

CHAPTER 3

Cost-Estimation Techniques



The objective of Chapter 3 is to present an assortment of methods for estimating important factors in an engineering economy study.

The High Cost of Office Rental Space

In 2008, your multinational firm needs to acquire a total of 50,000 square feet of additional office space in London, Hong Kong, and New York City. You have been tasked with developing a cost estimate for 20,000 square feet of space in London, 10,000 square feet of space in Hong Kong, and 20,000 square feet of space in New York City. While researching this topic, you find an article in *USA Today* (April 10, 2007, page B-1) that provides the following annual cost estimates per square foot of rental space in the three cities: London, \$233.57; Hong Kong, \$201.29; and New York City, \$175.00. How much should your firm expect to pay per year for the 50,000 square feet of office space? In Chapter 3, you will learn about several techniques that are highly useful in estimating the costs of engineering projects.

Decisions, both great and small, depend in part on estimates. “Looking down the barrel” need not be an embarrassment for the engineer if newer techniques, professional staffing, and a greater awareness are assigned to the engineering cost estimating function.

—Phillip F. Ostwald (1992)

3.1 Introduction

In Chapter 1, we described the engineering economic analysis procedure in terms of seven steps. In this chapter, we address Step 3, development of the outcomes and cash flows for each alternative. Because engineering economy studies deal with outcomes that extend into the future, estimating the future cash flows for feasible alternatives is a critical step in the analysis procedure. Often, the most difficult, expensive, and time-consuming part of an engineering economy study is the estimation of costs, revenues, useful lives, residual values, and other data pertaining to the alternatives being analyzed. A decision based on the analysis is economically sound only to the extent that these cost and revenue estimates are representative of what subsequently will occur. In this chapter, we introduce the role of *cost estimating* in engineering practice. Definitions and examples of important cost concepts were provided in Chapter 2.

Whenever an engineering economic analysis is performed for a major capital investment, the cost-estimating effort for that analysis should be an integral part of a comprehensive planning and design process requiring the active participation of not only engineering designers but also personnel from marketing, manufacturing, finance, and top management. Results of cost estimating are used for a variety of purposes, including the following:

1. Providing information used in setting a selling price for quoting, bidding, or evaluating contracts
2. Determining whether a proposed product can be made and distributed at a profit (for simplicity, $\text{price} = \text{cost} + \text{profit}$)
3. Evaluating how much capital can be justified for process changes or other improvements
4. Establishing benchmarks for productivity improvement programs

There are two fundamental approaches to cost estimating: the “top-down” approach and the “bottom-up” approach. The top-down approach basically uses historical data from similar engineering projects to estimate the costs, revenues, and other data for the current project by modifying these data for changes in inflation or deflation, activity level, weight, energy consumption, size, and other factors. This approach is best used early in the estimating process when alternatives are still being developed and refined.

The bottom-up approach is a more detailed method of cost estimating. This method breaks down a project into small, manageable units and estimates their economic consequences. These smaller unit costs are added together with other types of costs to obtain an overall cost estimate. This approach usually works best when the detail concerning the desired output (a product or a service) has been defined and clarified.

EXAMPLE 3-1 Estimating the Cost of a College Degree

A simple example of cost estimating is to forecast the expense of getting a Bachelor of Science (B.S.) from the university you are attending. In our solution, we outline the two basic approaches just discussed for estimating these costs.

Solution

A top-down approach would take the published cost of a four-year degree at the same (or a similar) university and adjust it for inflation and extraordinary items that an incoming student might encounter, such as fraternity/sorority membership, scholarships, and tutoring. For example, suppose that the published cost of attending your university is \$15,750 for the current year. This figure is anticipated to increase at the rate of 6% per year and includes full-time tuition and fees, university housing, and a weekly meal plan. Not included are the costs of books, supplies, and other personal expenses. For our initial estimate, these “other” expenses are assumed to remain constant at \$5,000 per year.

The total estimated cost for four years can now be computed. We simply need to adjust the published cost for inflation each year and add in the cost of “other” expenses.

Year	Tuition, Fees, Room and Board	“Other” Expenses	Total Estimated Cost for Year
1	$\$15,750 \times 1.06 = \$16,695$	\$5,000	\$21,695
2	$16,695 \times 1.06 = 17,697$	5,000	22,697
3	$17,697 \times 1.06 = 18,759$	5,000	23,759
4	$18,759 \times 1.06 = 19,885$	5,000	24,885
		Grand Total	\$93,036

In contrast with the top-down approach, a bottom-up approach to the same cost estimate would be to first break down anticipated expenses into the typical categories shown in Figure 3-1 for each of the four years at the university. Tuition and fees can be estimated fairly accurately in each year, as can books and supplies. For example, suppose that the average cost of a college textbook is \$100. You can estimate your annual textbook cost by simply multiplying the average cost per book by the number of courses you plan to take. Assume that you plan on taking five courses each semester during the first year. Your estimated textbook costs would be

$$\left(\frac{5 \text{ courses}}{\text{semester}}\right) (2 \text{ semesters}) \left(\frac{1 \text{ book}}{\text{course}}\right) \left(\frac{\$100}{\text{book}}\right) = \$1,000.$$

The other two categories, living expenses and transportation, are probably more dependent on your lifestyle. For example, whether you own and operate an automobile and live in a “high-end” apartment off-campus can dramatically affect the estimated expenses during your college years.

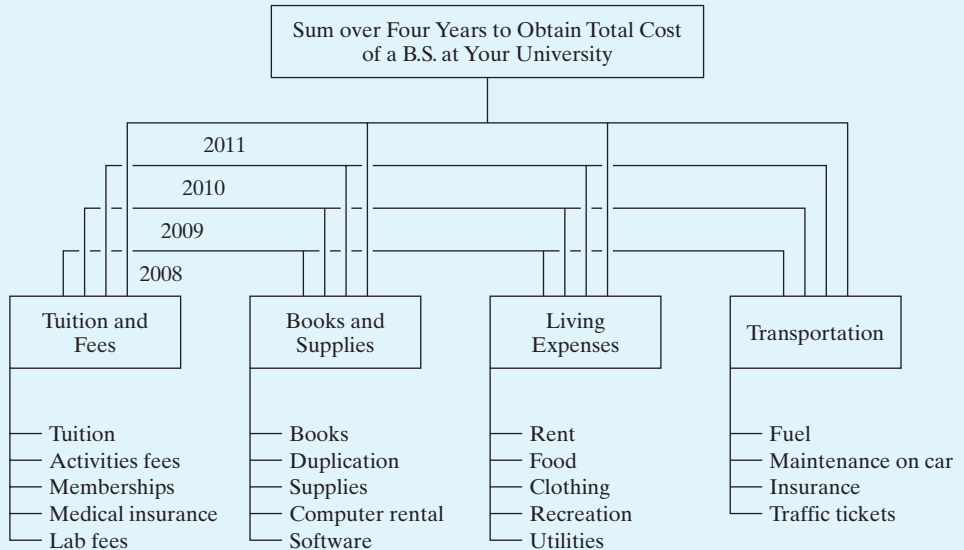


Figure 3-1 Bottom-Up Approach to Determining the Cost of a College Education

3.2 An Integrated Approach

An integrated approach to developing the net cash flows for feasible project alternatives is shown in Figure 3-2. This integrated approach includes three basic components:

1. **Work breakdown structure (WBS)** This is a technique for explicitly defining, at successive levels of detail, the work elements of a project and their interrelationships (sometimes called a *work element structure*).
2. **Cost and revenue structure (classification)** Delineation of the cost and revenue categories and elements is made for estimates of cash flows at each level of the WBS.
3. **Estimating techniques (models)** Selected mathematical models are used to estimate the future costs and revenues during the analysis period.

These three basic components, together with integrating procedural steps, provide an organized approach for developing the cash flows for the alternatives.

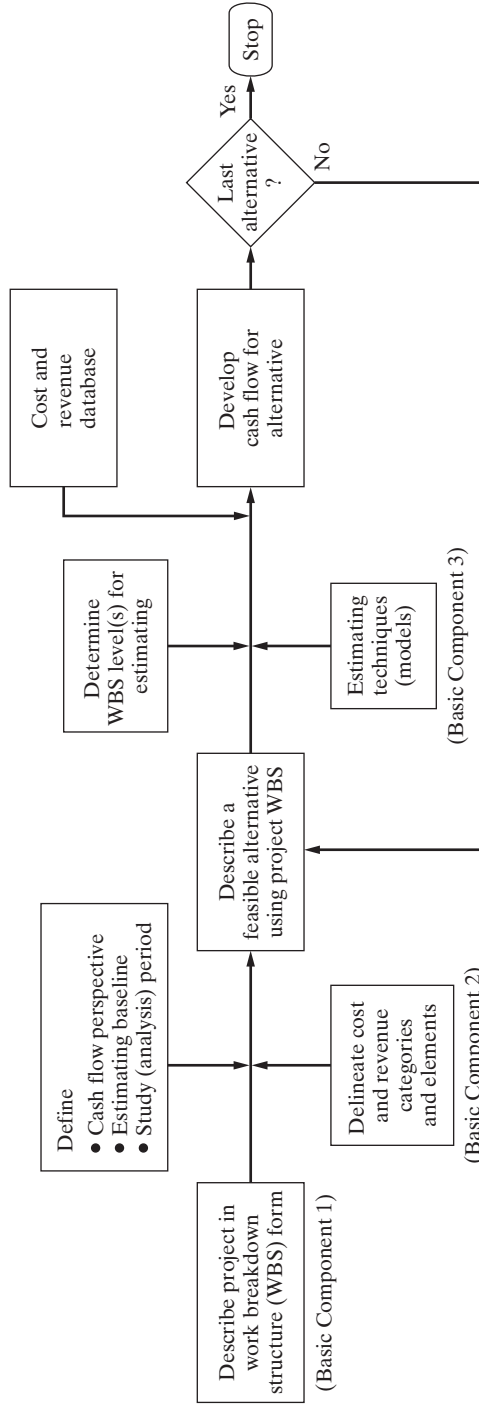


Figure 3-2 Integrated Approach for Developing the Cash Flows for Alternatives

As shown in Figure 3-2, the integrated approach begins with a description of the project in terms of a WBS. WBS is used to describe the project and each alternative's unique characteristics in terms of design, labor, material requirements, and so on. Then these variations in design, resource requirements, and other characteristics are reflected in the estimated future costs and revenues (net cash flow) for that alternative.

To estimate future costs and revenues for an alternative, the perspective (viewpoint) of the cash flow must be established and an estimating baseline and analysis period defined. Normally, cash flows are developed from the owner's viewpoint. The net cash flow for an alternative represents what is estimated to happen to future revenues and costs from the perspective being used. Therefore, the estimated changes in revenues and costs associated with an alternative have to be relative to a baseline that is consistently used for all the alternatives being compared.

3.2.1 The Work Breakdown Structure (WBS)

The first basic component in an integrated approach to developing cash flows is the work breakdown structure (WBS). The WBS is a basic tool in project management and is a vital aid in an engineering economy study. The WBS serves as a framework for defining all project work elements and their interrelationships, collecting and organizing information, developing relevant cost and revenue data, and integrating project management activities.

Figure 3-3 shows a diagram of a typical four-level WBS. It is developed from the top (project level) down in successive levels of detail. The project is divided into its major work elements (Level 2). These major elements are then divided to develop Level 3, and so on. For example, an automobile (first level of the WBS) can be divided into second-level components (or work elements) such as the chassis, drive train, and electrical system. Then each second-level component of the WBS can be subdivided further into third-level elements. The drive train, for example, can be subdivided into third-level components such as the engine, differential, and transmission. This process is continued until the desired detail in the definition and description of the project or system is achieved.

