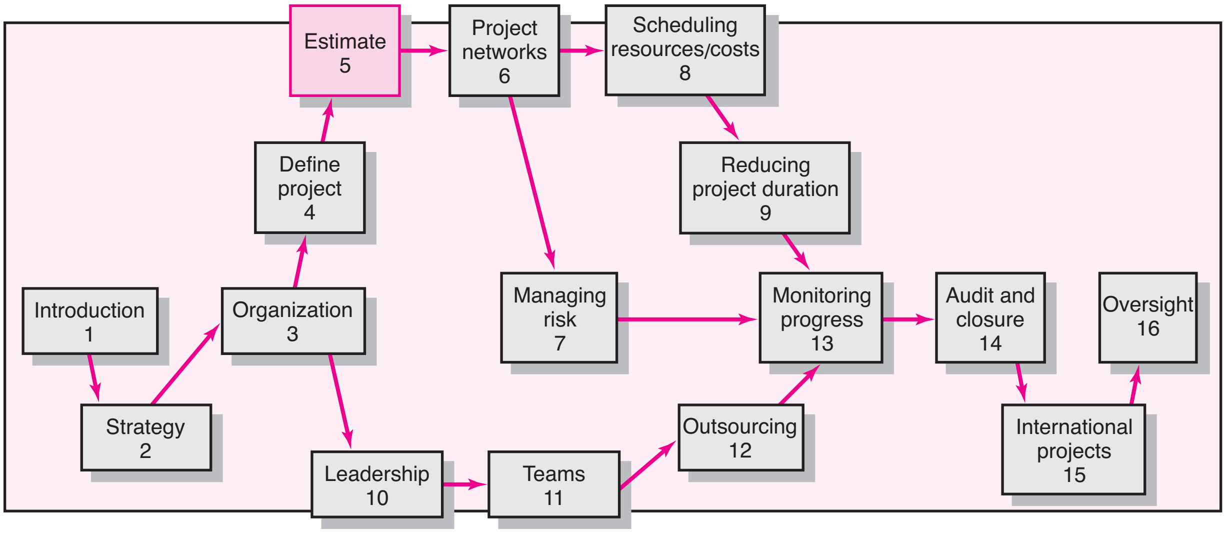

Estimating Project Times and Costs

CHAPTER FIVE

Estimating Project Times and Costs

*Project estimation is indeed a yardstick for project cost control. And if the yardstick is faulty, you start on the "wrong foot." . . . we exhort you not to underestimate the estimate.**

Given the urgency to start work on the project, managers sometimes minimize or avoid the effort to follow through on estimating project time and cost. This attitude is a huge mistake and costly. There are important reasons to make the effort and incur the cost of estimating for your project. Exhibit 5.1 summarizes some key reasons.

Estimating is the process of forecasting or approximating the time and cost of completing project deliverables. Estimating processes are frequently classified as top-down and bottom-up. Top-down estimates are usually done by senior management. Management will often derive estimates from analogy, group consensus, or mathematical relationships. Bottom-up estimates are typically performed by the people who are doing the work. Their estimates are based on estimates of elements found in the work breakdown structure.

All project stakeholders prefer accurate cost and time estimates, but they also understand the inherent uncertainty in all projects. Inaccurate estimates lead to false expectations and consumer dissatisfaction. Accuracy is improved with greater effort, but is it worth the time and cost—estimating costs money! Project estimating becomes a trade-off, balancing the benefits of better accuracy against the costs for securing increased accuracy.

Cost, time, and budget estimates are the lifeline for control; they serve as the standard for comparison of actual and plan throughout the life of the project. Project status reports depend on reliable estimates as the major input for measuring variances and taking corrective action. Ideally, the project manager, and in most cases the customer, would prefer to have a database of detailed schedule and cost estimates for every work package in the project. Regrettably, such detailed data gathering is not always possible or practical and other methods are used to develop project estimates.

Factors Influencing the Quality of Estimates

A typical statement in the field is the desire to "have a 95 percent probability of meeting time and cost estimates." *Past experience* is a good starting point for developing time and cost estimates. But past experience estimates must almost always be refined by other considerations to reach the 95 percent probability level. Factors related to the

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* O. P. Kharbanda and J. K. Pinto, *What Made Gertie Gallop: Learning from Project Failures* (New York: Von Nostrand Reinhold, 1996), p. 73.

EXHIBIT 5.1

Why Estimating Time and Cost Are Important

- Estimates are needed to support good decisions.
- Estimates are needed to schedule work.
- Estimates are needed to determine how long the project should take and its cost.
- Estimates are needed to determine whether the project is worth doing.
- Estimates are needed to develop cash flow needs.
- Estimates are needed to determine how well the project is progressing.
- Estimates are needed to develop time-phased budgets and establish the project baseline.

uniqueness of the project will have a strong influence on the accuracy of estimates. Project, people, and external factors all need to be considered to improve quality of estimates for project times and costs.

Planning Horizon

The quality of the estimate depends on the *planning horizon;* estimates of current events are close to 100 percent accurate but are reduced for more distant events. The accuracy of time and cost estimates should improve as you move from the conceptual phase to the point where individual work packages are defined.

Project Duration

Time to implement new *technology* has a habit of expanding in an increasing, nonlinear fashion. Sometimes poorly written scope specifications for new technology result in errors in estimating times and costs. Long-duration projects increase the uncertainty in estimates.

People

The *people* factor can also introduce errors in estimating times and cost. For example, accuracy of estimates depends on the skills of the people making the estimates. A close match of people skills to the task will influence productivity and learning time. Similarly, whether members of the project team have worked together before on similar projects will influence the time it takes to coalesce into an effective team. Sometimes factors such as staff turnover can influence estimates. It should be noted that adding new people to a project increases time spent communicating. Typically, people have only five to six productive hours available for each working day; the other hours are taken up with indirect work, such as meetings, paperwork, answering e-mail.

Project Structure and Organization

Which *project structure* is chosen to manage the project will influence time and cost estimates. One of the major advantages of a dedicated project team discussed earlier is the speed gained from concentrated focus and localized project decisions. This speed comes at an additional cost of tying up personnel full time. Conversely, projects operating in a matrix environment may reduce costs by more efficiently sharing personnel across projects but may take longer to complete since attention is divided and coordination demands are higher.

Padding Estimates

In some cases people are inclined to *pad estimates.* For example, if you are asked how long it takes you to drive to the airport, you might give an average time of 30 minutes, assuming a 50/50 chance of getting there in 30 minutes. If you are asked the fastest you could possibly get there, you might reduce the driving time to 20 minutes. Finally, if you are asked how long the drive would take if you absolutely had to be there to meet with the president, it is likely you would increase the estimate to say 50 minutes to ensure not being late.

In work situations where you are asked for time and cost estimates, most of us are inclined to add a little padding to increase the probability and reduce the risk of being late. If everyone at all levels of the project adds a little padding to reduce risk, the project duration and cost are seriously overstated. This phenomenon causes some managers or owners to call for a 10–15 percent cut in time and/or cost for the project. Of course the next time the game is played, the person estimating cost and/or time will pad the estimate to 20 percent or more. Clearly such games defeat chances for realistic estimates, which is what is needed to be competitive.

Organization Culture

Organization culture can significantly influence project estimates. In some organizations padding estimates is tolerated and even privately encouraged. Other organizations place a premium on accuracy and strongly discourage estimating gamesmanship. Organizations vary in the importance they attach to estimates. The prevailing belief in some organizations is that detailed estimating takes too much time and is not worth the effort or that it's impossible to predict the future. Other organizations subscribe to the belief that accurate estimates are the bedrock of effective project management. Organization culture shapes every dimension of project management; estimating is not immune to this influence.

Other Factors

Finally, *nonproject factors* can impact time and cost estimates. For example, equipment downtime can alter time estimates. National holidays, vacations, and legal limits can influence project estimates. Project priority can influence resource assignment and impact time and cost.

Project estimating is a complex process. The quality of time and cost estimates can be improved when these variables are considered in making the estimates. Estimates of time and cost together allow the manager to develop a time-phased budget, which is imperative for project control. Before discussing macro and micro estimating methods for times and costs, a review of estimating guidelines will remind us of some of the important "rules of the game" that can improve estimating.

Estimating Guidelines for Times, Costs, and Resources

Managers recognize time, cost, and resource estimates must be accurate if project planning, scheduling, and controlling are to be effective. However, there is substantial evidence suggesting poor estimates are a major contributor to projects that have failed. Therefore, every effort should be made to see that initial estimates are as accurate as possible since the choice of no estimates leaves a great deal to luck and is not palatable to serious project managers. Even though a project has never been done before, a manager can follow seven guidelines to develop useful work package estimates.

1. **Responsibility.** At the work package level, estimates should be made by the person(s) most familiar with the task. Draw on their expertise! Except for supertechnical tasks, those responsible for getting the job done on schedule and within budget are usually first-line supervisors or technicians who are experienced and familiar with the type of work involved. These people will not have some preconceived, imposed duration for a deliverable in mind. They will give an estimate based on experience and best judgment. A secondary benefit of using those responsible is the hope they will "buy in" to seeing that the estimate materializes when they implement the work package. If those involved are not consulted, it will be difficult to hold them responsible for failure to achieve the estimated time. Finally, drawing on the expertise of team members who will be responsible helps to build communication channels early.

