the project manager will need to modify the schedule and also track progress. Automated tools simplify the rescheduling and tracking.

In Chapter 3 portions of the RMO project schedule are depicted with two different views, a PERT/CPM and a Gantt chart. Historically, the PERT/CPM chart has been most useful in building the original schedule because it enabled the project manager to easily view dependencies. For project tracking, the tracking Gantt chart view is more helpful since it shows the project on a calendar backdrop. The most widely used project-scheduling tool is MS Project, and it provides both capabilities. However, MS Project has enhanced the Gantt chart view so that it is now often chosen both for building the chart and for tracking progress.

To use MS Project to build a schedule, the project manager must still do the "knowledge" work to build the work breakdown structure as shown in Figure B-1. Unfortunately, neither MS Project nor other tools can automate this work. However, once that task is done, building and modifying charts is straightforward.

As of this writing, MS Project 2003 is the latest version of the software available. MS Project supports both PERT/CPM and Gantt charts. It can also provide resource assignment and resource leveling, and estimate project costs based on manpower assignments. Also, a baseline project plan can be established and used to monitor changes, actual completion dates, and resource utilization during the life of the project.

Figure B-4 is a snapshot of the MS Project page that is used to enter activities and tasks. Notice in this figure that both the summary activities and the detailed tasks are included. The far-left column shows the row number for the task and activity IDs. MS Project assigns these numbers sequentially, and you cannot modify them. Notice also that those same numbers are used for the predecessors to denote task dependencies. As you insert additional tasks on an existing schedule, Project recalculates and adjusts these ID numbers, as well as any predecessor tasks you have already entered. The Task Name column contains the name of the task. MS Project can include a hierarchical numbering scheme, as we showed earlier in the WBS, if you desire (it is a display option). The third

FIGURE B-4

Task list from MS Project for RMO.

	Task Name	Duration	Start	Finish	Predecessors
1	**Project Planning Phase**	**34 days**	**Fri 2/4/05**	**Wed 3/23/05**	
2	**Define the problem**	**4 days**	**Fri 2/4/05**	**Wed 2/9/05**	
3	Meet with users	2 days	Fri 2/4/05	Mon 2/7/05	
4	Determine scope	1 day	Tue 2/8/05	Tue 2/8/05	3
5	Write business benefits	1 day	Wed 2/9/05	Wed 2/9/05	4
6	Write statement of need	1 day	Wed 2/9/05	Wed 2/9/05	4
7	Define system capabilities	1 day	Wed 2/9/05	Wed 2/9/05	4
8	Develop context diagram	1 day	Wed 2/9/05	Wed 2/9/05	4
9	**Produce project schedule**	**5 days**	**Thu 2/10/05**	**Wed 2/16/05**	
10	Develop work breakdown structure	2 days	Thu 2/10/05	Fri 2/11/05	8,5,6,7
11	Estimate resources, durations	1 day	Mon 2/14/05	Mon 2/14/05	10
12	Develop PERT chart	2 days	Tue 2/15/05	Wed 2/16/05	11
13	**Confirm project feasibility**	**5 days**	**Thu 2/17/05**	**Wed 2/23/05**	
14	Identify intangible costs/ benefits	1 day	Thu 2/17/05	Thu 2/17/05	12
15	Estimate tangible costs	1 day	Thu 2/17/05	Thu 2/17/05	12
16	Do cost/benefit analysis	2 days	Fri 2/18/05	Mon 2/21/05	14,15
17	Evaluate organization feasibility	1 day	Tue 2/22/05	Tue 2/22/05	16
18	Evaluate technical feasibility	2 days	Tue 2/22/05	Wed 2/23/05	16
19	Evaluate schedule feasibility	1 day	Tue 2/22/05	Tue 2/22/05	16
20	Evaluate resource availability	1 day	Tue 2/22/05	Tue 2/22/05	16
21	**Staff the project**	**20 days**	**Thu 2/24/05**	**Wed 3/23/05**	
22	Develop a project resource plan	1 day	Thu 2/24/05	Thu 2/24/05	20,17,18,19
23	Identify and request tech staff	1 day	Fri 2/25/05	Fri 2/25/05	22
24	Meet with users, identify staff	1 day	Fri 2/25/05	Fri 2/25/05	22
25	Organize project team	1 day	Mon 2/28/05	Mon 2/28/05	23,24
26	Conduct team building exercises	3 days	Mon 3/21/05	Wed 3/23/05	25,31
27	**Launch the project**	**18 days**	**Wed 2/23/05**	**Fri 3/18/05**	
28	Prepare presentation materials	1 day	Wed 2/23/05	Wed 2/23/05	20
29	Make executive presentation	1 day	Thu 2/24/05	Thu 2/24/05	28
30	Set up project facilities	3 days	Fri 2/25/05	Tue 3/1/05	29
31	Conduct official kick-off meeting	1 day	Fri 3/18/05	Fri 3/18/05	30,25