Different numbering schemes may be used. The objectives of numbering are to indicate the interrelationships of the work elements in the hierarchy. The scheme illustrated in Figure 3-3 is an alphanumeric format. Another scheme often used is all numeric—Level 1: 1-0; Level 2: 1-1, 1-2, 1-3; Level 3: 1-1-1, 1-1-2, 1-2-1, 1-2-2, 1-3-1, 1-3-2; and so on (i.e., similar to the organization of this book). Usually, the level is equal (except for Level 1) to the number of characters indicating the work element.

Other characteristics of a project WBS are as follows:

1. Both functional (e.g., planning) and physical (e.g., foundation) work elements are included in it:
 - (a) Typical functional work elements are logistical support, project management, marketing, engineering, and systems integration.
 - (b) Physical work elements are the parts that make up a structure, product, piece of equipment, or similar item; they require labor, materials, and other resources to produce or construct.

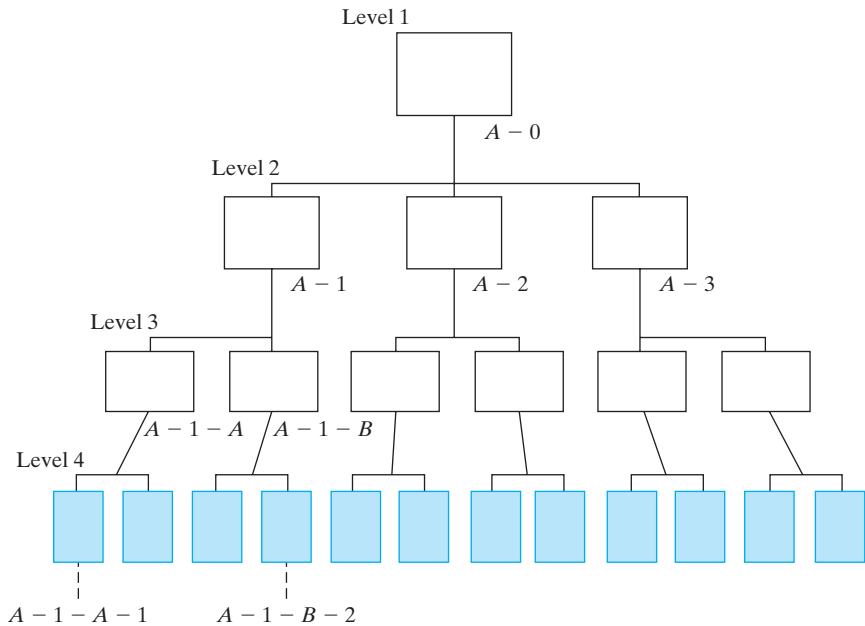


Figure 3-3 The WBS Diagram

2. The content and resource requirements for a work element are the sum of the activities and resources of related subelements below it.
3. A project WBS usually includes recurring (e.g., maintenance) and nonrecurring (e.g., initial construction) work elements.

EXAMPLE 3-2 A WBS for a Construction Project

You have been appointed by your company to manage a project involving construction of a small commercial building with two floors of 15,000 gross square feet each. The ground floor is planned for small retail shops, and the second floor is planned for offices. Develop the first three levels of a representative WBS adequate for all project efforts from the time the decision was made to proceed with the design and construction of the building until initial occupancy is completed.

Solution

There would be variations in the WBSs developed by different individuals for a commercial building. A representative three-level WBS is shown in Figure 3-4. Level 1 is the total project. At Level 2, the project is divided into seven major physical work elements and three major functional work elements. Then each of these major elements is divided into subelements as required (Level 3). The numbering scheme used in this example is all numeric.

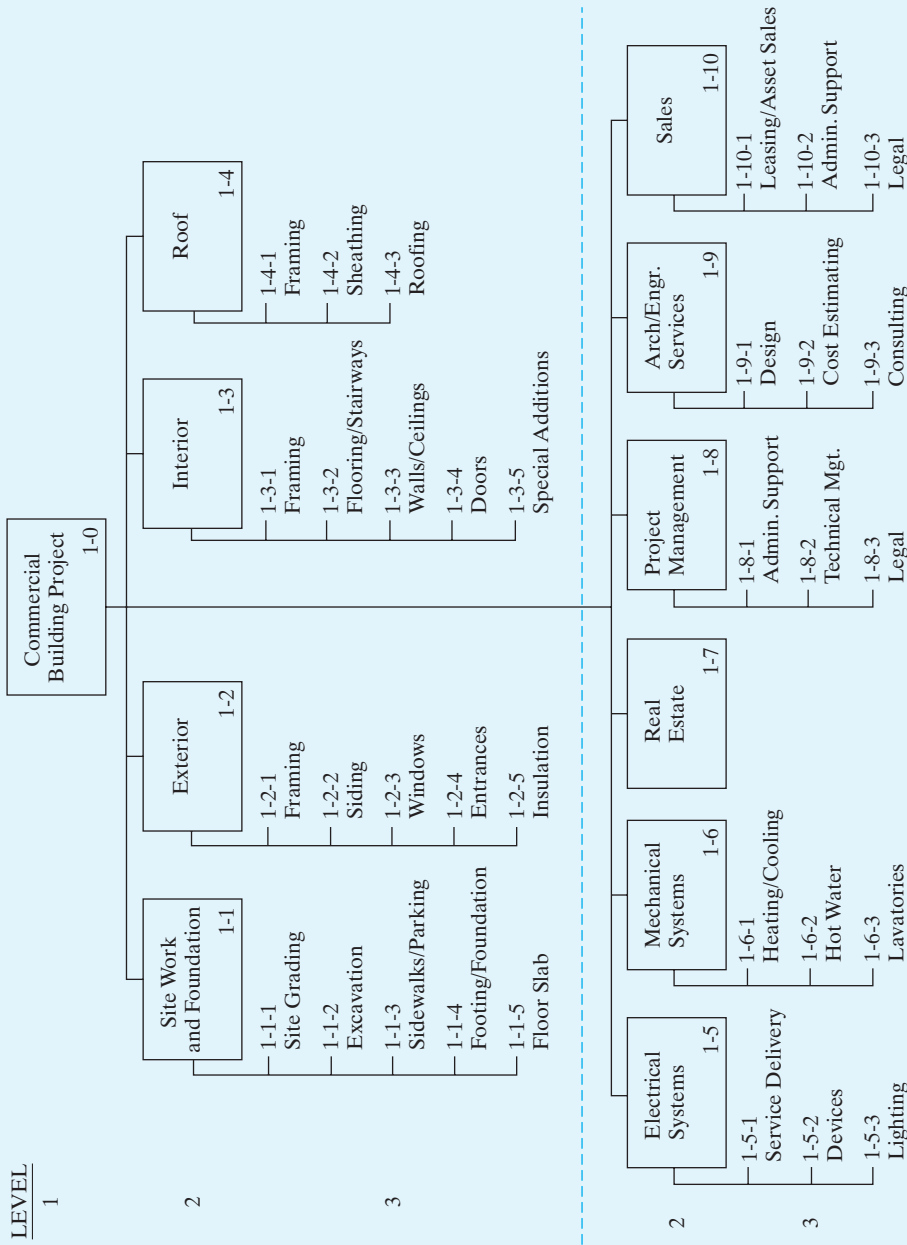


Figure 3-4 WBS (Three Levels) for Commercial Building Project in Example 3-2

3.2.2 The Cost and Revenue Structure

The second basic component of the integrated approach for developing cash flows (Figure 3-2) is the cost and revenue structure. This structure is used to identify and categorize the costs and revenues that need to be included in the analysis. Detailed data are developed and organized within this structure for use with the estimating techniques of Section 3.3 to prepare the cash-flow estimates.

The life-cycle concept and the WBS are important aids in developing the cost and revenue structure for a project. The life cycle defines a maximum time period and establishes a range of cost and revenue elements that need to be considered in developing cash flows. The WBS focuses the analyst's effort on the specific functional and physical work elements of a project and on its related costs and revenue.

Perhaps the most serious source of errors in developing cash flows is overlooking important categories of costs and revenues. The cost and revenue structure, prepared in tabular or checklist form, is a good means of preventing such oversights. Technical familiarity with the project is essential in ensuring the completeness of the structure, as are using the life-cycle concept and the WBS in its preparation.

The following is a brief listing of some categories of costs and revenues that are typically needed in an engineering economy study:

1. Capital investment (fixed and working)
2. Labor costs
3. Material costs
4. Maintenance costs
5. Property taxes and insurance
6. Overhead costs
7. Disposal costs
8. Revenues
9. Quality (and scrap) costs
10. Market (or salvage) values

3.2.3 Estimating Techniques (Models)

The third basic component of the integrated approach (Figure 3-2) involves estimating techniques (models). These techniques, together with the detailed cost and revenue data, are used to develop individual cash-flow estimates and the overall net cash-flow for each alternative.

The purpose of estimating is to develop cash-flow projections—*not to produce exact data* about the future, which is virtually impossible. Neither a preliminary estimate nor a final estimate is expected to be exact; rather, it should adequately suit the need at a reasonable cost and is often presented as a range of numbers.

Cost and revenue estimates can be classified according to detail, accuracy, and their intended use as follows:

1. **Order-of-magnitude estimates:** used in the planning and initial evaluation stage of a project.
2. **Semidetailed, or budget, estimates:** used in the preliminary or conceptual design stage of a project.
3. **Definitive (detailed) estimates:** used in the detailed engineering/construction stage of a project.

Order-of-magnitude estimates are used in selecting the feasible alternatives for the study. They typically provide accuracy in the range of ± 30 to 50% and are developed through semiformal means such as conferences, questionnaires, and generalized equations applied at Level 1 or 2 of the WBS.

Budget (semidetailed) estimates are compiled to support the preliminary design effort and decision making during this project period. Their accuracy usually lies in the range of $\pm 15\%$. These estimates differ in the fineness of cost and revenue breakdowns and the amount of effort spent on the estimate. Estimating equations applied at Levels 2 and 3 of the WBS are normally used.

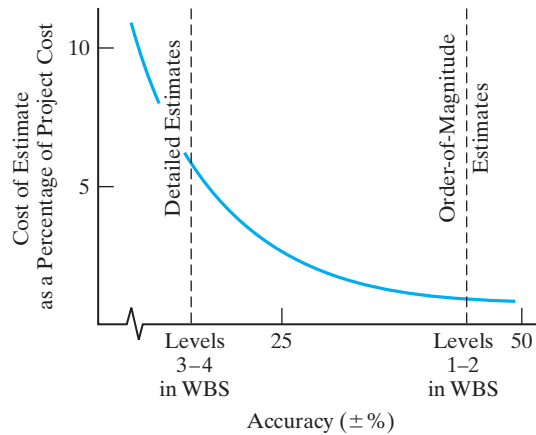
Detailed estimates are used as the basis for bids and to make detailed design decisions. Their accuracy is $\pm 5\%$. They are made from specifications, drawings, site surveys, vendor quotations, and in-house historical records and are usually done at Level 3 and successive levels in the WBS.

Thus, it is apparent that a cost or revenue estimate can vary from a “back of the envelope” calculation by an expert to a very detailed and accurate prediction of the future prepared by a project team. The level of detail and accuracy of estimates should depend on the following:

1. Time and effort available as justified by the importance of the study
2. Difficulty of estimating the items in question
3. Methods or techniques employed
4. Qualifications of the estimator(s)
5. Sensitivity of study results to particular factor estimates

As estimates become more detailed, accuracy typically improves, but the cost of making the estimate increases dramatically. This general relationship is shown in Figure 3-5 and illustrates the idea that cost and revenue estimates should be prepared with full recognition of how accurate a particular study requires them to be.