2. **Use several people to estimate.** It is well known that a cost or time estimate usually has a better chance of being reasonable and realistic when several people with relevant experience and/or knowledge of the task are used. True, people bring different biases based on their experience. But discussion of the individual differences in their estimate leads to consensus and tends to eliminate extreme estimate errors. This approach is similar to the Delphi estimating method, which can also be used.

3. **Normal conditions.** When task time, cost, and resource estimates are determined, they are based on certain assumptions. *Estimates should be based on normal conditions, efficient methods, and a normal level of resources*. Normal conditions are sometimes difficult to discern, but it is necessary to have a consensus in the organization as to what normal conditions mean in this project. If the normal workday is eight hours, the time estimate should be based on an eight-hour day. Similarly, if the normal workday is two shifts, the time estimate should be based on a two-shift workday. Any time estimate should reflect efficient methods for the resources normally available. The time estimate should represent the normal level of resources—people or equipment. For example, if three programmers are available for coding or two road graders are available for road construction, time and cost estimates should be based on these normal levels of resources unless it is anticipated the project will change what is currently viewed as "normal." In addition, possible conflicts in demand for resources on parallel or concurrent activities should not be considered at this stage. The need for adding resources will be examined when resource scheduling is discussed in a later chapter.

4. **Time units.** Specific time units to use should be selected early in the development phase of the project network. *All task time estimates need consistent time units.* Estimates of time must consider whether normal time is represented by calendar days, workdays, workweeks, person days, single shift, hours, minutes, etc. In practice the use of workdays is the dominant choice for expressing task duration. However, in projects such as a heart transplant operation, minutes probably would be more appropriate as a time unit. One such project that used minutes as the time unit was the movement of patients from an old hospital to an elegant new one across town. Since there were several life-endangering moves, minutes were used to ensure patient safety so proper emergency life-support systems would be available if needed. The point is, network analysis requires a standard unit of time. When computer programs allow more than one option, some notation should be made of any variance from the standard unit of time. If the standard unit of time is a five-day workweek and the estimated activity duration is in calendar days, it must be converted to the normal workweek.

5. **Independence.** Estimators should treat each task as independent of other tasks that might be integrated by the WBS. Use of first-line managers usually results in considering tasks independently; this is good. Top managers are prone to aggregate many tasks into one time estimate and then deductively make the individual task time estimates add to the total. If tasks are in a chain and performed by the same group or department, it is best not to ask for all the time estimates in the sequence at once to avoid the tendency for a planner or a supervisor to look at the whole path and try to adjust individual task times in the sequence to meet an arbitrary imposed schedule or some rough "guesstimate" of the total time for the whole path or segment of the project. This tendency does not reflect the uncertainties of individual activities and generally results in optimistic task time estimates. In summary, each task time estimate should be considered independently of other activities.

6. **Contingencies.** *Work package estimates should not include allowances for contingencies.* The estimate should assume normal or average conditions even though every work

package will not materialize as planned. For this reason top management needs to create an extra fund for contingencies that can be used to cover unforeseen events.

7. **Adding risk assessment to the estimate helps to avoid surprises to stakeholders.** It is obvious some tasks carry more time and cost risks than others. For example, a new technology usually carries more time and cost risks than a proven process. Simply identifying the degree of risk lets stakeholders consider alternative methods and alter process decisions. A simple breakdown by optimistic, most likely, and pessimistic for task time could provide valuable information regarding time and cost. See Chapter 7 for further discussion of project risk.

Where applicable, these guidelines will greatly help to avoid many of the pitfalls found so often in practice.

Top-Down versus Bottom-Up Estimating

Since estimating efforts cost money, the time and detail devoted to estimating is an important decision. Yet, when estimating is considered, you as a project manager may hear statements such as these:

> *Rough order of magnitude is good enough. Spending time on detailed estimating wastes money.*
>
> *Time is everything; our survival depends on getting there first! Time and cost accuracy is not an issue.*
>
> *The project is internal. We don't need to worry about cost.*
>
> *The project is so small, we don't need to bother with estimates. Just do it.*
>
> *We were burned once. I want a detailed estimate of every task by the people responsible.*

However, there are sound reasons for using top-down or bottom-up estimates. Table 5.1 depicts conditions that suggest when one approach is preferred over another.

Top-down estimates usually are derived from someone who uses experience and/or information to determine the project duration and total cost. These estimates are sometimes made by top managers who have very little knowledge of the processes used to complete the project. For example, a mayor of a major city making a speech noted that a new law building would be constructed at a cost of $23 million and would be ready for occupancy in two and one-half years. Although the mayor probably asked for an estimate from someone, the estimate could have come from a luncheon meeting with a local contractor who wrote an estimate (guesstimate) on a napkin. This is an extreme example, but in a relative sense this scenario is frequently played out in practice. See Snapshot from Practice: Council Fumes, for another example of this. But the question is, *do these estimates represent low-cost, efficient methods?* Do the top-down estimates of project time and cost become a self-fulfilling prophecy in terms of setting time and cost parameters?

TABLE 5.1
Conditions for Preferring Top-Down or Bottom-Up Time and Cost Estimates

Condition	Top-Down Estimates	Bottom-Up Estimates
Strategic decision making	X	
Cost and time important		X
High uncertainty	X	
Internal, small project	X	
Fixed-price contract		X
Customer wants details		X
Unstable scope	X	

Snapshot from Practice

Council Fumes as Tram Tale Unfolds*

Portland, Oregon's, Willamette riverfront development has exploded with seven condominium towers and a new health sciences center under construction. The health science complex is to be linked with Oregon Health Sciences University (OHSU), which is high on a nearby hill, with an aerial cable tram.

The aerial tram linking the waterfront district to OHSU is to support the university expansion, to increase biotechnology research, and to become Portland's icon equivalent to Seattle's Space Needle. All of the hype turned south when news from a hearing suggested that the real budget for the tram construction, originally estimated at $15 million, is going to be about $55–$60 million, nearly triple the original estimate. The estimate could even go higher. Commissioners want to find out why city staff knowingly relied on flawed estimates. Mike Lindberg, president of the nonprofit Aerial Transportation Inc., acknowledged "the $15 million number was not a good number. It was simply a guesstimate." Commissioner Erik Sten said, "Those numbers were presented as much more firm than they appear to have been. . . . It appears the actual design wasn't costed out. That's pretty shoddy."

* *The Oregonian,* January 13, 2006, by Frank Ryan, pages A1 and A14, and April 2, 2006, page A1.

If possible and practical, you want to push the estimating process down to the work package level for bottom-up estimates that establish low-cost, efficient methods. This process can take place after the project has been defined in detail. Good sense suggests project estimates should come from the people most knowledgeable about the estimate needed. The use of several people with relevant experience with the task can improve the time and cost estimate. The bottom-up approach at the work package level can serve as a check on cost elements in the WBS by rolling up the work packages and associated cost accounts to major deliverables. Similarly, resource requirements can be checked. Later, the time, resource, and cost estimates from the work packages can be consolidated into time-phased networks, resource schedules, and budgets that are used for control.

The bottom-up approach also provides the customer with an opportunity to compare the low-cost, efficient method approach with any imposed restrictions. For example, if the project completion duration is imposed at two years and your bottom-up analysis tells you the project will take two and one-half years, the client can now consider the trade-off of the low-cost method versus compressing the project to two years—or in rare cases canceling the project. Similar trade-offs can be compared for different levels of resources or increases in technical performance. The assumption is any movement away from the low-cost, efficient method will increase costs—e.g., overtime. The preferred approach in defining the project is to make rough top-down estimates, develop the WBS/OBS, make bottom-up estimates, develop schedules and budgets, and reconcile differences between top-down and bottom-up estimates. Hopefully, these steps will be done *before* final negotiation with either an internal or external customer. In conclusion, the ideal approach is for the project manager to allow enough time for both the top-down and bottom-up estimates to be worked out so a complete plan based on reliable estimates can be offered to the customer. In this way false expectations are minimized for all stakeholders and negotiation is reduced.

Methods for Estimating Project Times and Costs

Top-Down Approaches for Estimating Project Times and Costs

At the strategic level top-down estimating methods are used to evaluate the project proposal. Sometimes much of the information needed to derive accurate time and cost estimates is not available in the initial phase of the project—for example, design is not finalized. In these situations top-down estimates are used until the tasks in the WBS are clearly defined.

Consensus Methods

This method simply uses the pooled experience of senior and/or middle managers to estimate the total project duration and cost. This typically involves a meeting where experts discuss, argue, and ultimately reach a decision as to their best guess estimate. Firms seeking greater rigor will use the Delphi method to make these macro estimates. See Snapshot from Practice: The Delphi Method.

It is important to recognize that these first top-down estimates are only a rough cut and typically occur in the "conceptual" stage of the project. The top-down estimates are helpful in initial development of a complete plan. However, such estimates are sometimes significantly off the mark because little detailed information is gathered. At this level individual work items are not identified. Or, in a few cases, the top-down estimates are not realistic because top management "wants the project." Nevertheless, the initial top-down estimates are helpful in determining whether the project warrants more formal planning, which would include more detailed estimates. Be careful that macro estimates made by senior managers are not dictated to lower level managers who might feel compelled to accept the estimates even if they believe resources are inadequate.

Although your authors prefer to avoid the top-down approach if possible, we have witnessed surprising accuracy in estimating project duration and cost in isolated cases. Some examples are building a manufacturing plant, building a distribution warehouse, developing air control for skyscraper buildings, and road construction. However, we have also witnessed some horrendous miscalculations, usually in areas where the technology is new and unproven. Top-down methods can be useful if experience and judgment have been accurate in the past.

