can be adopted to produce a project deliverable (e.g., different conferencing methods to use for brainstorming a new product design, or different methods for conducting an R&D experiment). Not only would the costs be different, the risks associated with the costs and outcomes would also be different. While such cases are too complex to reproduce here, they are not uncommon, and are solvable by examining the expected values of the different budgets and outcomes.

**Simulation** Imagine that a consulting company is asked to prepare a budget for a project to develop a relationship management software program to be used by customer service representatives working in a bank’s branch locations. Having completed a number of projects of similar scope, the consulting firm accumulated a fair amount of historical data about the time required to complete each of the five major steps typical of these projects. Analysis of this data indicates that the first phase, requirements planning, requires 80 hours of software engineering time on average with a standard deviation of 15 hours. A summary of this data for all five major phases is provided in Table 4-8. Further analysis of the data indicates that the distribution of times to complete each phase is approximately normal.* Software engineers are paid an average of $60 per hour including benefits in this particular firm.

The spreadsheet shown in Table 4-9 explains the implications of the uncertainty surrounding the budget for this project. In this spreadsheet, cells B5:B9 were defined as

<table>
<thead>
<tr>
<th>Phase</th>
<th>Average Time (hours)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements Planning</td>
<td>80</td>
<td>15</td>
</tr>
<tr>
<td>Design</td>
<td>160</td>
<td>25</td>
</tr>
<tr>
<td>Prototype Development</td>
<td>320</td>
<td>70</td>
</tr>
<tr>
<td>Final Development</td>
<td>640</td>
<td>100</td>
</tr>
<tr>
<td>Test</td>
<td>120</td>
<td>20</td>
</tr>
</tbody>
</table>

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*We do not demonstrate it here, but CB can fit distributions to historical data. This is done by selecting the Fit button in CB's Distribution Gallery window. Then specify the location of the data. CB considers a wide variety of probability distributions and offers the user options regarding goodness-of-fit tests. Additional details are in the Crystal Ball® 2000 User Manual.*
assumption cells with their corresponding assumptions documented in the adjacent cells in column C. The outcome of this budget model is the Total Cost of the project, which is calculated in cell B2. Hence, cell B2 is defined as a forecast cell.

Because this is our first time dealing with the normal distribution, we illustrate the process of defining an assumption cell based on this distribution for the Requirements Planning phase (cell B5). After clicking on cell B5, selecting the Cell menu option, and selecting the Define Assumption option, the Distribution Gallery is displayed as we saw in Chapter 1. In this case we want to define an assumption cell based on the normal distribution. After selecting Normal from the Distribution Gallery, the Normal Distribution dialog box is displayed. Crystal Ball® will automatically fill in the Assumption Name textbox with “Requirements Planning” based on the label entered in cell A5. Therefore, the only information that needs to be entered are the two parameters for the normal distribution, the mean and standard deviation.

Referring to Table 4-8, we see that the Requirements Planning phase is expected to have a mean of 80 hours and standard deviation of 15. These values were entered in the Mean and Std Dev textboxes, respectively, as shown in Figure 4-6. Note that after clicking the Enter button the shape of the distribution changes based on the parameters entered. You can use this feature to visually inspect the distribution and to verify that it provides a reasonable approximation of the variable being modeled.

Referring to Figure 4-6, we see that according to the parameters entered, the Requirements Planning phase could take anywhere from 35 to 125 hours, but will most likely require approximately 80 hours. Because the distribution is symmetrical, we also assume that it is just as likely for this phase to require more than 80 hours as it is for it to require less than 80 hours. If based on past experience, one or more of these conditions do not seem reasonable, then one or both of the distribution parameters can be altered to try to obtain a better approximation. If preferred, a new distribution can be used to model the variable. Also, values can be entered in the textboxes to truncate the upper and lower values returned. For example, if past experience suggests that the Require-

![Figure 4-6 Normal Distribution dialog box.](image-url)
ements Planning phase never takes less than 55 hours, 55 could be entered for the lower bound as shown in Figure 4-7.

A summary of the results after replicating the model 1000 times is shown in Figures 4-8 and 4-9. Analysis of the simulation results indicates that the average or expected cost of completing this project across the 1000 trials is $79,037. This is very close to the expected value obtained by simply adding up the average times for each phase and multiplying by the $60 per hour rate, that is, \((80 + 160 + 320 + 640 + 120) 60 = 79,200\),
which serves to validate our results. Further analysis of the results suggests that on one trial the cost of the project reached $104,282 while on another trial the costs were only $49,536 (see Figure 4-9). It is exactly the distribution of likely project costs that determines the risk associated with the project. We would consider a project to have relatively little risk if across all trials of the simulation model the project costs varied little from the average or expected value. As the results from the simulation analysis become more spread out, however, the amount of uncertainty, and therefore risk, increases.

One way to quantify the amount of risk associated with a given project is to calculate the standard deviation. For example, across the 1000 trials of the simulation model, the standard deviation of the project cost was $7,342. You may recall from your statistics course that 95 percent of the observations fall within plus or minus two standard deviations of the mean for normally distributed data. Based on this, and assuming that the project completion costs follow a normal distribution, we can conclude that there is a 95 percent chance that the interval of $64,353 and $93,721 ($79,037 ± 2 × 7,342) contains the true project cost. Observe that the width of this interval increases as the standard deviation increases, again indicating greater uncertainty and more risk.