Figure 3-5
Accuracy of Cost
and Revenue
Estimates versus
the Cost of
Making Them



3.2.3.1 Sources of Estimating Data The information sources useful in cost and revenue estimating are too numerous to list completely. The following four major sources of information are listed roughly in order of importance:

1. **Accounting records.** Accounting records are a prime source of information for economic analyses; however, they are often not suitable for direct, unadjusted use.

A brief discussion of the accounting process and information was given in Appendix 2-A. In its most basic sense, accounting consists of a series of procedures for keeping a detailed record of monetary transactions between established categories of assets. Accounting records are a good source of historical data but have some limitations when used in making prospective estimates for engineering economic analyses. Moreover, accounting records rarely contain direct statements of incremental costs or opportunity costs, both of which are essential in most engineering economic analyses. Incremental costs are decision specific for one-of-a-kind investments and are unlikely to be available from the accounting system.

2. **Other sources within the firm.** The typical firm has a number of people and records that may be excellent sources of estimating information. Examples of functions within firms that keep records useful to economic analyses are engineering, sales, production, quality, purchasing, and personnel.
3. **Sources outside the firm.** There are numerous sources outside the firm that can provide helpful information. The main problem is in determining those that are most beneficial for particular needs. The following is a listing of some commonly used outside sources:

- (a) **Published information.** Technical directories, buyer indexes, U.S. government publications, reference books, and trade journals offer a wealth of information. For instance, *Standard and Poor's Industry Surveys* gives monthly information regarding key industries. *The Statistical Abstract of the United States* is a remarkably comprehensive source of cost indexes and data. The Bureau of Labor Statistics publishes many periodicals that are good sources of labor costs, such as the *Monthly Labor Review*, *Employment and Earnings*,

Current Wage Developments, Handbook of Labor Statistics, and the Chartbook on Wages, Prices and Productivity.

- (b) *Personal contacts* are excellent potential sources. Vendors, salespeople, professional acquaintances, customers, banks, government agencies, chambers of commerce, and even competitors are often willing to furnish needed information on the basis of a serious and tactful request.
4. **Research and development (R&D).** If the information is not published and cannot be obtained by consulting someone, the only alternative may be to undertake R&D to generate it. Classic examples are developing a pilot plant and undertaking a test market program.

The Internet can also be a source of cost-estimating data, though you should assure yourself that the information is from a reputable source. The following Web sites may be useful to you both professionally and personally.

www.enr.com	<i>Engineering News-Record</i>	Construction and labor costs
www.kbb.com	Kelley Blue Book	Automobile pricing
www.factsonfuel.com	American Petroleum Institute	Fuel costs

3.2.3.2 How Estimates Are Accomplished Estimates can be prepared in a number of ways, such as the following examples:

1. A *conference* of various people who are thought to have good information or bases for estimating the quantity in question. A special version of this is the *Delphi method*, which involves cycles of questioning and feedback in which the opinions of individual participants are kept anonymous.
2. *Comparison* with similar situations or designs about which there is more information and from which estimates for the alternatives under consideration can be extrapolated. This is sometimes called *estimating by analogy*. The comparison method may be used to approximate the cost of a design or product that is new. This is done by taking the cost of a more complex design for a similar item as an upper bound and the cost of a less complex item of similar design as a lower bound. The resulting approximation may not be very accurate, but the comparison method does have the virtue of setting bounds that might be useful for decision making.
3. *Using quantitative techniques*, which do not always have standardized names. Some selected techniques, with the names used being generally suggestive of the approaches, are discussed in the next section.

3.3 Selected Estimating Techniques (Models)

The estimating models discussed in this section are applicable for order-of-magnitude estimates and for many semidetained or budget estimates. They are useful in the initial selection of feasible alternatives for further analysis and in the conceptual or preliminary design phase of a project. Sometimes, these models can be used in the detailed design phase of a project.

3.3.1 Indexes

Costs and prices* vary with time for a number of reasons, including (1) technological advances, (2) availability of labor and materials, and (3) inflation. An *index* is a dimensionless number that indicates how a cost or a price has changed with time (typically escalated) with respect to a base year. Indexes provide a convenient means for developing present and future cost and price estimates from historical data. An estimate of the cost or selling price of an item in year n can be obtained by multiplying the cost or price of the item at an earlier point in time (year k) by the ratio of the index value in year n (\bar{I}_n) to the index value in year k (\bar{I}_k);† that is,

$$C_n = C_k \left(\frac{\bar{I}_n}{\bar{I}_k} \right), \quad (3-1)$$

where k = reference year (e.g., 2000) for which cost or price of item is known;
 n = year for which cost or price is to be estimated ($n > k$);
 C_n = estimated cost or price of item in year n ;
 C_k = cost or price of item in reference year k .

Equation (3-1) is sometimes referred to as the *ratio technique* of updating costs and prices. Use of this technique allows the cost or potential selling price of an item to be taken from historical data with a specified base year and updated with an index. This concept can be applied at the lower levels of a WBS to estimate the cost of equipment, materials, and labor, as well as at the top level of a WBS to estimate the total project cost of a new facility, bridge, and so on.

EXAMPLE 3-3 Indexing the Cost of a New Boiler

A certain index for the cost of purchasing and installing utility boilers is keyed to 1988, where its baseline value was arbitrarily set at 100. Company XYZ installed a 50,000-lb/hour boiler for \$525,000 in 2000 when the index had a value of 468. This same company must install another boiler of the same size in 2007. The index in 2007 is 542. What is the approximate cost of the new boiler?

Solution

In this example, n is 2007 and k is 2000. From Equation (3-1), an approximate cost of the boiler in 2007 is

$$C_{2007} = \$525,000(542/468) = \$608,013.$$

Indexes can be created for a single item or for multiple items. For a single item, the index value is simply the ratio of the cost of the item in the current year to the cost of the same item in the reference year, multiplied by the reference year factor

* The terms *cost* and *price* are often used together. The cost of a product or service is the total of the resources, direct and indirect, required to produce it. The price is the value of the good or service in the marketplace. In general, price is equal to cost plus a profit.

† In this section only, k is used to denote the reference year.

(typically, 100). A composite index is created by averaging the ratios of selected item costs in a particular year to the cost of the same items in a reference year. The developer of an index can assign different weights to the items in the index according to their contribution to total cost. For example, a general weighted index is given by

$$\bar{I}_n = \frac{W_1(C_{n1}/C_{k1}) + W_2(C_{n2}/C_{k2}) + \cdots + W_M(C_{nM}/C_{kM})}{W_1 + W_2 + \cdots + W_M} \times \bar{I}_k, \quad (3-2)$$

where M = total number of items in the index ($1 \leq m \leq M$);

C_{nm} = unit cost (or price) of the m th item in year n ;

C_{km} = unit cost (or price) of the m th item in year k ;

W_m = weight assigned to the m th item;

\bar{I}_k = composite index value in year k .

The weights W_1, W_2, \dots, W_M can sum to any positive number, but typically sum to 1.00 or 100. Almost any combination of labor, material, products, services, and so on can be used for a composite cost or price index.

EXAMPLE 3-4

Weighted Index for Gasoline Cost

Based on the following data, develop a weighted index for the price of a gallon of gasoline in 2006, when 1992 is the reference year having an index value of 99.2. The weight placed on *regular unleaded* gasoline is three times that of either premium or unleaded plus, because roughly three times as much regular unleaded is sold compared with premium or unleaded plus.

	Price (Cents/Gal) in Year		
	1992	1996	2006
Premium	114	138	240
Unleaded plus	103	127	230
Regular unleaded	93	117	221

Solution

In this example, k is 1992 and n is 2006. From Equation (3-2), the value of \bar{I}_{2006} is

$$\frac{(1)(240/114) + (1)(230/103) + (3)(221/93)}{1 + 1 + 3} \times 99.2 = 227.5.$$

Now, if the index in 2008, for example, is estimated to be 253, it is a simple matter to determine the corresponding 2008 prices of gasoline from $\bar{I}_{2006} = 227.5$:

$$\text{Premium: } 240 \text{ cents/gal} \left(\frac{253}{227.5} \right) = 267 \text{ cents/gal,}$$

$$\text{Unleaded plus: } 230 \text{ cents/gal} \left(\frac{253}{227.5} \right) = 256 \text{ cents/gal,}$$

$$\text{Regular unleaded: } 221 \text{ cents/gal} \left(\frac{253}{227.5} \right) = 246 \text{ cents/gal.}$$

Many indexes are periodically published, including the *Engineering News Record* Construction Index (www.enr.com), which incorporates labor and material costs and the Marshall and Stevens cost index.

3.3.2 Unit Technique

The *unit technique* involves using a per unit factor that can be estimated effectively. Examples are as follows:

1. Capital cost of plant per kilowatt of capacity
2. Revenue per mile
3. Capital cost per installed telephone
4. Revenue per customer served
5. Temperature loss per 1,000 feet of steam pipe
6. Operating cost per mile
7. Construction cost per square foot

Such factors, when multiplied by the appropriate unit, give a total estimate of cost, savings, or revenue.

As a simple example, suppose that we need a preliminary estimate of the cost of a particular house. Using a unit factor of, say, \$95 per square foot and knowing that the house is approximately 2,000 square feet, we estimate its cost to be $\$95 \times 2,000 = \$190,000$.

While the unit technique is very useful for preliminary estimating purposes, such average values can be misleading. In general, more detailed methods will result in greater estimation accuracy.

3.3.3 Factor Technique

The *factor technique* is an extension of the unit method in which we sum the product of several quantities or components and add these to any components estimated directly. That is,

$$C = \sum_d C_d + \sum_m f_m U_m, \quad (3-3)$$

where C = cost being estimated;

C_d = cost of the selected component d that is estimated directly;

f_m = cost per unit of component m ;

U_m = number of units of component m .

As a simple example, suppose that we need a slightly refined estimate of the cost of a house consisting of 2,000 square feet, two porches, and a garage. Using a unit factor of \$85 per square foot, \$10,000 per porch, and \$8,000 per garage for the two directly estimated components, we can calculate the total estimate as

$$(\$10,000 \times 2) + \$8,000 + (\$85 \times 2,000) = \$198,000.$$

We can also answer the question posed at the beginning of the chapter (page 71) using the factor technique. The rental expense per year will be approximately $20,000 \times \$233.57$ in London plus $10,000 \times \$201.29$ in Hong Kong plus $20,000 \times \$175.00$ in New York City. The total expense will be \$10,184,300 per year for the additional office space.

The factor technique is particularly useful when the complexity of the estimating situation does not require a WBS, but several different parts are involved. Example 3-5 and the product cost-estimating example to be presented in Section 3.5.1 further illustrate this technique.

EXAMPLE 3-5

Analysis of Building Space Cost Estimates

The detailed design of the commercial building described in Example 3-2 affects the utilization of the gross square feet (and, thus, the net rentable space) available on each floor. Also, the size and location of the parking lot and the prime road frontage available along the property may offer some additional revenue sources. As project manager, analyze the potential revenue impacts of the following considerations.

The first floor of the building has 15,000 gross square feet of retail space, and the second floor has the same amount planned for office use. Based on discussions with the sales staff, develop the following additional information:

- (a) The retail space should be designed for two different uses—60% for a restaurant operation (utilization = 79%, yearly rent = \$23/sq.ft.) and 40% for a retail clothing store (utilization = 83%, yearly rent = \$18/sq.ft.).
- (b) There is a high probability that all the office space on the second floor will be leased to one client (utilization = 89%, yearly rent = \$14/sq.ft.).
- (c) An estimated 20 parking spaces can be rented on a long-term basis to two existing businesses that adjoin the property. Also, one spot along the road frontage can be leased to a sign company, for erection of a billboard, without impairing the primary use of the property.