Snapshot from Practice The Delphi Method

Originally developed by the RAND Corporation in 1969 for technological forecasting, the *Delphi Method* is a group decision process about the likelihood that certain events will occur. The Delphi Method makes use of a panel of experts familiar with the kind of project in question. The notion is that well-informed individuals, calling on their insights and experience, are better equipped to estimate project costs/times than theoretical approaches or statistical methods. Their responses to estimate questionnaires are anonymous, and they are provided with a summary of opinions.

Experts are then encouraged to reconsider, and if appropriate to change their previous estimate in light of the replies of other experts. After two or three rounds it is believed that the group will converge toward the "best" response through this consensus process. The midpoint of responses is statistically categorized by the median score. In each succeeding round of questionnaires, the range of responses by the panelists will presumably decrease and the median will move toward what is deemed to be the "correct" estimate.

One distinct advantage of the Delphi Method is that the experts never need to be brought together physically. The process also does not require complete agreement by all panelists, since the majority opinion is represented by the median. Since the responses are anonymous, the pitfalls of ego, domineering personalities and the "bandwagon or halo effect" in responses are all avoided. On the other hand, future developments are not always predicted correctly by iterative consensus nor by experts, but at times by creative, "off the wall" thinking.

Ratio Methods

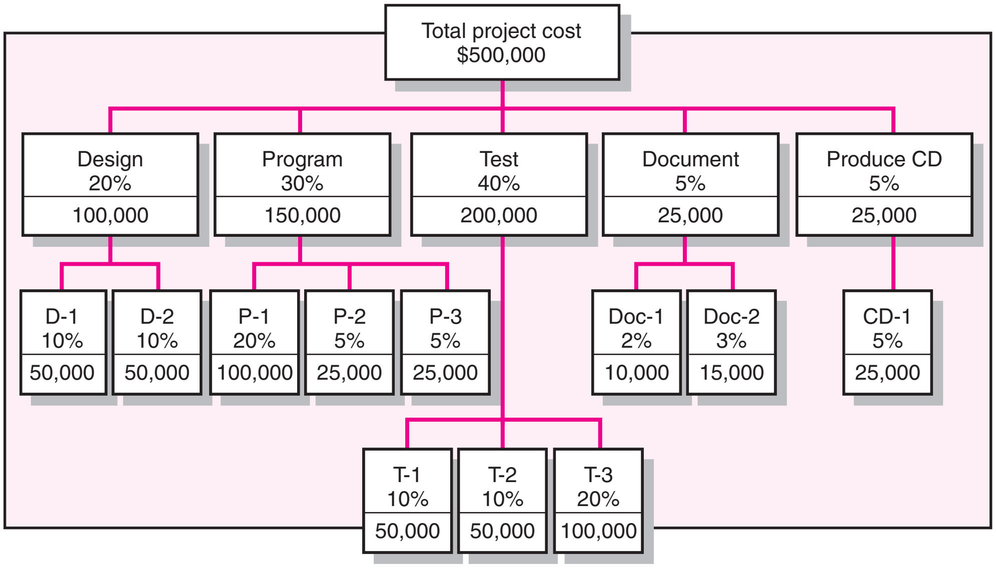
Top-down methods (sometimes called parametric) usually use ratios, or surrogates, to estimate project times or costs. Top-down approaches are often used in the concept or "need" phase of a project to get an initial duration and cost estimate for the project. For example, contractors frequently use number of square feet to estimate the cost and time to build a house; that is, a house of 2,700 square feet might cost $160 per square foot (2,700 feet × $160 per foot equals $432,000). Likewise, knowing the square feet and dollars per square foot, experience suggests it should take approximately 100 days to complete. Two other common examples of top-down cost estimates are the cost for a new plant estimated by capacity size, or a software product estimated by features and complexity.

Apportion Methods

This method is an extension to the ratio method. Apportionment is used when projects closely follow past projects in features and costs. Given good historical data, estimates can be made quickly with little effort and reasonable accuracy. This method is very common in projects that are relatively standard but have some small variation or customization.

Anyone who has borrowed money from a bank to build a house has been exposed to this process. Given an estimated total cost for the house, banks and the FHA (Federal Housing Authority) authorize pay to the contractor by completion of specific segments of the house. For example, foundation might represent 3 percent of the total loan, framing 25 percent, electric, plumbing and heating 15 percent, etc. Payments are made as these items are completed. An analogous process is used by some companies that apportion costs to deliverables in the WBS—given average cost percentages from past projects. Figure 5.1 presents an example similar to one found in practice. Assuming the total project cost is estimated, using a top-down estimate, to be $500,000, the costs are apportioned as a percentage of the total cost. For example, the costs apportioned to the "Document" deliverable are 5 percent of the total, or $25,000. The subdeliverables "Doc-1 and Doc-2" are allocated 2 and 3 percent of the total—$10,000 and $15,000, respectively.

FIGURE 5.1 Apportion Method of Allocating Project Costs Using the Work Breakdown Structure



Function Point Methods for Software and System Projects

In the software industry, software development projects are frequently estimated using weighted macro variables called "function points" or major parameters such as number of inputs, number of outputs, number of inquiries, number of data files, and number of interfaces. These weighted variables are adjusted for a complexity factor and added. The total adjusted count provides the basis for estimating the labor effort and cost for a project (usually using a regression formula derived from data of past projects). This latter method assumes adequate historical data by type of software project for the industry—for example, MIS systems. In the U.S. software industry, one-person month represents on average five function points. A person working one month can generate on average (across all types of software projects) about five function points. Of course each organization needs to develop its own average for its specific type of work. Such historical data provide a basis for estimating the project duration. Variations of this top-down approach are used by companies such as IBM, Bank of America, Sears Roebuck, HP, AT & T, Ford Motors, GE, Du Pont and many others. See Table 5.2 and Table 5.3 for a simplified example of function point count methodology.

TABLE 5.2 Simplified Basic Function Point Count Process for a Prospective Project or Deliverable

	Complexity Weighting			
Element	**Low**	**Average**	**High**	**Total**
Number of *inputs*	_____ × 2 +	_____ × 3 +	_____ × 4	= _____
Number of *outputs*	_____ × 3 +	_____ × 6 +	_____ × 9	= _____
Number of *inquiries*	_____ × 2 +	_____ × 4 +	_____ × 6	= _____
Number of *files*	_____ × 5 +	_____ × 8 +	_____ × 12	= _____
Number of *interfaces*	_____ × 5 +	_____ × 10 +	_____ × 15	= _____

TABLE 5.3
Example: Function Point Count Method

Software Project 13: Patient Admitting and Billing

15	Inputs	Rated complexity as low	(2)
5	Outputs	Rated complexity as average	(6)
10	Inquiries	Rated complexity as average	(4)
30	Files	Rated complexity as high	(12)
20	Interfaces	Rated complexity as average	(10)

Application of Complexity Factor

Element	Count	Low	Average	High	Total
Inputs	15	× 2			= 30
Outputs	5		× 6		= 30
Inquiries	10		× 4		= 40
Files	30			× 12	= 360
Interfaces	20		× 10		= 200
				Total	660

From historical data the organization developed the weighting scheme for complexity found in Table 5.2. Function points are derived from multiplying the number of kinds of elements by weighted complexity.

Table 5.3 shows the data collected for a specific task or deliverable: Patient Admitting and Billing—the number of inputs, outputs, inquiries, files and interfaces along with the expected complexity rating. Finally, the application of the element count is applied and the function point count total is 660. Given this count and the fact that one person month has historically been equal to 5 function points, the job will require 132 person months (660/5 = 132). Assuming you have 10 programmers who can work on this task, the duration would be approximately 13 months. The cost is easily derived by multiplying the labor rate per month times 132 person months. For example, if the monthly programmer rate is $4,000, then the estimated cost would be $528,000 (132 × 4,000). Although function point metrics are useful, their accuracy depends on adequate historical data, currency of data, and relevancy of the project/deliverable to past averages.

Learning Curves

Some projects require that the same task, group of tasks, or product be repeated several times. Managers know intuitively that the time to perform a task improves with repetition. This phenomenon is especially true of tasks that are labor intensive. In these circumstances the pattern of improvement phenomenon can be used to predict the reduction in time to perform the task. From empirical evidence across *all* industries, the pattern of this improvement has been quantified in the *learning curve* (also known as improvement curve, experience curve, and industrial progress curve), which is described by the following relationship:

> *Each time the output quantity doubles, the unit labor hours are reduced at a constant rate.*

In practice the improvement ratio may vary from 60 percent, representing very large improvement, to 100 percent, representing no improvement at all. Generally, as the difficulty of the work decreases the expected improvement also decreases and the improvement ratio that is used becomes greater. One significant factor to consider is the proportion of labor in the task in relation to machine-paced work. Obviously, a lower percentage of improvement can occur only in operations with high labor content. Appendix 5.1 at the end of the chapter provides a detailed example of how the improvement phenomenon can be used to estimate time and cost for repetitive tasks.

The main disadvantage of top-down approaches to estimating is simply that the time and cost for a specific task are not considered. Grouping many tasks into a common basket encourages errors of omission and the use of imposed times and costs.

Micro estimating methods are usually more accurate than macro methods. The bottom-up approach at the work package level can serve as a check on cost elements in the WBS by rolling up the work packages and associated cost accounts to major deliverables. Similarly, resource requirements can be checked. Later, the time, resource, and cost estimates from the work packages can be consolidated into time-phased networks, resource schedules, and budgets that are used for control.