column shows the durations. They are in fact true calendar durations. When you use MS Project, you must consider task duration and staffing conflicts to enter the correct durations. Summary activities are not assigned durations; MS Project calculates them by summing the detailed subtasks.

The fourth and fifth columns show the start and finish dates for each task. The default views for MS Project are the start time, which is the same as the early start time, and finish time. This is the default for both the Gantt view and the PERT view. You can modify the views to show early start and late start, if desired. In the Gantt view, to see other columns you simply put the mouse arrow on the column headings, right-click the mouse, and choose any other headings you want to insert.

The sixth column in the figure illustrates how Project handles the predecessor tasks. You must use the task IDs assigned by MS Project. Normally, you will want to leave the summary tasks out of the dependency list.

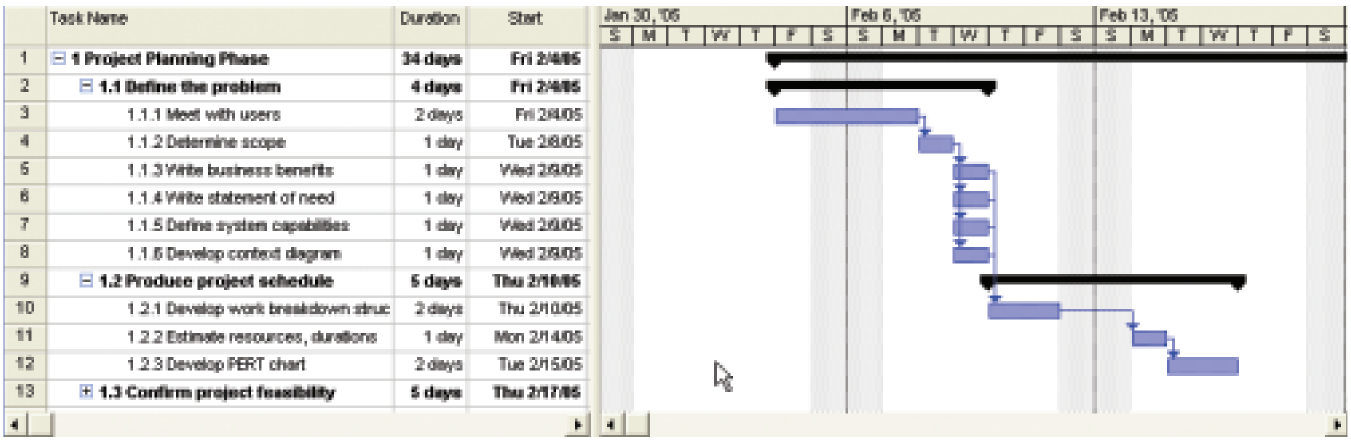
The easiest way to enter data into MS Project is to enter all of the tasks without worrying about the hierarchy, durations, or predecessors. Once all the tasks are entered, you can build the hierarchy by indenting the tasks that are subordinate to others. You can also select a group of tasks and then indent them to make them subordinate. After the hierarchy is built, you can then enter durations for the detailed tasks. The durations for the summary tasks will be calculated automatically. Start and finish dates are also calculated automatically. Finally, you assign predecessors based on your WBS analysis.