Solution

Based on this information, you estimate annual project revenue (\hat{R}) as

$$\hat{R} = W(r_1)(12) + \Upsilon(r_2)(12) + \sum_{j=1}^3 S_j(u_j)(d_j),$$

where W = number of parking spaces;

Υ = number of billboards;

r_1 = rate per month per parking space = \$22;

r_2 = rate per month per billboard = \$65;

j = index of type of building space use;

S_j = space (gross square feet) being used for purpose j ;

u_j = space j utilization factor (% net rentable);

d_j = rate per (rentable) square foot per year of building space used for purpose j .

Then,

$$\begin{aligned}\hat{R} &= [20(\$22)(12) + 1(\$65)(12)] + [9,000(0.79)(\$23) \\ &\quad + 6,000(0.83)(\$18) + 15,000(0.89)(\$14)] \\ \hat{R} &= \$6,060 + \$440,070 = \$446,130.\end{aligned}$$

A breakdown of the annual estimated project revenue shows that

1.4% is from miscellaneous revenue sources;

98.6% is from leased building space.

From a detailed design perspective, changes in annual project revenue due to changes in building space utilization factors can be easily calculated. For example, an average 1% improvement in the ratio of rentable space to gross square feet would change the annual revenue ($\Delta\hat{R}$) as follows:

$$\begin{aligned}\Delta\hat{R} &= \sum_{j=1}^3 S_j(u_j + 0.01)(d_j) - (\$446,130 - \$6,060) \\ &= \$445,320 - \$440,070 \\ &= \$5,250 \text{ per year.}\end{aligned}$$

3.4 Parametric Cost Estimating

Parametric cost estimating is the use of historical cost data and statistical techniques to predict future costs. Statistical techniques are used to develop cost estimating relationships (CERs) that tie the cost or price of an item (e.g., a product, good,

TABLE 3-1 Examples of Cost Drivers Used in Parametric Cost Estimates

Product	Cost Driver (Independent Variable)
Construction	Floor space, roof surface area, wall surface area
Trucks	Empty weight, gross weight, horsepower
Passenger car	Curb weight, wheel base, passenger space, horsepower
Turbine engine	Maximum thrust, cruise thrust, specific fuel consumption
Reciprocating engine	Piston displacement, compression ratio, horsepower
Aircraft	Empty weight, speed, wing area
Electrical power plants	KiloWatts
Motors	Horsepower
Software	Number of lines of code

service, or activity) to one or more independent variables (i.e., cost drivers). Recall from Chapter 2 that cost drivers are design variables that account for a large portion of total cost behavior. Table 3-1 lists a variety of items and associated cost drivers. The unit technique described in the previous section is a simple example of parametric cost estimating.

Parametric models are used in the early design stages to get an idea of how much the product (or project) will cost, on the basis of a few physical attributes (such as weight, volume, and power). The output of the parametric models (an estimated cost) is used to gauge the impact of design decisions on the total cost.

Various statistical and other mathematical techniques are used to develop the CERs. For example, simple linear regression and multiple linear regression models, which are standard statistical methods for estimating the value of a dependent variable (the unknown quantity) as a function of one or more independent variables, are often used to develop estimating relationships. This section describes two commonly used estimating relationships, the power-sizing technique and the learning curve, followed by an overview of the procedure used to develop CERs.

3.4.1 Power-Sizing Technique

The *power-sizing technique*, which is sometimes referred to as an *exponential model*, is frequently used for developing capital investment estimates for industrial plants and equipment. This CER recognizes that cost varies as some power of the change in capacity or size. That is,

$$\frac{C_A}{C_B} = \left(\frac{S_A}{S_B} \right)^X,$$

$$C_A = C_B \left(\frac{S_A}{S_B} \right)^X, \quad (3-4)$$

for the 200-MW plant in Example 3-6, we find that the current cost of a 100-MW plant is

$$C_A = \$300 \text{ million} \left(\frac{100 \text{ MW}}{200 \text{ MW}} \right)^{0.79}$$

$$C_A = \$300 \text{ million} \times 0.58 = \$174 \text{ million.}$$

3.4.2 Learning and Improvement

A *learning curve* is a mathematical model that explains the phenomenon of increased worker efficiency and improved organizational performance with repetitive production of a good or service. The learning curve is sometimes called an *experience curve* or a *manufacturing progress function*; fundamentally, it is an estimating relationship. The learning (improvement) curve effect was first observed in the aircraft and aerospace industries with respect to labor hours per unit. However, it applies in many different situations. For example, the learning curve effect can be used in estimating the professional hours expended by an engineering staff to accomplish successive detailed designs within a family of products, as well as in estimating the labor hours required to assemble automobiles.

The basic concept of learning curves is that some input resources (e.g., energy costs, labor hours, material costs, engineering hours) decrease, on a per-output-unit basis, as the number of units produced increases. Most learning curves are based on the assumption that a constant percentage reduction occurs in, say, labor hours, as the number of units produced is *doubled*. For example, if 100 labor hours are required to produce the first output unit and a 90% learning curve is assumed, then $100(0.9) = 90$ labor hours would be required to produce the second unit. Similarly, $100(0.9)^2 = 81$ labor hours would be needed to produce the fourth unit, $100(0.9)^3 = 72.9$ hours to produce the eighth unit, and so on. Therefore, a 90% learning curve results in a 10% reduction in labor hours each time the production quantity is doubled.

Equation (3-5) can be used to compute resource requirements assuming a constant percentage reduction in input resources each time the output quantity is doubled.

$$Z_u = K(u^n), \quad (3-5)$$

where u = the output unit number;

Z_u = the number of input resource units needed to produce output unit u ;

K = the number of input resource units needed to produce the first output unit;

s = the learning curve slope parameter expressed as a decimal ($s = 0.9$ for a 90% learning curve);

$n = \frac{\log s}{\log 2}$ = the learning curve exponent.

EXAMPLE 3-7

Learning Curve for a Formula Car Design Team

The Mechanical Engineering department has a student team that is designing a formula car for national competition. The time required for the team to assemble the first car is 100 hours. Their improvement (or learning rate) is 0.8, which means that as output is doubled, their time to assemble a car is reduced by 20%. Use this information to determine

- the time it will take the team to assemble the 10th car.
- the *total time* required to assemble the first 10 cars.
- the estimated *cumulative average* assembly time for the first 10 cars.

Solve by hand and by spreadsheet.



Solution by Hand

- From Equation (3-5), and assuming a proportional decrease in assembly time for output units between doubled quantities, we have

$$\begin{aligned} Z_{10} &= 100(10)^{\log 0.8 / \log 2} \\ &= 100(10)^{-0.322} \\ &= \frac{100}{2.099} = 47.6 \text{ hours.} \end{aligned}$$

- The total time to produce x units, T_x , is given by

$$T_x = \sum_{u=1}^x Z_u = \sum_{u=1}^x K(u^n) = K \sum_{u=1}^x u^n. \quad (3-6)$$

Using Equation (3-6), we see that

$$T_{10} = 100 \sum_{u=1}^{10} u^{-0.322} = 100[1^{-0.322} + 2^{-0.322} + \dots + 10^{-0.322}] = 631 \text{ hours.}$$

- The cumulative average time for x units, C_x , is given by

$$C_x = T_x/x. \quad (3-7)$$

Using Equation (3-7), we get

$$C_{10} = T_{10}/10 = 631/10 = 63.1 \text{ hours.}$$

Spreadsheet Solution

Figure 3-6 shows the spreadsheet solution for this example problem. For each unit number, the unit time to complete the assembly, the cumulative total time, and the cumulative average time are computed with the use of Equations (3-5),

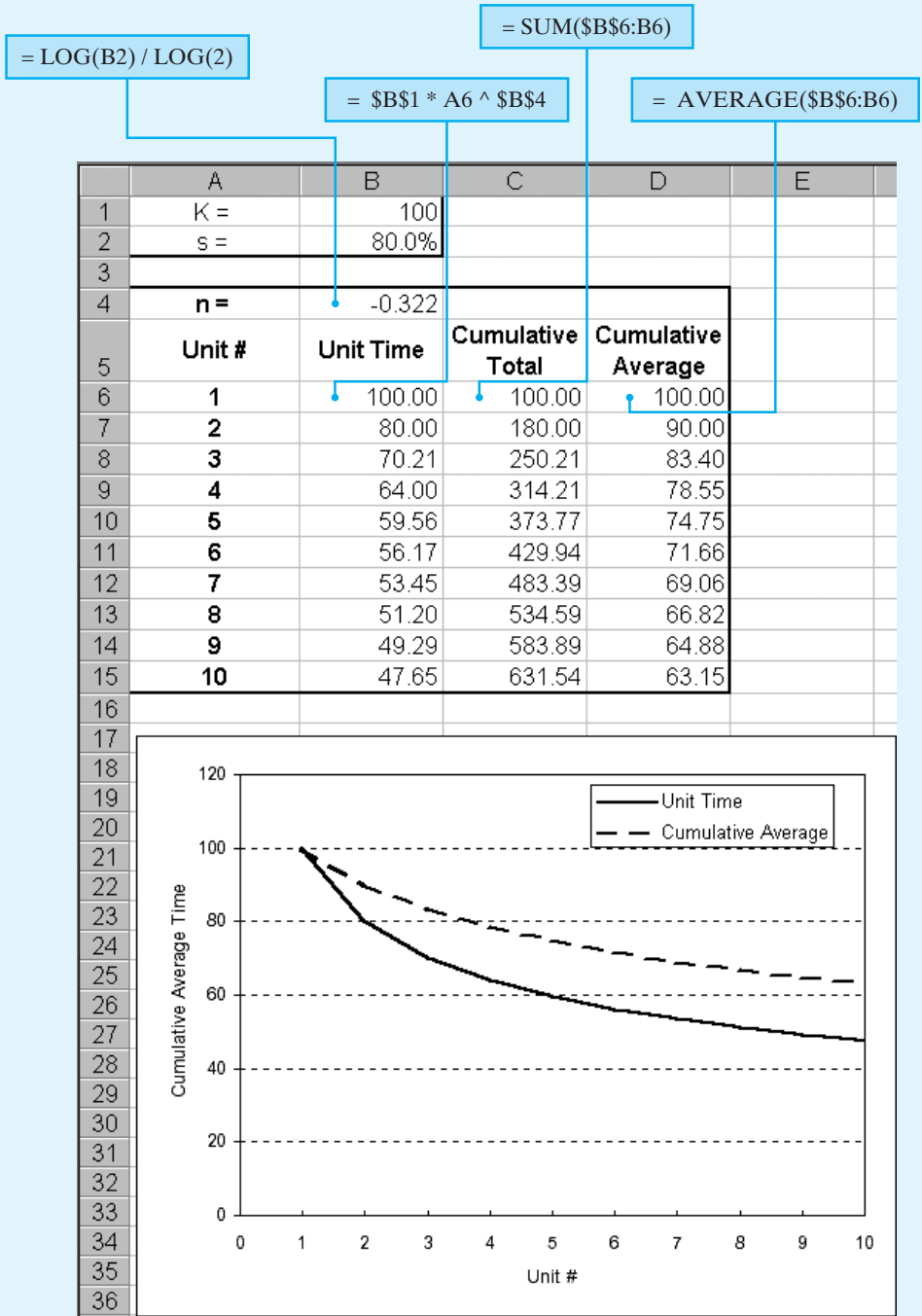


Figure 3-6 Spreadsheet Solution, Example 3-7

(3-6), and (3-7), respectively. Note that these formulas are entered once in row 6 of the spreadsheet and are then simply copied into rows 7 through 15.