Bottom-Up Approaches for Estimating Project Times and Costs

Template Methods

If the project is similar to past projects, the costs from past projects can be used as a starting point for the new project. Differences in the new project can be noted and past times and costs adjusted to reflect these differences. For example, a ship repair drydock firm has a set of standard repair projects (i.e., templates for overhaul, electrical, mechanical) that are used as starting points for estimating the cost and duration of any new project. Differences from the appropriate standardized project are noted (for times, costs, and resources) and changes are made. This approach enables the firm to develop a potential schedule, estimate costs, and develop a budget in a very short time span. Development of such templates in a database can quickly reduce estimate errors.

Parametric Procedures Applied to Specific Tasks

Just as parametric techniques such as cost per square foot can be the source of top-down estimates, the same technique can be applied to specific tasks. For example, as part of an MS Office conversion project, 36 different computer workstations needed to be converted. Based on past conversion projects, the project manager determined that on average one person could convert three workstations per day. Therefore the task of converting the 36 workstations would take three technicians four days [(36/3)/3]. Similarly, to estimate the wallpapering allowance on a house remodel, the contractor figured a cost of $5 per square yard of wallpaper and $2 per yard to install it, for a total cost of $7. By measuring the length and height of all the walls she was able to calculate the total area in square yards and multiply it by $7.

Detailed Estimates for the WBS Work Packages

Probably the most reliable method for estimating time and cost is to use the WBS and to ask the people responsible for the work package to make the estimates. They know from experience or know where to find the information to estimate work package durations—especially those that depend on labor hours and costs. When work packages have significant uncertainty associated with the time to complete, it is a prudent policy to require three time estimates—low, average, and high. Figure 5.2 presents a template training form using three time estimates for work packages by three different estimators. The form illustrates how this information can identify large differences among estimators and how the use of averages can give a more balanced time estimate. This time estimating approach gives the project manager and owner an opportunity to assess the risks associated with project times (and thus, costs). The approach helps to reduce surprises as the project progresses. The three-time estimate approach also provides a basis for assessing risk and determining the contingency fund. (See Chapter 7 for a discussion of contingency funds.)

FIGURE 5.2 **SB45 Support Cost Estimate Worksheet**

Project Number: *17*						**Project Manager:** *Kathleen Walling*								
Project Description: *Road Diversion Project*						**Date:**		**5 - 07**						
		Estimator 1			**Estimator 2**			**Estimator 3**			**Estimator Averages**			**Ratio***
		Low	**Aver.**	**High**	**Low**	**Aver.**	**High**	**Low**	**Aver.**	**High**	**Aver.**	**Aver.**	**Aver.**	**Range/**
WBS	**Description**	**Est.**	**Est.**	**Est.**	**Est.**	**Est.**	**Est.**	**Est.**	**Est.**	**Est.**	**Low**		**High**	**Aver.**
ID		**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	**Days**	
102	Engineering	95	100	105	97	100	103	93	96	100	95.0	98.7	102.7	0.08
103	Project Management	14	15	17	14	16	18	13	14	15	13.7	15.0	16.7	0.20
104	R/W Property Acceptances	44	48	52	45	50	52	43	46	49	44.0	48.0	51.0	0.15
105	Base Maps	36	38	40	36	37	39	35	36	37	35.7	37.0	38.7	0.08
106	Coordinate Utilities	7	8	9	7	8	9	8	9	10	7.3	8.3	9.3	0.24
107	EPA Acceptance	13	14	15	14	15	16	13	15	17	13.3	14.7	16.0	0.18
108	Alignment Surveys	32	35	38	32	35	37	32	34	35	32.0	34.7	36.7	0.14
•														
•														
•					* Note: = ABS (Average Low - Average High)/Average									
•					This ratio indicates the degree of variability in the estimates.									

A Hybrid: Phase Estimating

This approach begins with a top-down estimate for the project and then refines estimates for phases of the project as it is implemented. Some projects by their nature cannot be rigorously defined because of the uncertainty of design or the final product. Although rare, such projects do exist. These projects are often found in aerospace projects, IT projects, new technology projects, and construction projects where design is incomplete. In these projects, phase or life-cycle estimating is frequently used.

Phase estimating is used when an unusual amount of uncertainty surrounds a project and it is impractical to estimate times and costs for the entire project. Phase estimating uses a two-estimate system over the life of the project. A detailed estimate is developed for the immediate phase and a macro estimate is made for the remaining phases of the project. Figure 5.3 depicts the phases of a project and the progression of estimates over its life.

For example, when the project need is determined, a macro estimate of the project cost and duration is made so analysis and decisions can be made. Simultaneously a detailed estimate is made for deriving project specifications and a macro estimate for the remainder of the project. As the project progresses and specifications are solidified, a detailed estimate for design is made and a macro estimate for the remainder of the project is computed. Clearly, as the project progresses through its life cycle and more information is available, the reliability of the estimates should be improving.

Phase estimating is preferred by those working on projects where the final product is not known and the uncertainty is very large—for example, the integration of wireless phones and computers. The commitment to cost and schedule is only necessary over the next phase of the project and commitment to unrealistic future schedules and costs based

Snapshot from Practice Estimate Accuracy

The smaller the element of a work package, the more accurate the overall estimate is likely to be. The extent of this improvement varies by type of project. The table below is developed to reflect this observation. For example, information technology projects that determine their time and cost estimates in the conceptual stage can expect their "actuals" to err up to 200 percent over cost and duration and, perhaps, as much as 30 percent under estimates. Conversely, estimates for buildings, roads, etc., made after the work packages are clearly defined, have a smaller error in actual costs and times of 15 percent over estimate and 5 percent less than estimate. Although these estimates vary by project, they can serve as ballpark numbers for project stakeholders selecting how project time and cost estimates will be derived.

Time and Cost Estimate Accuracy by Type of Project

	Bricks and Mortar	Information Technology
Conceptual stage	+60% to −30%	+200% to −30%
Deliverables defined	+30% to −15%	+100% to −15%
Work packages defined	+15% to −5%	+50% to −5%

on poor information is avoided. This progressive macro/micro method provides a stronger basis for using schedule and cost estimates to manage progress during the next phase.

Unfortunately your customer—internal or external—will want an accurate estimate of schedule and cost the moment the decision is made to implement the project. Additionally, the customer who is paying for the project often perceives phase estimating as a blank check because costs and schedules are not firm over most of the project life cycle. Even though the reasons for phase estimating are sound and legitimate, most customers have to be sold on its legitimacy. A major advantage for the customer is the opportunity to change features, re-evaluate, or even cancel the project in each new phase. In conclusion, phase estimating is very useful in projects that possess huge uncertainties concerning the final nature (shape, size, features) of the project.

See Figure 5.4 for a summary of the differences between top-down and bottom-up estimates.

Obtaining accurate estimates is a challenge. Committed organizations accept the challenge of coming up with meaningful estimates and invest heavily in developing their capacity to do so. Accurate estimates reduce uncertainty and support a discipline for effectively managing projects.

FIGURE 5.3
Phase Estimating over Project Life Cycle

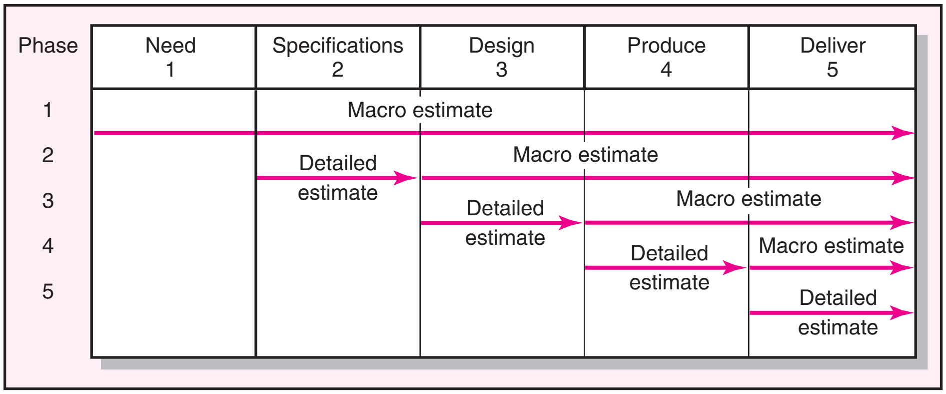


FIGURE 5.4
Top-Down and Bottom-Up Estimates

Top-Down Estimates	Bottom-Up Estimates
Intended Use Feasibility/conceptual phase Rough time/cost estimate Fund requirements Resource capacity planning	**Intended Use** Budgeting Scheduling Resource requirements Fund timing
Preparation Cost 1/10 to 3/10 of a percent of total project cost	**Preparation Cost** 3/10 of a percent to 1.0 percent of total project cost
Accuracy Minus 20%, to plus 60%	**Accuracy** Minus 10%, to plus 30%
Method Consensus Ratio Apportion Function point Learning curves	**Method** Template Parametric WBS packages

Level of Detail

Level of detail is different for different levels of management. At any level the detail should be no more than is necessary and sufficient. Top management interests usually center on the total project and major milestone events that mark major accomplishments—e.g., "Build Oil Platform in the North Sea" or "Complete Prototype." Middle management might center on one segment of the project or one milestone. First-line managers' interests may be limited to one task or work package. One of the beauties of WBS is the ability to aggregate network information so each level of management can have the kind of information necessary to make decisions.