Once the data are entered, you can view the results in the Gantt chart view, as shown in Figure B-5. This view contains the calendar along the top and the tasks as horizontal bars. Summary tasks are black with the V-shaped end points. Milestones are tasks with zero duration and are depicted as diamonds. The dependencies are shown by the connecting arrows. Dependencies can be defined as finish-to-start, start-to-start, and so forth and show lead or lag time. For example, a two-day lead between finish-to-start for tasks A and B indicates that task B starts two days before task A finishes, while a two-day lag indicates that B starts two days after A finishes.

MS Project has a zoom feature so that you can compress the schedule so that instead of showing days it shows weeks and months. With this feature, the project manager can

FIGURE *B-5*

A partial Gantt chart from MS Project for RMO.



make general comparisons for the various tasks. A filter feature also allows the project manager to view selected tasks, such as all milestones or only summary tasks. Again, these features help the project manager understand various aspects of the project. Figure B-5 shows only the first two major activities. The horizontal scale is expanded so that individual days, including weekends, are shown. On later diagrams, the scale is reduced to view more of the schedule.

A partial PERT/CPM chart is shown in Figure B-6. As mentioned, this chart is good for viewing the critical path. However, MS Project generally does not lay out the activities and tasks in an easy-to-read fashion. You must usually rearrange the tasks so that they follow a straightforward left-to-right flow. Simple drag-and-drop editing allows the tasks to be rearranged. Note in the figure that the critical path tasks are highlighted in red. The summary tasks are included in the figure but not in the flow. The reason they are excluded from the flow is that they were not assigned predecessor tasks. Only the tasks for the first three activities are shown.

You will notice that the format for the boxes in MS Project is different from the manual examples developed earlier. The default view of MS Project is to show the start and