A plot of unit time and cumulative average time is easily created with the spreadsheet software. This spreadsheet model can be used to examine the impact of a different learning slope parameter (e.g., $s = 90\%$) on predicted car assembly times by changing the value of cell B2.

3.4.3 Developing a Cost Estimating Relationship (CER)

A CER is a mathematical model that describes the cost of an engineering project as a function of one or more design variables. CERs are useful tools because they allow the estimator to develop a cost estimate quickly and easily. Furthermore, estimates can be made early in the design process before detailed information is available. As a result, engineers can use CERs to make early design decisions that are cost-effective in addition to meeting technical requirements.

There are four basic steps in developing a CER:

1. Problem definition
2. Data collection and normalization
3. CER equation development
4. Model validation and documentation

3.4.3.1 Problem Definition The first step in any engineering analysis is to define the problem to be addressed. A well-defined problem is much easier to solve. For the purposes of cost estimating, developing a WBS is an excellent way of describing the elements of the problem. A review of the completed WBS can also help identify potential cost drivers for the development of CERs.

3.4.3.2 Data Collection and Normalization The collection and normalization of data is the most critical step in the development of a CER. We're all familiar with the adage "garbage in—garbage out." Without reliable data, the cost estimates obtained by using the CER would be meaningless. The WBS is also helpful in the data collection phase. The WBS helps to organize the data and ensure that no elements are overlooked.

Data can be obtained from both internal and external sources. Costs of similar projects in the past are one source of data. Published cost information is another source of data. Once collected, data must be normalized to account for differences due to inflation, geographical location, labor rates, and so on. For example, cost indexes or the price inflation techniques to be described in Chapter 8 can be used to normalize costs that occurred at different times. Consistent definition of the data is another important part of the normalization process.

3.4.3.3 CER Equation Development The next step in the development of a CER is to formulate an equation that accurately captures the relationship between

TABLE 3-2 Typical Equation Forms

Type of Relationship	Generalized Equation
Linear	Cost = $b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \dots$
Power	Cost = $b_0 + b_1x_1^{b_{11}}x_2^{b_{12}} + \dots$
Logarithmic	Cost = $b_0 + b_1 \log(x_1) + b_2 \log(x_2) + b_3 \log(x_3) + \dots$
Exponential	Cost = $b_0 + b_1 \exp^{b_{11}x_1} + b_2 \exp^{b_{22}x_2} + \dots$

the selected cost driver(s) and project cost. Table 3-2 lists four general equation types commonly used in CER development. In these equations, b_0 , b_1 , b_2 , and b_3 are constants, while x_1 , x_2 , and x_3 represent design variables.

A simple, yet very effective, way to determine an appropriate equation form for the CER is to plot the data. If a plot of the data on regular graph paper appears to follow a straight line, then a linear relationship is suggested. If a curve is suggested, then try plotting the data on semilog or log-log paper. If a straight line results on semilog paper, then the relationship is logarithmic or exponential. If a straight line results on log-log paper, then the relationship is a power curve.

Once we have determined the basic equation form for the CER, the next step is to determine the values of the coefficients in the CER equation. The most common technique used to solve for the coefficient values is the method of least squares. Basically, this method seeks to determine a straight line through the data that minimizes the total deviation of the actual data from the predicted values. (The line itself represents the CER.) This method is relatively easy to apply manually and is also available in many commercial software packages. (Most spreadsheet packages are capable of performing a least-squares fit of data.) The primary requirement for the use of the least-squares method is a linear relationship between the independent variable (the cost driver) and the dependent variable (project cost).*

All of the equation forms presented in Table 3-2 can easily be transformed into a linear form. The following equations can be used to calculate the values of the coefficients b_0 and b_1 in the simple linear equation $y = b_0 + b_1x$:

$$b_1 = \frac{n \sum_{i=1}^n x_i y_i - \left(\sum_{i=1}^n x_i \right) \left(\sum_{i=1}^n y_i \right)}{n \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2}, \quad (3-8)$$

$$b_0 = \frac{\sum_{i=1}^n y_i - b_1 \sum_{i=1}^n x_i}{n}. \quad (3-9)$$

Note that the variable n in the foregoing equations is equal to the number of data sets used to estimate the values of b_0 and b_1 .

* In addition, the observations should be independent. The difference between predicted and actual values is assumed to be normally distributed with an expected value of zero. Furthermore, the variance of the dependent variable is assumed to be equal for each value of the independent variable.

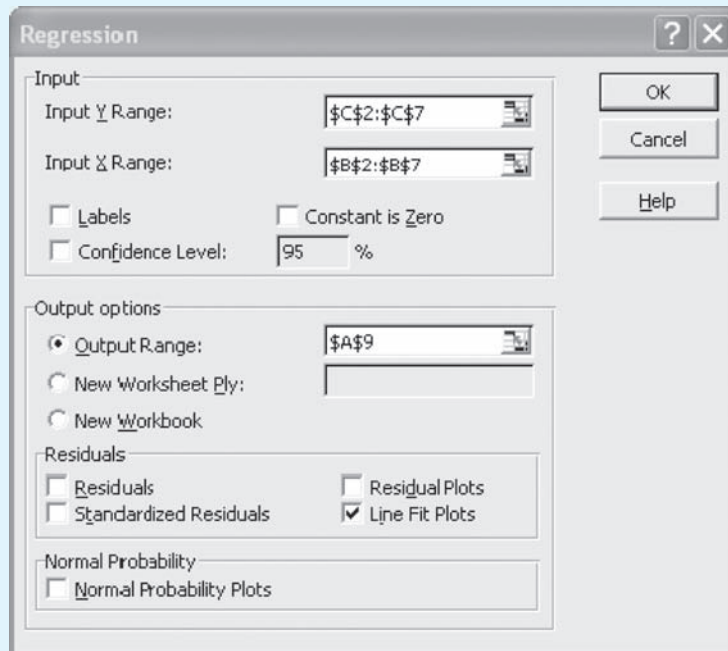
EXAMPLE 3-8 Cost Estimating Relationship (CER) for a Spacecraft

In the early stages of design, it is believed that the cost of a Martian rover spacecraft is related to its weight. Cost and weight data for six spacecraft have been collected and normalized and are shown in the next table. A plot of the data suggests a linear relationship. Use a spreadsheet model to determine the values of the coefficients for the CER.

Spacecraft i	Weight (lb) x_i	Cost (\$ million) y_i
1	400	278
2	530	414
3	750	557
4	900	689
5	1,130	740
6	1,200	851

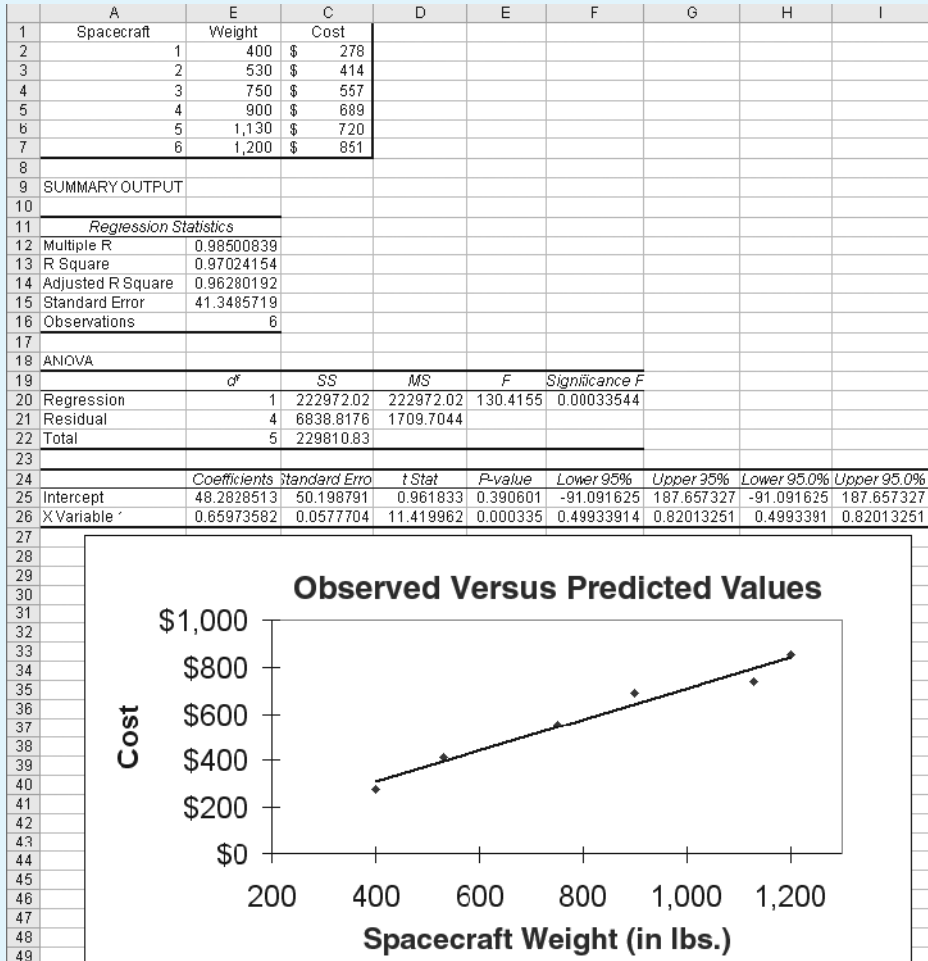
Spreadsheet Solution

Figure 3-7 displays the spreadsheet model for determining the coefficients of the CER. This example illustrates the basic regression features of Excel. No formulas



(a) Regression Dialog Box

Figure 3-7 Spreadsheet Solution, Example 3-8



(b) Regression Results

Figure 3-7 (continued)

are entered, only the cost and weight data for the spacecraft. The challenge in spreadsheet regression lies in making sure that the underlying regression assumptions are satisfied and in interpreting the output properly.

The *Tools | Data Analysis | Regression* menu command brings up the Regression dialog box shown in Figure 3-7(a) and shows the values used for this model. The results of the analysis are generated by Excel and are displayed beginning in cell A9 of Figure 3-7(b). For the purposes of this example, the coefficients b_0 and b_1 of the CER are found in cells B25 and B26, respectively.

The resulting CER relating spacecraft cost (in millions of dollars) to spacecraft weight is

$$\text{Cost} = 48.28 + 0.6597x,$$

where x represents the weight of the spacecraft in pounds, and $400 \leq x \leq 1,200$.

3.4.3.4 Model Validation and Documentation Once the CER equation has been developed, we need to determine how well the CER can predict cost (i.e., model validation) and document the development and appropriate use of the CER. Validation can be accomplished with statistical “goodness of fit” measures such as standard error and the correlation coefficient. Analysts must use goodness of fit measures to infer how well the CER predicts cost as a function of the selected cost driver(s). Documenting the development of the CER is important for future use of the CER. It is important to include in the documentation the data used to develop the CER and the procedures used for normalizing the data.

The standard error (SE) measures the average amount by which the actual cost values and the predicted cost values vary. The SE is calculated by

$$SE = \sqrt{\frac{\sum_{i=1}^n (y_i - \text{Cost}_i)^2}{n - 2}}, \quad (3-10)$$

where Cost_i is the cost predicted by using the CER with the independent variable values for data set i and y_i is the actual cost. A small value of SE is preferred.