Getting the level of detail in the WBS to match management needs for effective implementation is crucial, but the delicate balance is difficult to find. See Snapshot from Practice: Level of Detail. The level of detail in the WBS varies with the complexity of the project; the need for control; the project size, cost, duration; and other factors. If the structure reflects excessive detail, there is a tendency to break the work effort into department assignments. This tendency can become a barrier to success, since the emphasis will be on departmental outcomes rather than on deliverable outcomes. Excessive detail also means more unproductive paperwork. Note that if the level of the WBS is increased by one, the number of cost accounts may increase geometrically. On the other hand, if the level of detail is not adequate, an organization unit may find the structure falls short of meeting its needs. Fortunately, the WBS has built-in flexibility. Participating organization units may expand their portion of the structure to meet their special needs. For example, the engineering department may wish to further break their work on a deliverable into smaller packages by electrical, civil, and mechanical. Similarly, the marketing department may wish to break their new product promotion into TV, radio, periodicals, and newspapers.

Snapshot from Practice Level of Detail—Rule of Thumb

Practicing project managers advocate keeping the level of detail to a minimum. But there are limits to this suggestion. One of the most frequent errors of new project managers is to forget that the task time estimate will be used to control schedule and cost performance. A frequent rule of thumb used by practicing project managers says that a task duration should not exceed 5 workdays or at the most 10 workdays, if workdays are the time units used for the project. Such a rule probably will result in a more detailed network, but the additional detail pays off in controlling schedule and cost as the project progresses.

Suppose the task is "build prototype computer-controlled conveyor belt," the time estimate is 40 workdays, and the budget $300,000. It may be better to divide the task into seven or eight smaller tasks for control purposes. If one of the smaller tasks gets behind because of problems or a poor time estimate, it will be possible to take corrective action quickly and avoid delaying successive tasks and the project. If the single task of 40 workdays is used, it is possible that no corrective action would be taken until day 40, since many people have a tendency to "wait and see" or avoid admitting they are behind or passing on bad news; the result may mean far more than 5 days behind schedule.

The 5- to 10-day rule of thumb applies to cost and performance goals. If using the rule of thumb suggested above results in too many network tasks, an alternative is available, but it has conditions. The activity time can be extended beyond the 5- to 10-day rule only *IF* control monitoring checkpoints for segments of the task can be established so clear measures of progress can be identified by a specific percent complete.

This information is invaluable to the control process of measuring schedule and cost performance—for example, payments for contract work are paid on "percent complete" basis. Defining a task with clear definable start and end points and intermediate points enhances the chances of early detection of problems, corrective action, and on-time project completion.

Types of Costs

Assuming work packages are defined, detailed cost estimates can be made. Here are typical kinds of costs found in a project:

1. Direct costs
   a. Labor
   b. Materials
   c. Equipment
   d. Other
2. Project overhead costs
3. General and administrative (G&A) overhead costs

The total project cost estimate is broken down in this fashion to sharpen the control process and improve decision making.

Direct Costs

These costs are clearly chargeable to a specific work package. Direct costs can be influenced by the project manager, project team, and individuals implementing the work package. These costs represent real cash outflows and must be paid as the project progresses; therefore, direct costs are usually separated from overhead costs. Lower-level project rollups frequently include only direct costs.

Direct Overhead Costs

Direct overhead rates more closely pinpoint which resources of the organization are being used in the project. Direct overhead costs can be tied to project deliverables or work packages. Examples include the salary of the project manager and temporary rental space for the project team. Although overhead is not an immediate out-of-pocket expense, it is *real*

FIGURE 5.5
Contract Bid Summary Costs

Direct costs	$80,000
Direct overhead	$20,000
Total direct costs	$100,000
G&A overhead (20%)	$20,000
Total costs	$120,000
Profit (20%)	$24,000
Total bid	$144,000

and must be covered in the long run if the firm is to remain viable. These rates are usually a ratio of the dollar value of the resources used—e.g., direct labor, materials, equipment. For example, a direct labor burden rate of 20 percent would add a direct overhead charge of 20 percent to the direct labor cost estimate. A direct charge rate of 50 percent for materials would carry an additional 50 percent charge to the material cost estimate. Selective direct overhead charges provide a more accurate project (job or work package) cost, rather than using a blanket overhead rate for the whole project.

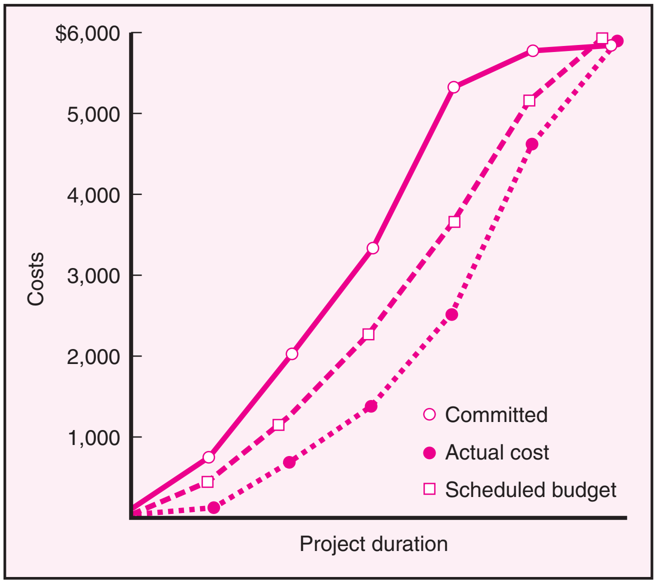
General and Administrative (G&A) Overhead Costs

These represent organization costs that are not directly linked to a specific project. These costs are carried for the duration of the project. Examples include organization costs across all products and projects such as advertising, accounting, and senior management above the project level. Allocation of G&A costs varies from organization to organization. However, G&A costs are usually allocated as a percent of total direct cost, or a percent of the total of a specific direct cost such as labor, materials, or equipment.

Given the totals of direct and overhead costs for individual work packages, it is possible to cumulate the costs for any deliverable or for the entire project. A percentage can be added for profit if you are a contractor. A breakdown of costs for a proposed contract bid is presented in Figure 5.5.

Perceptions of costs and budgets vary depending on their users. The project manager must be very aware of these differences when setting up the project budget and when communicating these differences to others. Figure 5.6 depicts these different perceptions. The project manager can commit costs months before the resource is used. This information is

FIGURE 5.6
Three Views of Cost



Snapshot from Practice

How Do You Estimate the Cost of a Nuclear Power Plant?

O. P. Kharbanda in his book (co-authored with Jeffrey Pinto) *What Made Gertie Gallop: Learning from Project Failures* makes the important point that estimating is as much an art as a skill. For example, early in his career (1960s), he was involved with the fabrication of a nuclear reactor in India at a time when the local facilities were not geared for such sophisticated jobs. Having had no experience in building complex equipment with (almost) unheard of tolerances and precision, it was virtually impossible to create a reasonable advance estimate of the cost. The estimators did the best they could, then added a little more than normal margin before quoting a price to the client.

Soon after, O. P. happened to attend a week-long international nuclear power conference that included stalwarts in this field from all over the world. About midweek, he was fortunate to come face-to-face with the chief engineer of the company that had supplied the first reactor to India, identical in design to the one his company had recently bid on. This was the chance of a lifetime to finally get the inside information on accurate cost estimating. In fact, the expert confessed that his company lost "their shirt" on the Indian reactor. Then in reply to the innocent question, "How do you estimate a nuclear reactor?" the expert answered with cool confidence, "Do your normal cautious estimating, add more than normal margin and then after a short pause, double it!" O. P. confessed that in their ignorance, they had skipped the last vital step, but this short, casual conversation proved most valuable. "We were forewarned, we took it seriously, and got forearmed. It saved us several millions of dollars."

useful to the financial officer of the organization in forecasting future cash outflows. The project manager is interested in when the budgeted cost is expected to occur, and when the budgeted cost actually is charged (earned); the respective timings of these two cost figures are used to measure project schedule and cost variances.

Refining Estimates

As described earlier in Chapter 4, detailed work package estimates are aggregated and "rolled up" by deliverable to estimate the total direct cost of the project. Similarly, estimated durations are entered into the project network to establish the project schedule and determine the overall duration of the project. Experience tells us that for many projects the total estimates do not materialize and the actual costs and schedule of some projects significantly exceed original work package–based estimates. See Snapshot from Practice: How Do You Estimate the Cost of a Nuclear Power Plant? for a dramatic example of this. In order to compensate for the problem of actual cost and schedule exceeding estimates, some project managers adjust total costs by some multiplier (i.e., total estimated costs × 1.20).

The practice of adjusting original estimates by 20 or even 100 percent begs the question of why, after investing so much time and energy on detailed estimates, could the numbers be so far off? There are a number of reasons for this, most of which can be traced to the estimating process and the inherent uncertainty of predicting the future. Some of these reasons are discussed below.

- **Interaction costs are hidden in estimates.** According to the guidelines, each task estimate is supposed to be done independently. However, tasks are rarely completed in a vacuum. Work on one task is dependent upon prior tasks, and the hand-offs between tasks require time and attention. For example, people working on prototype development need to interact with design engineers after the design is completed, whether to simply ask clarifying questions or to make adjustments in the original design. Similarly, the time necessary to coordinate activities is typically not reflected in independent estimates. Coordination is reflected in meetings and briefings as well as time necessary to resolve disconnects between tasks. Time, and therefore cost, devoted to managing interactions rises exponentially as the number of people and different disciplines involved increases on a project.