Another way to help quantify the risk associated with project cost is to use the chart of simulation results as shown in Figure 4-8. We can use this frequency chart to calculate the probability for any number of scenarios. For example, in Figure 4-10 the probability that total project costs exceed $85,000 was calculated to be 20.8 percent.

In particular, two characteristics of the frequency chart should be examined. First, the amount of variation or range of the observations should be noted. Higher levels of variation correspond to higher levels of risk. The second characteristic that should be observed is the shape of the frequency chart. A symmetrical distribution such as the normal distribution indicates that the project is just as likely to be completed under budget as it is to be completed over budget. A right-skewed distribution suggests that there is a chance that the project will require a much larger than expected budget to complete while a left-skewed distribution suggests that there is a chance that the project will require a much smaller budget than expected. The frequency chart shown in Figure 4-8 appears to be roughly symmetrical.

**Risk Response Planning**  Risk response typically involves decisions about which risks to prepare for and which to ignore and simply accept as potential threats. The main prepa-
ration for a risk is the development of a risk response plan. Such a plan includes contingency plans and logic charts detailing exactly what to do depending on particular events (Mallak, Kurstedt, and Patzak, 1997). For example, Iceland is frequently subjected to unexpected avalanches and has thus prepared a detailed response plan for such events, stating who is in charge, the tasks that various agencies are to do at particular times, and so on.

Beyond this, however, it is helpful to conduct actual tests of the risk response plan by conducting simulations such as tabletop exercises (Mallak, Kurstedt, and Patzak, 1997) or partial dress rehearsals. Tabletop exercises simulate the decision making and actions to be taken in response to specific risks. These are primarily soft simulations where the actions are just stated instead of being executed. More realism can be injected, at some cost, by partially (or fully) taking the actions, such as with fire drills. Practice in taking these actions can be helpful in the event the risk actually comes to pass. More detailed simulations might include full dress rehearsals where even more fully realistic actions are taken.

**Risk Monitoring and Control** Like risk management planning, monitoring and control are tasks for the parent organization, as well as for the project. If the overall risk management group is not involved along with the project in performing the tasks of recording and maintaining records of what risks were identified, how they were analyzed and responded to, and what resulted from the responses, the records have a high probability of being lost forever when the project is completed (or abandoned). If records are lost or not easily available, the chance that other projects will “learn from the experiences of others” is very low.

It is the job of the risk management group to maintain records for how all projects deal with risks. The group, however, is not merely a passive record holder. It should be involved in the search for new risks, for developing new and better techniques of measuring and handling risk, and estimating the impact of risks on projects. Thus, the group should become an advisor to project risk management teams. It should provide an ongoing evaluation of current risk identification, measurement, analysis, and response techniques. Fundamentally, the group is devoted to the improvement of the organization’s risk management activities.
In spite of the effort taken to make realistic budget estimates, it can still be useful to prepare for changes in the budget as the project unfolds. Such changes derive from multiple sources, including technology, economics, improved project understanding, and mandates. To the extent possible, it is best to try to include these contingencies in the contract in case they come to pass. Risk management consists of risk planning identification, qualitative and quantitative analysis, response, and monitoring. We deal with risk through means such as decision tables, simulation, and response, which entail identifying which risks will be prepared for and which will be ignored and simply accepted.

We are now ready to consider the scheduling problem. Because durations, like costs, are uncertain, we will continue our discussion of the matter, adding some powerful but reasonably simple techniques for dealing with the uncertainty surrounding both project schedule and cost.

**REVIEW QUESTIONS**

1. Contrast the disadvantages of top-down budgeting and bottom-up budgeting.
2. What is the logic in charging administrative costs based on total time to project completion?
3. Would you expect a task in a manufacturing plant that uses lots of complex equipment to have a learning curve rate closer to 70 percent or 95 percent?
4. How does a tracking signal improve budget estimates?
5. Are there other kinds of changes in a project in addition to the three basic types described in Section 4.4? Might a change be the result of two types at the same time?
6. Distinguish among highly probable risks, extremely serious risks, and highly vulnerable areas in risk identification.

**DISCUSSION QUESTIONS**

7. Given the tendency of accountants to allocate a project's estimated costs evenly over the duration of the task, what danger might this pose for a project manager who faces the following situation? The major task for a $5 million project is budgeted at $3 million, mostly for highly complex and expensive equipment. The task has a six-month duration, and requires the purchase of the equipment at the beginning of the task to enable the project team to conduct the activities required to complete the task. The task begins December 1.

8. The chapter describes the problems of budgeting projects with S-shaped and exponential-shaped life-cycle curves. What might be the budget problems if the life cycle of a project was just a straight diagonal line from 0 at project start to 100 percent at project completion?

9. If a firm uses program budgeting for its projects, is an activity budget not needed? If it is, then of what value is the program budget?

10. As a senior manager, you oversee a project with a total estimated cost of 245 engineer-months of effort. Three months ago, however, the project had fallen behind by about 25 engineer-months so you authorized the hiring of three additional engineers, which you felt should more than make up for the delay in the remaining year of the project (3 x 12 months = 36 engineer-months). You have just received the latest quarterly project status report and are surprised to learn that the project is now 40 engineer-months behind schedule! Your first reaction is to calculate how many more engineers need to be hired to make up for the increased delay. Using Brooks's concept of the "mythical man month," explain what might be happening here.

11. So what was wrong with the purchasing manager’s assistant’s solution (outlined in Section 4.3) to the problem of having an inadequate supply of hard-to-obtain parts?