The correlation coefficient (R) measures the closeness of the actual data points to the regression line ($y = b_0 + b_1x$). It is simply the ratio of explained deviation to total deviation.

$$R = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\left[\sum_{i=1}^n (x_i - \bar{x})^2 \right] \left[\sum_{i=1}^n (y_i - \bar{y})^2 \right]}}, \quad (3-11)$$

where $\bar{x} = \frac{1}{n} \sum_{i=1}^n x_i$ and $\bar{y} = \frac{1}{n} \sum_{i=1}^n y_i$. The sign (+/−) of R will be the same as the sign of the slope (b_1) of the regression line. Values of R close to one (or minus one) are desirable in that they indicate a strong linear relationship between the dependent and independent variables.

In cases where it is not clear which is the “best” cost driver to select or which equation form is best, you can use the goodness of fit measures to make a selection.

In general, all other things being equal, the CER with better goodness of fit measures should be selected.

EXAMPLE 3-9**Regression Statistics for the Spacecraft CER**

Determine the SE and the correlation coefficient for the CER developed in Example 3-8.

Solution

From the spreadsheet for Example 3-8 (Figure 3-7), we find that the SE is 41.35 (cell B15) and that the correlation coefficient is 0.985 (cell B12). The value of the correlation coefficient is close to one, indicating a strong positive linear relationship between the cost of the spacecraft and the spacecraft's weight.

In summary, CERs are useful for a number of reasons. First, given the required input data, they are quick and easy to use. Second, a CER usually requires very little detailed information, making it possible to use the CER early in the design process. Finally, a CER is an excellent predictor of cost if correctly developed from good historical data.

3.5 Cost Estimation in the Design Process

Today's companies are faced with the challenge of providing quality goods and services at competitive prices. The price of their product is based on the overall cost of making the item plus a built-in profit. To ensure that products can be sold at competitive prices, cost must be a major factor in the design of the product.

In this section, we will discuss both a *bottom-up* approach and a *top-down* approach to determining product costs and selling price. Used together with the concepts of target costing, design-to-cost, and value engineering, these techniques can assist engineers in the design of cost-effective systems and competitively priced products.

3.5.1 The Elements of Product Cost and "Bottom-Up" Estimating

As discussed in Chapter 2, product costs are classified as direct or indirect. Direct costs are easily assignable to a specific product, while indirect costs are not easily allocated to a certain product. For instance, direct labor would be the wages of a machine operator; indirect labor would be supervision.

Manufacturing costs have a distinct relationship to production volume in that they may be fixed, variable, or step-variable. Generally, administrative costs are fixed, regardless of volume; material costs vary directly with volume; and equipment cost is a step function of production level.

The primary costs within the manufacturing expense category include engineering and design, development costs, tooling, manufacturing labor,

materials, supervision, quality control, reliability and testing, packaging, plant overhead, general and administrative, distribution and marketing, financing, taxes, and insurance. Where do we start?

Major types of costs that must be estimated are as follows:

1. Tooling costs, which consist of repair and maintenance plus the cost of any new equipment.
2. Manufacturing labor costs, which are determined from standard data, historical records, or the accounting department. Learning curves are often used for estimating direct labor.
3. Materials costs, which can be obtained from historical records, vendor quotations, and the bill of materials. Scrap allowances must be included.
4. Supervision, which is a fixed cost based on the salaries of supervisory personnel.
5. Factory overhead, which includes utilities, maintenance, and repairs. As discussed in Chapter 2 and Appendix 2-A, there are various methods used to allocate overhead, such as in proportion to direct labor hours or machine hours.
6. General and administrative costs, which are sometimes included with the factory overhead.

A “bottom-up” procedure for estimating total product cost is commonly used by companies to help them make decisions about what to produce and how to price their products. The term “bottom-up” is used because the procedure requires estimates of cost elements at the lower levels of the cost structure, which are then added together to obtain the total cost of the product. The following simple example shows the general bottom-up procedure for making a per-unit product cost estimate and illustrates the use of a typical spreadsheet form of the cost structure for preparing the estimate.

The spreadsheet in Figure 3-8 shows the determination of the cost of a throttle assembly. Column A shows typical cost elements that contribute to total product cost. The list of cost elements can easily be modified to meet a company’s needs. This spreadsheet allows for per-unit estimates (column B), factor estimates (column C), and direct estimates (column D). The shaded rows are selected subtotals.

Typically, direct labor costs are estimated via the unit technique. The manufacturing process plan is used to estimate the total number of direct labor hours required per output unit. This quantity is then multiplied by the composite labor rate to obtain the total direct labor cost. In this example, 36.48 direct labor hours are required to produce 50 throttle assemblies and the composite labor rate is \$10.54 per hour, which yields a total direct labor cost of \$384.50.

Indirect costs, such as quality control and planning labor, are often allocated to individual products by using factor estimates. Estimates are obtained by expressing the cost as a percentage of another cost. In this example, planning labor and quality control are expressed as 12% and 11% of direct labor cost (row A), respectively. This gives a total labor cost of \$472.93. Factory overhead and general and administrative expenses are estimated as percentages of the total labor cost (row D).

Entries for cost elements for which direct estimates are available are placed in column D. The total production materials cost for the 50 throttle assemblies is

	Column A	Column B		Column C		Column D	Column E
		Unit Estimate		Factor Estimate		Direct	Row
		Unit	Cost/Unit	Factor	of Row	Estimate	Total
A:	Factory Labor	36.48	\$ 10.54				\$ 384.50
B:	Planning Labor			12%	A		46.14
C:	Quality Control			11%	A		42.29
D:	TOTAL LABOR						472.93
E:	Factory Overhead			105%	D		496.58
F:	General & Admin. Expense			15%	D		70.94
G:	Production Material					\$ 167.17	167.17
H:	Outside Manufacture					28.00	28.00
I:	SUBTOTAL						1,235.62
J:	Packing Costs			5%	I		61.78
K:	TOTAL DIRECT CHARGE						1,297.41
L:	Other Direct Charge			1%	K		12.97
M:	Facility Rental						--
N:	TOTAL MANUFACTURING COST						1,310.38
O:	Quantity (lot size)						50
P:	MANUFACTURING COST / UNIT						26.21
Q:	Profit/Fee			10%	P		2.62
R:	UNIT SELLING PRICE						\$ 28.83

Figure 3-8 Manufacturing Cost-Estimating Spreadsheet

\$167.17. A direct estimate of \$28.00 applies to the outside manufacture of required components. The subtotal of cost elements at this point is \$1,235.62.

Packing costs are estimated as 5% of all previous costs (row I), giving a total direct charge of \$1,297.41. The cost of other miscellaneous direct charges are figured in as 1% of the current subtotal (row K). This results in a total manufacturing cost of \$1,310.38 for the entire lot of 50 throttle assemblies. The manufacturing cost per assembly is $\$1,310.38/50 = \26.21 .

The price of a product is based on the overall cost of making the item plus a built-in profit. The bottom of the spreadsheet in Figure 3-8 shows the computation of unit selling price based on this strategy. In this example, the desired profit (often called the profit margin) is 10% of the unit manufacturing cost, which corresponds to a profit of \$2.62 per throttle assembly. The total selling price of a throttle assembly is then $\$26.21 + \$2.62 = \$28.83$.

3.5.2 Target Costing and Design to Cost: A “Top-Down” Approach

Traditionally, American firms determine an initial estimate of a new product’s selling price by using the bottom-up approach described in the previous section. That is, the estimated selling price is obtained by accumulating relevant fixed and variable costs and then adding a profit margin, which is a percentage of total manufacturing costs. This process is often termed *design to price*. The estimated selling price is then used by the marketing department to determine whether the new product can be sold.

In contrast, Japanese firms apply the concept of *target costing*, which is a top-down approach. The focus of target costing is “what *should* the product cost” instead of “what *does* the product cost.” The objective of target costing is to design costs

out of products before those products enter the manufacturing process. In this top-down approach, cost is viewed as an input to the design process, not as an outcome of it.

Target costing is initiated by conducting market surveys to determine the selling price of the best competitor's product. A target cost is obtained by deducting the desired profit from the best competitor's selling price:

$$\text{Target cost} = \text{Competitor's price} - \text{Desired profit.} \quad (3-12)$$

Desired profit is often expressed as a percentage of the total manufacturing cost, called the profit margin. For a specific profit margin (e.g., 10%), the target cost can be computed from the following equation:

$$\text{Target cost} = \frac{\text{Competitor's price}}{(1 + \text{Profit margin})}. \quad (3-13)$$

This target cost is obtained prior to the design of the product and is used as a goal for engineering design, procurement, and production.

EXAMPLE 3-10 Target Costing at the Throttle Assembly Plant

Recall the throttle assemblies discussed in the previous example. Suppose that a market survey has shown that the best competitor's selling price is \$27.50 per assembly. If a profit margin of 10% (based on total manufacturing cost) is desired, determine a target cost for the throttle assembly.

Solution

Since the desired profit has been expressed as a percentage of total manufacturing costs, we can use Equation (3-13) to determine the target cost:

$$\text{Target cost} = \frac{\$27.50}{(1 + 0.10)} = \$25.00.$$

Note that the total manufacturing cost calculated in Figure 3-8 was \$26.21 per assembly. Since this cost exceeds the target cost, a redesign of the product itself or of the manufacturing process is needed to achieve a competitive selling price.

Figure 3-9 illustrates the relationship between target costing and the design process. It is important to note that target costing takes place before the design process begins. Engineers use the target cost as a cost performance requirement. Now the final product must satisfy both technical and cost performance requirements. The practice of considering both cost performance as important as technical performance during the design process is termed *design to cost*. The design to cost procedure begins with the target cost as the cost goal for the entire product. This target cost is then broken down into cost goals for major subsystems, components, and subassemblies. These cost goals would cover targets for direct material costs and direct labor.

Once cost goals have been established, the preliminary engineering design process is initiated. Conventional tools, such as WBS and cost estimating, are