- **Normal conditions do not apply.** Estimates are supposed to be based on normal conditions. While this is a good starting point, it rarely holds true in real life. This is especially true when it comes to the availability of resources. Resource shortages, whether in the form of people, equipment, or materials, can extend original estimates. For example, under normal conditions four bulldozers are typically used to clear a certain site size in five days, but the availability of only three bulldozers would extend the task duration to eight days. Similarly, the decision to outsource certain tasks can increase costs as well as extend task durations since time is added to acclimating outsiders to the particulars of the project and the culture of the organization.
- **Things go wrong on projects.** Design flaws are revealed after the fact, extreme weather conditions occur, accidents happen, and so forth. Although you shouldn't plan for these risks to happen when estimating a particular task, the likelihood and impact of such events need to be considered.
- **Changes in project scope and plans.** As one gets further and further into the project, a manager obtains a better understanding of what needs to be done to accomplish the project. This may lead to major changes in project plans and costs. Likewise, if the project is a commercial project, changes often have to be made midstream to respond to new demands by the customer and/or competition. Unstable project scopes are a major source of cost overruns. While every effort should be made up front to nail down the project scope, it is becoming increasingly difficult to do so in our rapidly changing world.

The reality is that for many projects not all of the information needed to make accurate estimates is available, and it is impossible to predict the future. The dilemma is that without solid estimates, the credibility of the project plan is eroded. Deadlines become meaningless, budgets become rubbery, and accountability becomes problematic.

Challenges similar to those described above will influence the final time and cost estimates. Even with the best estimating efforts, it may be necessary to revise estimates based on relevant information *prior* to establishing a baseline schedule and budget.

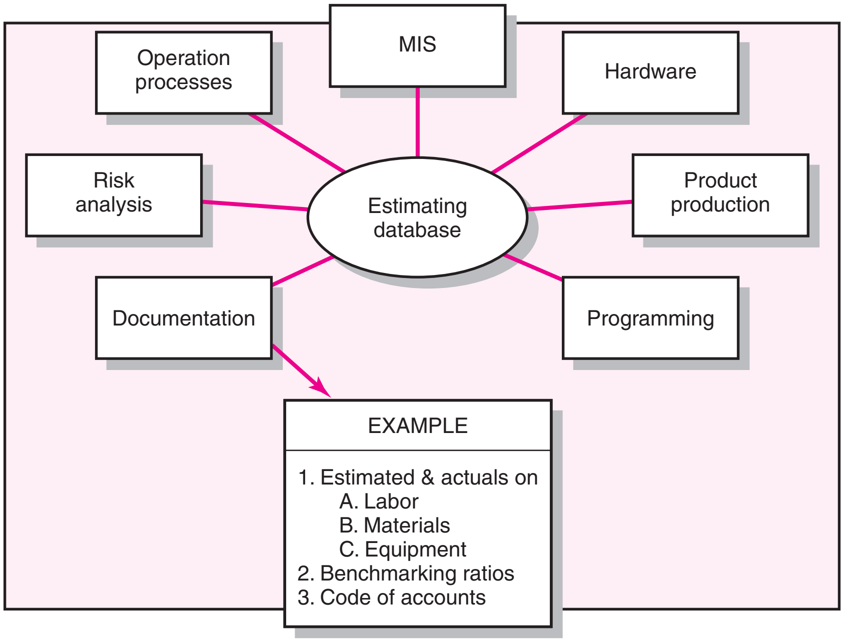
Effective organizations adjust estimates of specific tasks once risks, resources, and particulars of the situation have been more clearly defined. They recognize that the rolled up estimates generated from a detailed estimate based on the WBS are just the starting point. As they delve further into the project-planning process, they make appropriate revisions both in the time and cost of specific activities. They factor the final assignment of resources into the project budget and schedule. For example, when they realize that only three instead of four bulldozers are available to clear a site, they adjust both the time and cost of that activity. They adjust estimates to account for specific actions to mitigate potential risks on the project. For example, to reduce the chances of design code errors, they would add the cost of independent testers to the schedule and budget. Finally, organizations adjust estimates to take into account abnormal conditions. For example, if soil samples reveal excessive ground water, then they adjust foundation costs and times.

There will always be some mistakes, omissions, and adjustments that will require additional changes in estimates. Fortunately every project should have a change management system in place to accommodate these situations and any impact on the project baseline. Change management and contingency funds will be discussed later in Chapter 7.

Creating a Database for Estimating

The best way to improve estimates is to collect and archive data on past project estimates and actuals. Saving historical data—estimates and actuals—provides a knowledge base for improving project time and cost estimating. Creating an estimating database is a "best practice" among leading project management organizations.

FIGURE 5.7
Estimating Database Templates



Some organizations have large estimating departments of professional estimators—e.g., Boeing, Kodak, IBM—that have developed large time and cost databases. Others collect these data through the project office. This database approach allows the project estimator to select a specific work package item from the database for inclusion. The estimator then makes any necessary adjustments concerning the materials, labor, and equipment. Of course any items not found in the database can be added to the project—and ultimately to the database if desired. Again, the quality of the database estimates depends on the experience of the estimators, but over time the data quality should improve. Such structured databases serve as feedback for estimators and as benchmarks for cost and time for each project. In addition, comparison of estimate and actual for different projects can suggest the degree of risk inherent in estimates. See Figure 5.7 for the structure of a database similar to those found in practice.

Summary

Quality time and cost estimates are the bedrock of project control. Past experience is the best starting point for these estimates. The quality of estimates is influenced by other factors such as people, technology, and downtimes. The key for getting estimates that represent realistic average times and costs is to have an organization culture that allows errors in estimates without incriminations. If times represent average time, we should expect that 50 percent will be less than the estimate and 50 percent will exceed the estimate. The use of teams that are highly motivated can help in keeping task times and costs near the average. For this reason, it is crucial to get the team to buy into time and cost estimates.

Using top-down estimates is good for initial and strategic decision making or in situations where the costs associated with developing better estimates have little benefit. However, in most cases the bottom-up approach to estimating is preferred and more reliable because it assesses each work package, rather than the whole project, section, or deliverable of a project. Estimating time and costs for each work package facilitates development of the project schedule and a time-phased budget, which are needed to control the project as it is implemented. Using the estimating guidelines will help eliminate many common mistakes made by those unacquainted with estimating times and costs for project control. Establishing a time and cost estimating database fits well with the learning organization philosophy.

The level of time and cost detail should follow the old saying of "no more than is necessary and sufficient." Managers must remember to differentiate between committed outlays, actual costs, and scheduled costs. It is well known that up-front efforts in clearly defining project objectives, scope, and specifications vastly improve time and cost estimate accuracy.

Finally, how estimates are gathered and how they are used can affect their usefulness for planning and control. The team climate, organization culture, and organization structure can strongly influence the importance attached to time and cost estimates and how they are used in managing projects.

Key Terms

Apportionment methods
Bottom-up estimates
Contingency funds
Delphi method
Direct costs
Function points
Learning curves
Overhead costs
Padding estimates
Phase estimating
Ratio methods
Template method
Time and cost databases
Top-down estimates

Review Questions

1. Why are accurate estimates critical to effective project management?
2. How does the culture of an organization influence the quality of estimates?
3. What are the differences between bottom-up and top-down estimating approaches? Under what conditions would you prefer one over the other?
4. What are the major types of costs? Which costs are controllable by the project manager?

Exercises

1. Mrs. Tolstoy and her husband, Serge, are planning their dream house. The lot for the house sits high on a hill with a beautiful view of the Appalachian Mountains. The plans for the house show the size of the house to be 2,900 square feet. The average price for a lot and house similar to this one has been $120 per square foot. Fortunately, Serge is a retired plumber and feels he can save money by installing the plumbing himself. Mrs. Tolstoy feels she can take care of the interior decorating.

   The following average cost information is available from a local bank that makes loans to local contractors and disperses progress payments to contractors when specific tasks are verified as complete.

24%	Excavation and framing complete
8%	Roof and fireplace complete
3%	Wiring roughed in
6%	Plumbing roughed in
5%	Siding on
17%	Windows, insulation, walks, plaster, and garage complete
9%	Furnace installed
4%	Plumbing fixtures installed
10%	Exterior paint, light fixtures installed, finish hardware installed
6%	Carpet and trim installed
4%	Interior decorating
4%	Floors laid and finished

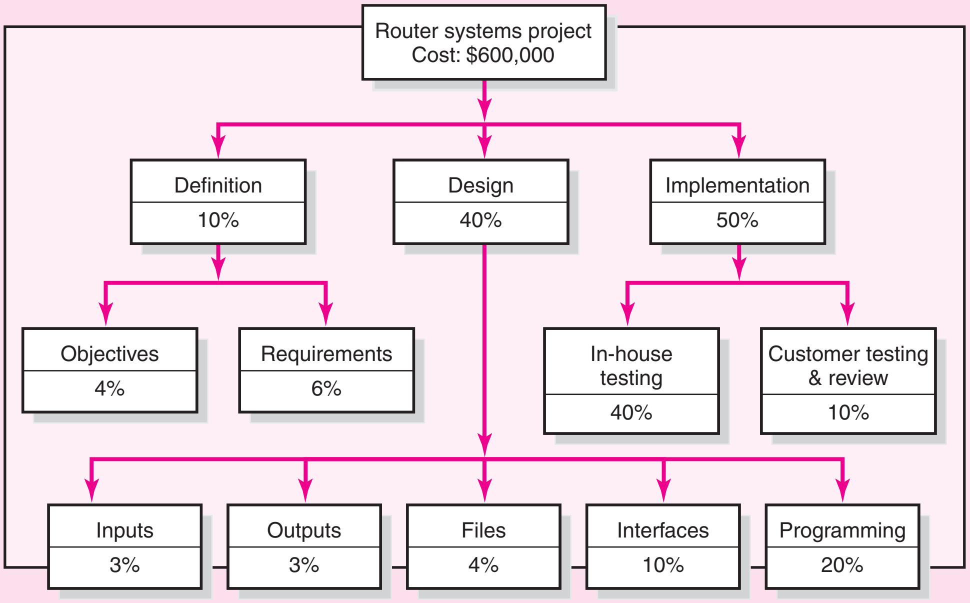
a. What is the estimated cost for the Tolstoy's house if they use contractors to complete all of the house?

b. Estimate what the cost of the house would be if the Tolstoys use their talents to do some of the work themselves.