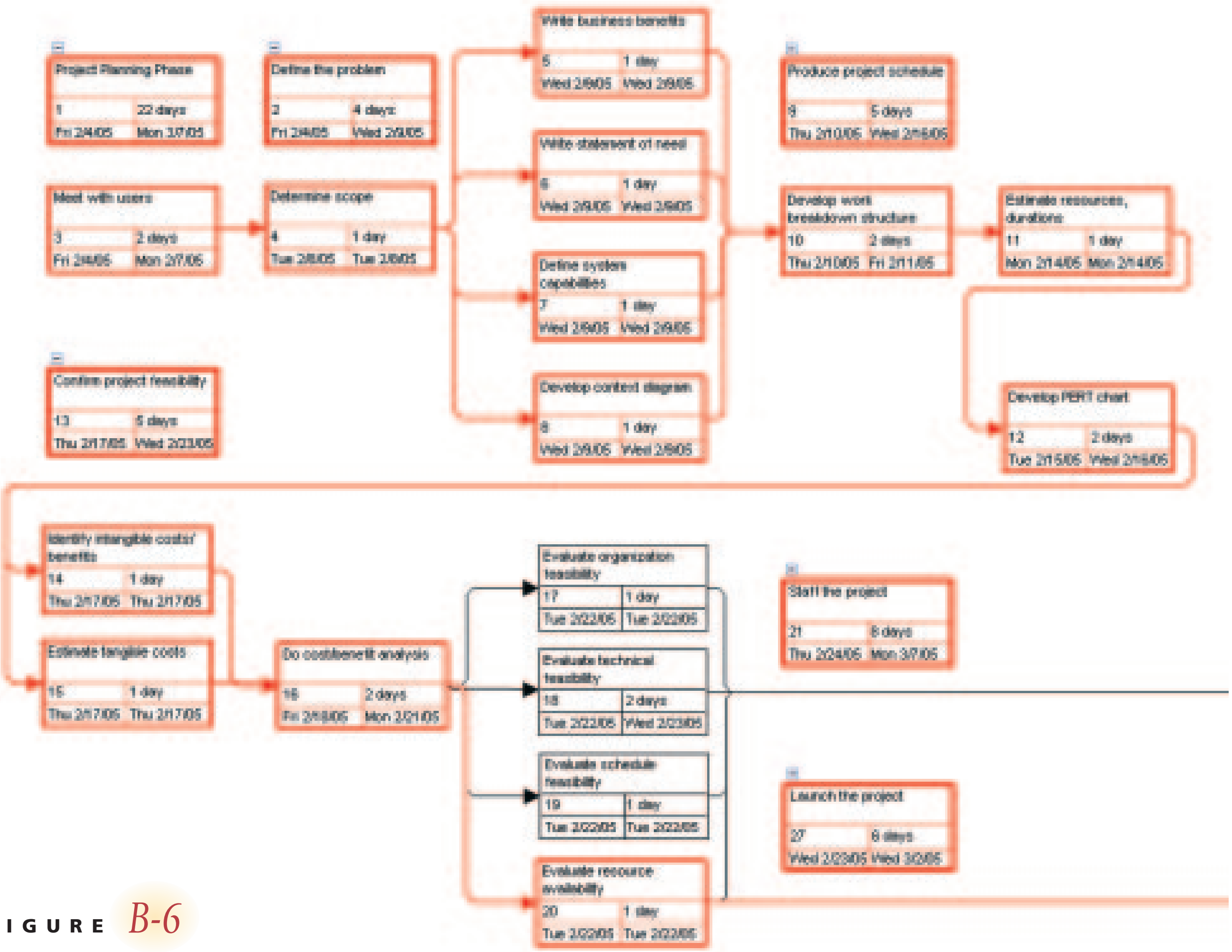


FIGURE *B-6*

A partial PERT/CPM chart from MS Project for RMO.

finish dates for each task. However, Project does allow various display options so that you can observe early and late start dates. You can also generate a report that shows all tasks with slack times and the amount of the slack time.

Although not shown here, human resources can be identified and allocated to tasks. They can be identified as individuals or simply as a type of employee, such as a programmer analyst. These resources can also be assigned a cost factor. Resources such as employees can be assigned cost factors by hour. Other resources, such as computers, can be allocated a cost per use or per item. Individual work schedules, such as full time, part time, normal workday or week, can also be built. Project managers can generate various reports to show resource allocation—to check to see whether you have double-scheduled a resource or whether that person is underutilized. Since costs are assigned to resources, the estimated costs of the project based on the schedule are calculated automatically when you assign resources. This information can be viewed by adding a cost column to the Gantt chart view.

One of the more advanced features of MS Project is the ability to do resource leveling. As a project manager builds the schedule of work, sometimes resources are overallocated. In other words, they are scheduled to work more than a normal eight-hour day. The automatic resource leveling feature in Project will move the tasks to later points in the project to make sure that no resources are overallocated. It does so while maintaining the task dependencies.

Once all of this information is entered, it can be saved as a baseline schedule for later comparison. As the project progresses, actual completion dates and resource utilization can be entered. Figure B-7 shows a partial tracking Gantt chart view of the RMO schedule. Notice that each task has two bars. The project was first saved with a baseline. The baseline is the estimate that was developed and shown in Figure B-5. The gray bar, which is on the bottom half of the pair of bars, represents the baseline, and it is frozen. The top bar is the actual time that was required to complete the task. This figure shows increased time to complete task eight, *Develop context diagram,* from one day to two days. Note how the rest of the schedule is shifted to accommodate the increased time for a task that is a predecessor task to other tasks. In other words, all critical path days are now projected to be one day late.

The heavy vertical line represents the current day's date. Tasks to the left of the bar should be completed to be on schedule; tasks to the right should still be open. Tasks to the left that are not completed are behind schedule; completed tasks to the right are ahead of schedule. Uncompleted tasks that are on the critical path are shown in red. Figure 3-11 illustrates a complete tracking Gantt chart of the project planning phase with a few of the early tasks completed (and without the delay for task eight).

Even though MS Project cannot figure out automatically how the project should progress as described in the task durations and dependencies, it should be apparent how useful it is for putting the schedule together and for tracking. MS Project can help in other ways to manage a project. For example, it can track resources assigned to tasks and indicate when they are overallocated. Estimated and actual project expenditures can also be recorded. The numerous reports and views that can be generated provide additional tools to help a project manager analyze and understand the progress of the project.