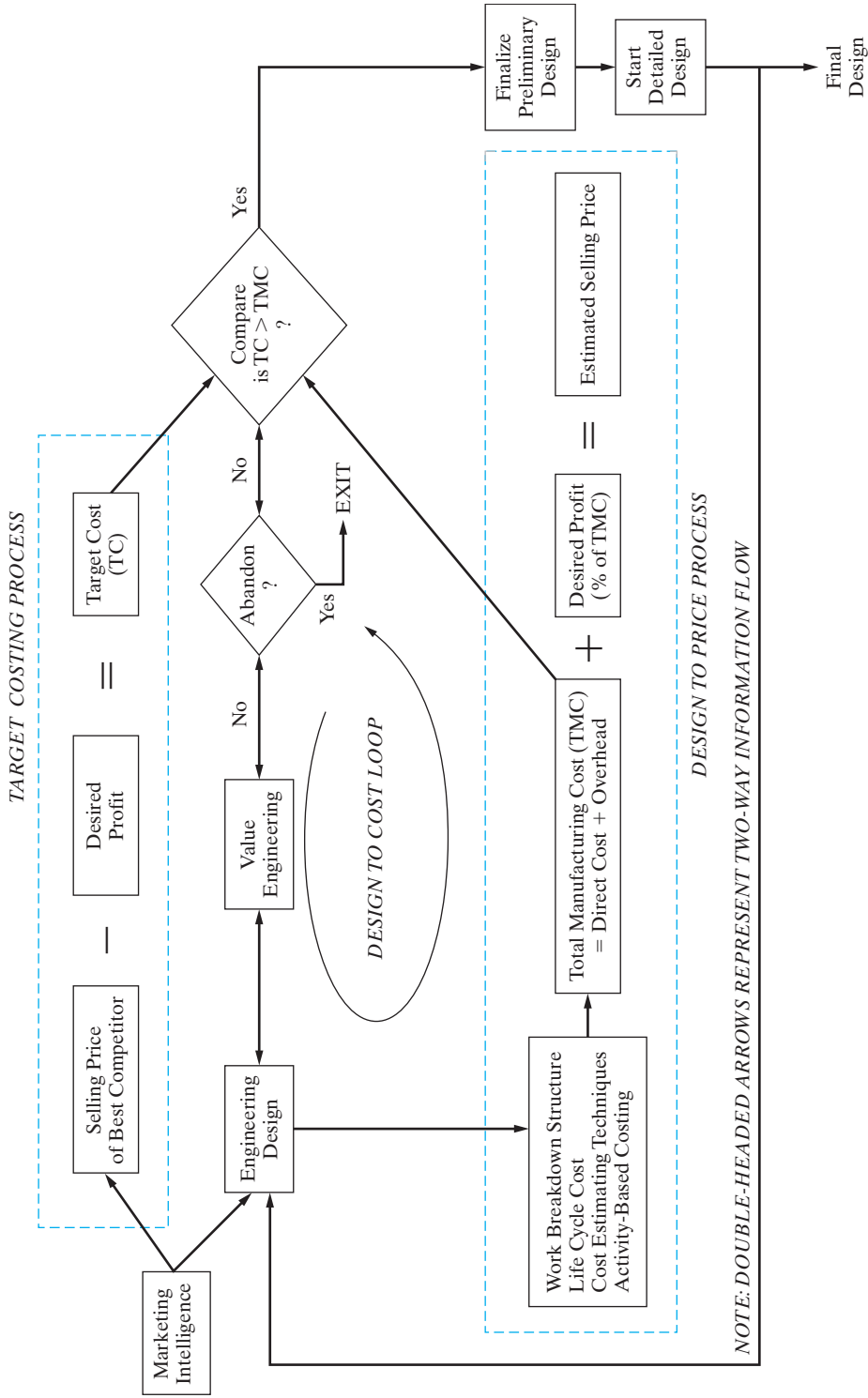


Figure 3-9 The Concept of Target Costing and Its Relationship to Design

used to prepare a bottom-up total manufacturing cost projection (discussed in the previous section). The total manufacturing cost represents an *initial* appraisal of what it would cost the firm to design and manufacture the product being considered. The total manufacturing cost is then compared with the top-down target cost. If the total manufacturing cost is more than the target cost, then the design must be fed back into the *value engineering process* (to be discussed in Section 3.5.3) to challenge the functionality of the design and attempt to reduce the cost of the design. This iterative process is a key feature of the design to cost procedure. If the total manufacturing cost can be made less than the target cost, the design process continues into detailed design, culminating in the final design to be produced. If the total manufacturing cost cannot be reduced to the target cost, the firm should seriously consider abandoning the product.

Figure 3-10 illustrates the use of the manufacturing cost-estimating spreadsheet to compute both a target cost and the cost reductions necessary to achieve the target cost. As computed in Example 3-10, the target cost for the throttle assembly is \$25.00. Since the initial total manufacturing cost (determined to be \$26.21 in Figure 3-8) is greater than the target cost, we must work backward from the total manufacturing cost, changing values of a chosen (single) cost element to the level required to reduce the cost to the desired target. This method of establishing new cost targets for individual elements can be accomplished by trial and error (manually manipulating the spreadsheet values) or by making use of the “solver” feature of the software package (if one is available). Figure 3-10 shows one possible result of this process. If the process of assembling the throttles could be made more efficient, such that

Column A	Column B		Column C		Column D	Column E
	Unit Estimate	Factor Estimate	Direct	Row		
MANUFACTURING COST ELEMENTS	Units	Cost/Unit	Factor	of Row	Estimate	Total
A: Factory labor	34.48	\$ 10.54				\$ 363.42
B: Planning labor			12%	A		43.61
C: Quality control			11%	A		39.98
D: TOTAL LABOR						447.01
E: Factory overhead			105%	D		469.36
F: General & admin. expense			15%	D		67.05
G: Production material					\$ 167.17	167.17
H: Outside manufacture					28.00	28.00
I: SUBTOTAL						1,178.58
J: Packing costs			5%	I		58.93
K: TOTAL DIRECT CHARGE						1,237.51
L: Other direct charge			1%	K		12.38
M: Facility rental						-
N: TOTAL MANUFACTURING COST						1,249.89
O: Quantity (lot size)						50
P: MANUFACTURING COST / UNIT						25.00
Competitor's selling price	\$ 27.50					
Desired return on sales	10%					
Target cost	\$ 25.00					

Figure 3-10 Manufacturing Cost Estimating and Target Costing

total direct labor requirements are reduced to 34.48 hours (instead of 36.48), the target cost could be realized. Now the challenge is to find a way, either through product or process redesign, to reduce the direct labor requirements.

EXAMPLE 3-11**Cost Goal for Production Material at the Throttle Assembly Plant**

Given the current estimated total manufacturing cost of \$26.21, as shown in Figure 3-8, determine a cost goal for production material that would allow us to achieve a target cost of \$25.00.

Solution

With the spreadsheet in Figure 3-8 as a starting point, one approach to determining a cost goal for production material would be to iteratively change the value entered in Row G and Column D until the desired total manufacturing cost of \$25.00 is obtained. The following table shows a series of costs for production material and the resulting total manufacturing cost per assembly:

Production Material Cost per 50 Assemblies (\$)	Total Manufacturing Cost per Assembly (\$)
167.17	26.21
150.00	25.84
140.00	25.63
130.00	25.42
120.00	25.21
110.00	25.00

As seen in the table, a production material cost of \$110 per batch of 50 assemblies would result in a total manufacturing cost of \$25.00, the target cost. Now it is left to design engineers to determine if a different, less costly material could be used or if process improvements could be made to reduce material scrap. Other possibilities would be to negotiate a new purchase price with the supplier of the material or seek a new supplier.

The chapter case study on the demanufacturing of computers illustrates the versatility of target costing concepts.

3.5.3 Value Engineering

This section introduces the topic of value engineering (VE). The objective of VE is very similar to that of design to cost. The VE objective is to provide the required product functions at a minimum cost. VE necessitates a detailed examination of a product's functions, and the cost of each, in addition to a

thorough review of product specifications. VE is performed by a team of specialists from a variety of disciplines (design, manufacturing, marketing, etc.), and the team focuses on determining the most cost-effective way to provide high value at an acceptable cost to the customer. VE is most appropriately applied early in the life cycle where there is more potential for cost savings. It is applied repeatedly during the design phase as new information becomes available. Note that, in Figure 3-9, the VE function appears within the design to cost loop and is a critical part of obtaining a total manufacturing cost that is less than the target cost.

The key to successful VE is to ask critical questions and seek creative answers. Table 3-3 lists some sample questions that should be included in a VE study. It is important to question everything and not take anything for granted. Cost-reduction opportunities are sometimes so simple that they get overlooked. Creative solutions can be obtained by using classical brainstorming or the Nominal Group Technique (discussed in Chapter 1). Alternatives that seem promising should be analyzed to determine if cost reduction is possible without compromising functionality. For example, many airlines today are looking for creative ways to reduce fuel costs. Some of these ways include using winglets, or upturned tabs on wingtips, to reduce air resistance when flying and to cut fuel costs. It has been estimated that winglets reduce fuel consumption by 5%. Airlines are also reducing their fuel reserves aboard aircraft, reducing aircraft weight by removing ovens on short flights on which hot meals are no longer served or by placing manuals on laptops for pilots, and reducing air speed. One airline estimates that it saved \$10.6 million a year without compromising safety by reducing fuel reserves on its transoceanic flights.

The examples that follow illustrate how VE has been used to obtain enhanced functionality and improved value. The redesign of the remote control console (for a TV/DVD) is a classic example of VE. In Figure 3-11, the product on the left looks more like a calculator than a remote control console. VE was used to identify many unnecessary functions that customers did not want and would not pay for. By eliminating these unwanted functions, we were able to cut significant production costs. The redesigned remote control on the right-hand side projects a highly simplified, user-friendly appearance. This design, therefore, enhances use value and esteem value even before considering the effect of production cost savings on the product's selling price.

TABLE 3-3 Value Engineering Checklist

Are all the functions provided required by the customer?	Are all the machined surfaces necessary?
Can less-expensive material be used?	Would product redesign eliminate a quality problem?
Can the number of different materials used be reduced?	Is the current level of packaging necessary?
Can the design be simplified to reduce the number of parts?	Can a part designed for another product be used?

Figure 3-11 Remote Control Consoles



3.6 CASE STUDY—Demanufacturing of Computers

Let's consider a case that deals with a timely important issue concerning environmental economics. What are companies to do with all of the old computers that typically accumulate at their facilities?

As one possible solution to this problem, a number of states and companies have jointly established "resource recovery" facilities to process the handling of old electronic equipment, such as used computers. Demanufacturing of computers involves disassembly, refurbishing, and either donating or reselling the units. However, there are some residuals, or remaining components, that cannot be reused, are harmful to the environment, and contribute to the cost of demanufacturing.

Let's consider the case of one resource recovery center in the Northeast that currently handles approximately 2,000 computers per year. Of these computers, approximately 50% are refurbished and donated, 40% are remanufactured and resold, and 10% are "residuals." What to do with the residuals is a challenging problem.

The facility currently has a contract with an outside source to take the monitors and CPUs. This leads to storage requirements in their facility, and there are issues concerning the determination of the optimal truckload capacity. The labor costs for the outside contractor are \$10.00 per unit, and transportation costs are \$1.70 per unit, for a total of \$11.70 per unit, based on a full capacity truck load.

The recovery facility is seeking an alternative solution to the handling of residuals. One alternative under consideration is to establish a method for demanufacturing of the computers that will consider the CPUs only, since there are environmental issues associated with computer monitors.

The recovery facility recently completed a work measurement study to develop a method for demanufacture of the CPUs. The method is as follows:

1. Remove fasteners or screws.
2. Remove metal casing.

3. Remove power and data cables from floppy drive.
4. Unfasten floppy drive.
5. Unfasten supporting bar.
6. Remove support and floppy drive.
7. Remove power and data cables from power supply.
8. Remove motherboard.
9. Unfasten and remove power supply.
10. Unfasten drive housing.
11. Remove rubber feet.

From the predetermined time study, it is determined that the demanufacturing rate is 7.35 minutes/unit. The facility uses an internal labor rate of \$12.00/hour, and it is estimated that training costs for the demanufacturing method will be 10% of total labor costs. Setup costs and transportation costs are estimated at 150% and 20% of total labor costs, respectively. The facility's goal is to demanufacture 200 units during regular operations. Determine the estimated cost per unit for the proposed demanufacturing method. What percentage reduction is this over the per unit cost of using the outside contractor?

Solution

As one possible solution, the industrial engineer performs the following calculations. For 200 units, the labor quantity is estimated as


$$7.35 \text{ minutes/unit} \times 200 \text{ units} = 1,470 \text{ minutes} = 24.5 \text{ hours.}$$

The engineer develops the cost template provided below:

Demanufacturing Cost Elements	Unit Elements		Factor Estimates		Row Total
	Units	Cost/Unit	Factor	of Row	
A: Factory labor	24.5 hrs	\$12.00/hr			\$294.00
B: Quality costs—Training			10%	A	\$29.40
C: Total Labor					\$323.40
D: Factory overhead—Setup costs			150%	C	\$485.10
E: Transportation cost			20%	C	\$64.68
F: Total Direct Charge					\$550.08
G: Facility rental					—
H: Total Demanufacturing Cost					\$873.48
I: Quantity—Lot size					200
J: Demanufacturing cost per unit					\$4.37
Outside cost per unit—Target cost	\$ 11.70				

The per unit cost of the proposed internal demanufacturing method is \$4.37, while the per unit cost of using the outside contractor (i.e., the target cost) is \$11.70. Should the proposed demanufacturing method be adopted, the estimated per unit

cost savings is \$7.33 for a 62.6% reduction over the per unit cost for the outside contractor.