2. Below is a project WBS with cost apportioned by percents. If the total project cost is estimated to be $600,000, what are the estimated costs for the following deliverables?
   a. Design?
   b. Programming?
   c. In-house testing?

   What weaknesses are inherent in this estimating approach?

EXERCISE 5.2
WBS Figure



3. Firewall Project XT. Using the "complexity weighting" scheme shown in Table 5.2 and the function point complexity weighted table shown below, estimate the total function point count. Assume historical data suggest five function points equal one person a month and six people can work on the project.

Complexity Weight Table

Number of inputs	10	Rated complexity low
Number of outputs	20	Rated complexity average
Number of inquires	10	Rated complexity average
Number of files	30	Rated complexity high
Number of interfaces	50	Rated complexity high

a. What is the estimated project duration?

b. If 20 people are available for the project, what is the estimated project duration?

c. If the project must be completed in six months, how many people will be needed for the project?

References

Dalkey, N. C., D. L. Rourke, R. Lewis, and D. Snyder, *Studies in the Quality of Life: Delphi and Decision Making* (Lexington, MA: Lexington Books, 1972).

Gray, N. S., "Secrets to Creating the Elusive 'Accurate Estimate,'" *PM Network,* 15 (8) August 2001, p. 56.

Jeffery, R., G. C. Low, and M. Barnes, "A Comparison of Function Point Counting Techniques," *IEEE Transactions on Software Engineering,* 19 (5) 1993, pp. 529–32.

Jones, C., *Applied Software Measurement* (New York: McGraw-Hill, 1991).

Jones, C., *Estimating Software Costs* (New York: McGraw-Hill, 1998).

Kharbanda, O. P., and J. K. Pinto, *What Made Gertie Gallop: Learning from Project Failures* (New York: Von Nostrand Reinhold, 1996).

Magne, E., K. Emhjellenm, and P. Osmundsen, "Cost Estimation Overruns in the North Sea," *Project Management Journal* 34 (1) 2003, pp. 23–29.

McLeod, G., and D. Smith, *Managing Information Technology Projects* (Cambridge, MA: Course Technology, 1996).

Milosevic, D. Z., *Project Management ToolBox* (Upper Saddle River, NJ: John Wiley, 2003), p. 229.

Pressman, R. S., *Software Engineering: A Practitioner's Approach, 4th edition* (New York: McGraw-Hill, 1997).

Symons, C. R., "Function Point Analysis: Difficulties and Improvements," *IEEE Transactions on Software Engineering,* 14 (1) 1988, pp. 2–11.

Case

Sharp Printing, AG

Three years ago the Sharp Printing (SP) strategic management group set a goal of having a color laser printer available for the consumer and small business market for less than $200. A few months later the senior management met off-site to discuss the new product. The results of this meeting were a set of general technical specifications along with major deliverables, a product launch date, and a cost estimate based on prior experience.

Shortly afterward, a meeting was arranged for middle management explaining the project goals, major responsibilities, the project start date, and importance of meeting the product launch date within the cost estimate. Members of all departments involved attended the meeting. Excitement was high. Although everyone saw the risks as high, the promised rewards for the company and the personnel were emblazoned in their minds. A few participants questioned the legitimacy of the project duration and cost estimates. A couple of R&D people were worried about the technology required to produce the high-quality product for less than $200. But given the excitement of the moment, everyone agreed the project was worth doing and doable. The color laser printer project was to have the highest project priority in the company.

Lauren was selected to be the project manager. She had 15 years of experience in printer design and manufacture, which included successful management of several projects related to printers for commercial markets. Since she was one of those uncomfortable with the project cost and time estimates, she felt getting good bottom-up time and cost estimates for the deliverables was her first concern. She quickly had a meeting with the significant stakeholders to create a WBS identifying the work packages and organizational unit responsible for implementing the work packages. Lauren stressed she wanted time and cost estimates from those who would do the work or were the most knowledgeable, if possible. Getting estimates from more than one source was encouraged. Estimates were due in two weeks.

The compiled estimates were placed in the WBS/OBS. The corresponding cost estimate seemed to be in error. The cost estimate was $1,250,000 over the senior management estimate; this represents about a 20 percent overrun! The time estimate from the developed project network was only four months over the top management time estimate. Another meeting was scheduled with the significant stakeholders to check the estimates and to brainstorm for alternative solutions; the cost and time estimates appeared to be reasonable. Some of the suggestions for the brainstorming session are listed below.

- Change scope.
- Outsource technology design.
- Use the priority matrix (found in Chapter 4) to get top management to clarify their priorities.
- Partner with another organization or build a research consortium to share costs and to share the newly developed technology and production methods.
- Cancel the project.
- Commission a break-even study for the laser printer.

Very little in the way of concrete savings was identified, although there was consensus that time could be compressed to the market launch date, but at additional costs.

Lauren met with the marketing (Connor), production (Kim), and design (Gage) managers who yielded some ideas for cutting costs, but nothing significant enough to have a large impact. Gage remarked, "I wouldn't want to be the one to deliver the message to top management that their cost estimate is $1,250,000 off! Good luck, Lauren."

1. At this point, what would you do if you were the project manager?
2. Was top management acting correctly in developing an estimate?
3. What estimating techniques should be used for a mission critical project such as this?

Appendix 5.1

Learning Curves for Estimating

A forecast estimate of the time required to perform a work package or task is a basic necessity for scheduling the project. In some cases, the manager simply uses judgment and past experience to estimate work package time, or may use historical records of similar tasks.

Most managers and workers intuitively know that improvement in the amount of time required to perform a task or group of tasks occurs with repetition. A worker can perform a task better/quicker the second time and each succeeding time she/he performs it (without any technological change). It is this pattern of improvement that is important to the project manager and project scheduler.

This improvement from repetition generally results in a reduction of labor hours for the accomplishment of tasks and results in lowers project costs. From empirical evidence across *all* industries, the pattern of this improvement has been quantified in the *learning curve* (also known as improvement curve, experience curve, and industrial progress curve), which is described by the following relationship:

Each time the output quantity doubles, the unit labor hours are reduced at a constant rate.

For example, assume that a manufacturer has a new contract for 16 prototype units and a total of 800 labor hours were required for the first unit. Past experience has indicated that on similar types of units the improvement rate was 80 percent. This relationship of improvement in labor hours is shown below:

Unit		Labor Hours
1		800
2	800 × .80 =	640
4	640 × .80 =	512
8	512 × .80 =	410
16	410 × .80 =	328

By using Table A5.1 unit values, similar labor hours per unit can be determined. Looking across the 16 unit level and down the 80 percent column, we find a ratio of .4096. By multiplying this ratio times the labor hours for the first unit, we obtained the per unit value:

$$.4096 \times 800 = 328 \text{ hours or } 327.68$$

That is, the 16th unit should require close to 328 labor hours, assuming an 80 percent improvement ratio.

Obviously, a project manager may need more than a single unit value for estimating the time for some work packages. The cumulative values in Table A5.2 provide factors for computing the cumulative total labor hours of all units. In the previous example, for the first 16 units, the total labor hours required would be

$$800 \times 8.920 = 7{,}136 \text{ hours}$$

By dividing the total cumulative hours (7,136) by the units, the average unit labor hours can be obtained:

$$7{,}136 \text{ labor hours}/16 \text{ units} = 446 \text{ average labor hours per unit}$$

Note how the labor hours for the 16th unit (328) differs from average for all 16 units (446). The project manager, knowing the average labor costs and processing costs, could estimate the total prototype costs. (The mathematical derivation of factors found in Tables A5.1 and A5.2 can be found in Jelen, F. C. and J. H. Black, *Cost and Optimization Engineering,* 2nd ed. (New York: McGraw-Hill, 1983.)

FOLLOW-ON CONTRACT EXAMPLE

Assume the project manager gets a follow-on order of 74 units, how should she estimate labor hours and cost? Going to the cumulative Table A5.2 we find at the 80 percent ratio and 90 total units intersection—a 30.35 ratio.

800 × 30.35 =	24,280 labor hours for 90 units
Less previous 16 units =	7,136
Total follow-on order =	17,144 labor hours
17,144/74 equals 232 average labor hours per unit	

Labor hours for the 90th unit can be obtained from Table A5.1: .2349 × 800 = 187.9 labor hours. (For ratios between given values, simply estimate.)