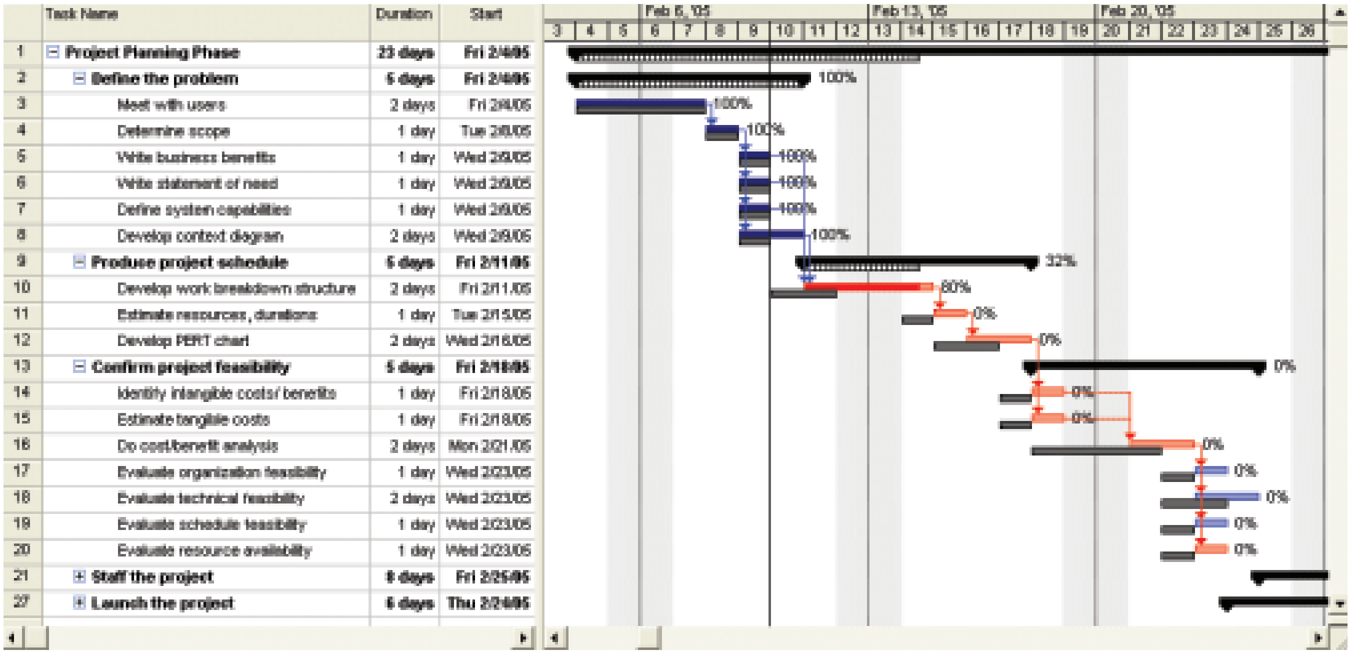


FIGURE B-7 A partial view of a tracking Gantt chart from MS Project for RMO.

KEY TERMS

early start time, p. 769

late start time, p. 769

slack time, p. 769

REVIEW QUESTIONS

1. Why is it important to develop a detailed list of tasks when preparing to build a project schedule?
2. Explain in your own words the process of calculating the late start times on a PERT/CPM chart.
3. Discuss the difference between a PERT/CPM chart and a Gantt chart. List comparative advantages and disadvantages of each.
4. Can a project have two paths that are critical paths? Explain why or why not. Give an example, if possible.

THINKING CRITICALLY

1. You have a younger friend who is getting ready for college. Make a list of all the activities you think she needs to do to start college. How did you decide how detailed to make your list?
2. Expand the list into individual tasks. Build a work breakdown structure showing activities and tasks.
3. Draw a PERT/CPM chart of the tasks listed in problem 2.
4. Draw a Gantt chart for the tasks listed in problem 2.
5. Draw a PERT/CPM chart for getting ready for class in the morning. Identify the critical path and the total time it takes.
6. Think back on one of your classes where you had a research project with other students—a term paper, a programming project, or some other major activity. Develop a work breakdown structure and a PERT/CPM chart for the project. Since this is a team project, you should be able to have multiple concurrent paths. Show the critical path.
7. Illustrate the tasks for problem 6 on a Gantt chart.