TABLE A5.1
Learning Curves Unit Values

Unit	60%	65%	70%	75%	80%	85%	90%	95%
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	.6000	.6500	.7000	.7500	.8000	.8500	.9000	.9500
3	.4450	.5052	.5682	.6338	.7021	.7729	.8462	.9219
4	.3600	.4225	.4900	.5625	.6400	.7225	.8100	.9025
5	.3054	.3678	.4368	.5127	.5956	.6857	.7830	.8877
6	.2670	.3284	.3977	.4754	.5617	.6570	.7616	.8758
7	.2383	.2984	.3674	.4459	.5345	.6337	.7439	.8659
8	.2160	.2746	.3430	.4219	.5120	.6141	.7290	.8574
9	.1980	.2552	.3228	.4017	.4930	.5974	.7161	.8499
10	.1832	.2391	.3058	.3846	.4765	.5828	.7047	.8433
12	.1602	.2135	.2784	.3565	.4493	.5584	.6854	.8320
14	.1430	.1940	.2572	.3344	.4276	.5386	.6696	.8226
16	.1296	.1785	.2401	.3164	.4096	.5220	.6561	.8145
18	.1188	.1659	.2260	.3013	.3944	.5078	.6445	.8074
20	.1099	.1554	.2141	.2884	.3812	.4954	.6342	.8012
22	.1025	.1465	.2038	.2772	.3697	.4844	.6251	.7955
24	.0961	.1387	.1949	.2674	.3595	.4747	.6169	.7904
25	.0933	.1353	.1908	.2629	.3548	.4701	.6131	.7880
30	.0815	.1208	.1737	.2437	.3346	.4505	.5963	.7775
35	.0728	.1097	.1605	.2286	.3184	.4345	.5825	.7687
40	.0660	.1010	.1498	.2163	.3050	.4211	.5708	.7611
45	.0605	.0939	.1410	.2060	.2936	.4096	.5607	.7545
50	.0560	.0879	.1336	.1972	.2838	.3996	.5518	.7486
60	.0489	.0785	.1216	.1828	.2676	.3829	.5367	.7386
70	.0437	.0713	.1123	.1715	.2547	.3693	.5243	.7302
80	.0396	.0657	.1049	.1622	.2440	.3579	.5137	.7231
90	.0363	.0610	.0987	.1545	.2349	.3482	.5046	.7168
100	.0336	.0572	.0935	.1479	.2271	.3397	.4966	.7112
120	.0294	.0510	.0851	.1371	.2141	.3255	.4830	.7017
140	.0262	.0464	.0786	.1287	.2038	.3139	.4718	.6937
160	.0237	.0427	.0734	.1217	.1952	.3042	.4623	.6869
180	.0218	.0397	.0691	.1159	.1879	.2959	.4541	.6809
200	.0201	.0371	.0655	.1109	.1816	.2887	.4469	.6757
250	.0171	.0323	.0584	.1011	.1691	.2740	.4320	.6646
300	.0149	.0289	.0531	.0937	.1594	.2625	.4202	.5557
350	.0133	.0262	.0491	.0879	.1517	.2532	.4105	.6482
400	.0121	.0241	.0458	.0832	.1453	.2454	.4022	.6419
450	.0111	.0224	.0431	.0792	.1399	.2387	.3951	.6363
500	.0103	.0210	.0408	.0758	.1352	.2329	.3888	.6314
600	.0090	.0188	.0372	.0703	.1275	.2232	.3782	.6229
700	.0080	.0171	.0344	.0659	.1214	.2152	.3694	.6158
800	.0073	.0157	.0321	.0624	.1163	.2086	.3620	.6098
900	.0067	.0146	.0302	.0594	.1119	.2029	.3556	.6045
1,000	.0062	.0137	.0286	.0569	.1082	.1980	.3499	.5998
1,200	.0054	.0122	.0260	.0527	.1020	.1897	.3404	.5918
1,400	.0048	.0111	.0240	.0495	.0971	.1830	.3325	.5850
1,600	.0044	.0102	.0225	.0468	.0930	.1773	.3258	.5793
1,800	.0040	.0095	.0211	.0446	.0895	.1725	.3200	.5743
2,000	.0037	.0089	.0200	.0427	.0866	.1683	.3149	.5698
2,500	.0031	.0077	.0178	.0389	.0606	.1597	.3044	.5605
3,000	.0027	.0069	.0162	.0360	.0760	.1530	.2961	.5530

TABLE A5.2
Learning Curves Cumulative Values

Units	60%	65%	70%	75%	80%	85%	90%	95%
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	1.600	1.650	1.700	1.750	1.800	1.850	1.900	1.950
3	2.045	2.155	2.268	2.384	2.502	2.623	2.746	2.872
4	2.405	2.578	2.758	2.946	3.142	3.345	3.556	3.774
5	2.710	2.946	3.195	3.459	3.738	4.031	4.339	4.662
6	2.977	3.274	3.593	3.934	4.299	4.688	5.101	5.538
7	3.216	3.572	3.960	4.380	4.834	5.322	5.845	6.404
8	3.432	3.847	4.303	4.802	5.346	5.936	6.574	7.261
9	3.630	4.102	4.626	5.204	5.839	6.533	7.290	8.111
10	3.813	4.341	4.931	5.589	6.315	7.116	7.994	8.955
12	4.144	4.780	5.501	6.315	7.227	8.244	9.374	10.62
14	4.438	5.177	6.026	6.994	8.092	9.331	10.72	12.27
16	4.704	5.541	6.514	7.635	8.920	10.38	12.04	13.91
18	4.946	5.879	6.972	8.245	9.716	11.41	13.33	15.52
20	5.171	6.195	7.407	8.828	10.48	12.40	14.64	17.13
22	5.379	6.492	7.819	9.388	11.23	13.38	15.86	18.72
24	5.574	6.773	8.213	9.928	11.95	14.33	17.10	20.31
25	5.668	6.909	8.404	10.19	12.31	14.80	17.71	21.10
30	6.097	7.540	9.305	11.45	14.02	17.09	20.73	25.00
35	6.478	8.109	10.13	12.72	15.64	19.29	23.67	28.86
40	6.821	8.631	10.90	13.72	17.19	21.43	26.54	32.68
45	7.134	9.114	11.62	14.77	18.68	23.50	29.37	36.47
50	7.422	9.565	12.31	15.78	20.12	25.51	32.14	40.22
60	7.941	10.39	13.57	17.67	22.87	29.41	37.57	47.65
70	8.401	11.13	14.74	19.43	25.47	33.17	42.87	54.99
80	8.814	11.82	15.82	21.09	27.96	36.80	48.05	62.25
90	9.191	12.45	16.83	22.67	30.35	40.32	53.14	69.45
100	9.539	13.03	17.79	24.18	32.65	43.75	58.14	76.59
120	10.16	14.16	19.57	27.02	37.05	50.39	67.93	90.71
140	10.72	15.08	21.20	29.67	41.22	56.78	77.46	104.7
160	11.21	15.97	22.72	32.17	45.20	62.95	86.80	118.5
180	11.67	16.79	24.14	34.54	49.03	68.95	95.96	132.1
200	12.09	17.55	25.48	36.80	52.72	74.79	105.0	145.7
250	13.01	19.28	28.56	42.08	61.47	88.83	126.9	179.2
300	13.81	20.81	31.34	46.94	69.66	102.2	148.2	212.2
350	14.51	22.18	33.89	51.48	77.43	115.1	169.0	244.8
400	15.14	23.44	36.26	55.75	84.85	127.6	189.3	277.0
450	15.72	24.60	38.48	59.80	91.97	139.7	209.2	309.0
500	16.26	25.68	40.58	63.68	98.85	151.5	228.8	340.6
600	17.21	27.67	44.47	70.97	112.0	174.2	267.1	403.3
700	18.06	29.45	48.04	77.77	124.4	196.1	304.5	465.3
800	18.82	31.09	51.36	84.18	136.3	217.3	341.0	526.5
900	19.51	32.60	54.46	90.26	147.7	237.9	376.9	587.2
1,000	20.15	34.01	57.40	96.07	158.7	257.9	412.2	647.4
1,200	21.30	36.59	62.85	107.0	179.7	296.6	481.2	766.6
1,400	22.32	38.92	67.85	117.2	199.6	333.9	548.4	884.2
1,600	23.23	41.04	72.49	126.8	218.6	369.9	614.2	1001.
1,800	24.06	43.00	76.85	135.9	236.8	404.9	678.8	1116.
2,000	24.83	44.84	80.96	144.7	254.4	438.9	742.3	1230.
2,500	26.53	48.97	90.39	165.0	296.1	520.8	897.0	1513.
3,000	27.99	52.62	98.90	183.7	335.2	598.9	1047.	1791.

Exercise A5.1

Norwegian Satellite Development Company
Cost estimates
for
World Satellite Telephone Exchange Project

NSDC has a contract to produce eight satellites to support a worldwide telephone system (for Alaska Telecom, Inc.) that allows individuals to use a single, portable telephone in any location on earth to call in and out. NSDC will develop and produce the eight units. NSDC has estimated that the R&D costs will be NOK (Norwegian Krone) 12,000,000. Material costs are expected to be NOK 6,000,000. They have estimated the design and production of the first satellite will require 100,000 labor hours and an 80 percent improvement curve is expected. Skilled labor cost is NOK 300 per hour. Desired profit for all projects is 25 percent of total costs.

A. How many labor hours should the eighth satellite require?
B. How many labor hours for the whole project of eight satellites?
C. What price would you ask for the project? Why?
D. Midway through the project your design and production people realize that a 75 percent improvement curve is more appropriate. What impact does this have on the project?
E. Near the end of the project Deutsch Telefon AG has requested a cost estimate for four satellites identical to those you have already produced. What price will you quote them? Justify your price.