This case illustrates that developing creative solutions for internal demanufacturing methods not only results in cost savings of approximately 63% from current practices for the case company, but proper demanufacturing methods will minimize the number of computer residuals entering the waste stream. What makes economic sense is also good for the environment! 

3.7 Summary

Developing the cash flow for each alternative in a study is a pivotal, and usually the most difficult, step in the engineering economic analysis procedure. An integrated approach for developing cash flows includes three major components: (1) a WBS definition of the project, (2) a cost and revenue structure that identifies all the cost and revenue elements involved in the study, and (3) estimating techniques (models).

Estimating techniques (models) are used to develop the cash flows for the alternatives as they are defined by the WBS. Thus, the estimating techniques form a bridge between the WBS and detailed cost and revenue data and the estimated cash flows for the alternatives.

The results of the cost-estimating process are a set of cash flows for a proposed engineering project. Since these cash flows will occur at different points in time over the life cycle of the project, Chapter 4 will demonstrate how to account for the time value of money in our analysis. Then, in Chapter 5, we will learn procedures for determining the profitability, or economic feasibility, of the proposed project.

Problems

The number in parentheses that follows each problem refers to the section from which the problem is taken.

3-1. Develop an estimate for the cost of washing and drying a 12-pound load of laundry. Remember to consider all the costs. Your time is worth nothing unless you have an opportunity to use it for making (or saving) money on other activities. (3.2)

3-2. You are planning to build a new home with approximately 2,000–2,500 gross square feet of living space on one floor. In addition, you are planning an attached two-car garage (with storage space) of approximately 450 gross square feet. Develop a cost and revenue structure for designing and constructing, operating (occupying) for 10 years, and then selling the home at the end of the 10th year. (3.2)

3-3. Estimate the cost of an oil change (5 quarts of oil) and a new oil filter for your automobile at a local service

station. It takes a technician 20 minutes to do this job. Compare your estimate with the actual cost of an oil change at the service station. What percent markup is being made by the service station? (3.3)

3-4. A large electric utility company spews 62 million tons of greenhouse gases (mostly carbon dioxide) into the environment each year. This company has committed to spending \$1.2 billion in capital over the next five years to reduce its annual emissions by 5%. More will be spent after five years to reduce greenhouse gases further. (3.3)

- a. What is the implicit cost of a ton of greenhouse gas?
- b. If the United States produces 3 billion tons of greenhouse gases per year, how much capital must be spent to reduce total emissions by 3% over the next five years based on your answer in Part (a)?

3-5. The proposed small office building in Example 3-2 has 24,000 net square feet of area heated by a natural gas furnace. The owner of the building wants to know the approximate cost of heating the structure from October through March (six months) because she will lease heated space to the building's occupants. During the heating season, the building will require roughly 60,000 Btu per square foot of heated area. Natural gas has 1,000 Btu per cubic foot, and natural gas costs \$9.00 per thousand cubic foot. What will the owner pay to heat her building? (3.3)

3-6. An electric power distributor charges residential customers \$0.10 per kilowatt-hour (kWh). The company advertises that "green power" is available in 150 kWh blocks for an additional \$4 per month. (Green power is generated from solar, wind power, and methane sources.) (3.3)

- If a certain customer uses an average of 400 kWh per month and commits to one monthly 150 kWh block of green power, what is her annual power bill?
- What is the average cost per kWh with green power during the year?
- Why does green power cost more than conventional power?

3-7. Suppose that your brother-in-law has decided to start a company that produces synthetic lawns for senior homeowners. He anticipates starting production in 18 months. In estimating future cash flows of the company, which of the following items would be relatively easy versus relatively difficult to obtain? Also, suggest how each might be estimated with reasonable accuracy. (3.2)

- Cost of land for a 10,000-square-foot building.
- Cost of the building (cinder block construction).
- Initial working capital.
- Total capital investment cost.
- First year's labor and material costs.
- First year's sales revenues.

3-8. Transportation equipment that was purchased in 2004 for \$200,000 must be replaced at the end of 2009. What is the estimated cost of the replacement, based on the following equipment cost index? (3.3)

Year	Index	Year	Index
2004	223	2007	257
2005	238	2008	279
2006	247	2009	293

3-9. Prepare a composite (weighted) index for housing construction costs in 2008, using the following data: (3.3)

Type of Housing	Percent	Reference year (I = 100)	2008
Single Units	70	41	} \$/ft ² 57 } \$/ft ² 53 }
Duplex Units	5	38	
Multiple	25	33	

3-10. A microbrewery was built in 2004 at a total cost of \$650,000. Additional information is given in the accompanying table (all 2000 indices = 100). (3.3)

Cost Element	Average Percentage of Total Brewery Cost	Index (2004)	Index (2008)
Labor	30	160	200
Materials	20	145	175
Equipment	50	135	162

- Calculate a weighted index for microbrewery construction in 2008.
- Prepare a budget estimate for a microbrewery in 2008.

3-11. The purchase price of a natural gas-fired commercial boiler (capacity X) was \$181,000 eight years ago. Another boiler of the same basic design, except with capacity 1.42X, is currently being considered for purchase. If it is purchased, some optional features presently costing \$28,000 would be added for your application. If the cost index was 162 for this type of equipment when the capacity X boiler was purchased and is 221 now, and the applicable cost capacity factor is 0.8, what is your estimate of the purchase price for the new boiler? (3.3, 3.4)

3-12. The manufacturer of commercial jets has a cost index equal to 94.9 per aircraft in 2005. The anticipated cost index for the airplane in 2010

is 106.8. The average compound rate of growth should hold steady for the next 15 years. If an aircraft costs \$10.2 million to build in 2006, what is its expected cost in 2008? State your assumptions. (3.3)

3-13. Six years ago, an 80-kW diesel electric set cost \$160,000. The cost index for this class of equipment six years ago was 187 and is now 194. The cost-capacity factor is 0.6. (3.4)

- a. The plant engineering staff is considering a 120-kW unit of the same general design to power a small isolated plant. Assume we want to add a precompressor, which (when isolated and estimated separately) currently costs \$18,000. Determine the total cost of the 120-kW unit.
- b. Estimate the cost of a 40-kW unit of the same general design. Include the cost of the \$18,000 precompressor.

3-14. In a new 55-and-over gated community, light poles and underground cables need to be installed. It is estimated that 25 miles of underground cabling will be needed and that each mile of cabling costs \$15,000 (includes labor). A light pole is to be installed every 50 yards, on average, and the cost of the pole and installation is \$2,500. What is the estimated cost for the entire job? (3.4)

3-15. In a building construction project, 7,500 feet of insulated ductwork is required. The ductwork is made from 14-gauge steel costing \$8.50 per pound. The 24-inch-diameter duct weighs 15 pounds per foot. Insulation for the ductwork costs \$10 per foot. Engineering design will cost \$16,000, and labor to install the ductwork will amount to \$180,000. What is the total cost of the installed ductwork for this project? (3.3)

3-16. Four hundred pounds of copper go into a 2,000-square-foot, newly constructed house. Today's price of copper is \$3.50 per pound. If the cost of copper is expected to increase 4.5% per year into the foreseeable future, what is the cost of copper going to be in a new 2,400 square foot house 10 years from now. Assume the cost capacity factor for increases of copper in houses equals 1.0. (3.4)

3-17. The structural engineering design section within the engineering department of a regional electrical utility corporation has developed several standard designs for a group of similar transmission line towers. The detailed design for each tower is based on one of the

standard designs. A transmission line project involving 50 towers has been approved. The estimated number of engineering hours needed to accomplish the first detailed tower design is 126. Assuming a 95% learning curve,

- a. What is your estimate of the number of engineering hours needed to design the eighth tower and to design the last tower in the project?
- b. What is your estimate of the cumulative average hours required for the first five designs? (3.4)

3-18. The overhead costs for a company are presently \$X per month. The management team of the company, in cooperation with the employees, is ready to implement a comprehensive improvement program to reduce these costs. If you (a) consider an observation of actual overhead costs for one month analogous to an output unit, (b) estimate the overhead costs for the first month of program implementation to be 1.15X due to extra front-end effort, and (c) consider a 90% improvement curve applicable to the situation, what is your estimate of the percentage reduction in present overhead costs per month after 30 months of program implementation? (3.4)

3-19. In a learning curve application, 846.2 work-hours are required for the third production unit and 783.0 work-hours are required for the fifth production unit. Determine the value of n (and therefore s) in Equation (3-5). (3.4)

3-20. You have been asked to estimate the cost of 100 prefabricated structures to be sold to a local school district. Each structure provides 1,000 square feet of floor space, with 8-foot ceilings. In 1999, you produced 70 similar structures consisting of the same materials and having the same ceiling height, but each provided only 800 square feet of floor space. The material cost for each structure was \$25,000 in 1999, and the cost capacity factor is 0.65. The cost index values for 1999 and 2006 are 200 and 289, respectively. The estimated manufacturing cost for the first 1,000-square-foot structure is \$12,000. Assume a learning curve of 88% and use the cost of the 50th structure as your standard time for estimating manufacturing cost. Estimate the total material cost and the total manufacturing cost for the 100 prefabricated structures. (3.3, 3.4)

3-21. The cost of building a supermarket is related to the total area of the building. Data for the last 10

supermarkets built for Regork, Inc., are shown in the accompanying table.

Building	Area (ft ²)	Cost (\$)
1	14,500	800,000
2	15,000	825,000
3	17,000	875,000
4	18,500	972,000
5	20,400	1,074,000
6	21,000	1,250,000
7	25,000	1,307,000
8	26,750	1,534,000
9	28,000	1,475,500
10	30,000	1,525,000

- a. Develop a CER for the construction of supermarkets. Use the CER to estimate the cost of Regork’s next store, which has a planned area of 23,000 square feet. (3.4)
- b. Compute the standard error and correlation coefficient for the CER developed in Part (a). (3.4)

3-22. In the packaging department of a large aircraft parts distributor, a fairly reliable estimate of packaging and processing costs can be determined by knowing the weight of an order. Thus, the weight is a cost driver that accounts for a sizable fraction of the packaging and processing costs at this company. Data for the past 10 orders are given as follows: (3.4)

Packaging and Processing Costs (\$), <i>y</i>	Weight (Pounds), <i>x</i>
97	230
109	280
88	210
86	190
123	320
114	300
112	280
102	260
107	270
86	190

- a. Estimate the b_0 and b_1 coefficients, and determine the linear regression equation to fit these data.

- b. What is the correlation coefficient (R)?
- c. If an order weighs 250 lb, how much should it cost to package and process it?

3-23. Using the costing worksheet provided in this chapter (Figure 3-8), estimate the unit cost and selling price of manufacturing metal wire cutters in lots of 100 when these data have been obtained: (3.5)

Factory (direct) labor:	4.2 hours at \$11.15/hour
Factory overhead:	150% of factory labor
Outside manufacture:	\$74.87
Production material:	\$26.20
Packing costs:	7% of factory labor
Desired profit:	12% of total manufacturing cost

3-24. You have been asked to estimate the per unit selling price of a new line of clothing. Pertinent data are as follows:

Direct labor rate:	\$15.00 per hour
Production material:	\$375 per 100 items
Factory overhead:	125% of direct labor
Packing costs:	75% of direct labor
Desired profit:	20% of total manufacturing cost

Past experience has shown that an 80% learning curve applies to the labor required for producing these items. The time to complete the first item has been estimated to be 1.76 hours. Use the estimated time to complete the 50th item as your standard time for the purpose of estimating the unit selling price. (3.4, 3.5)

3-25. An electronics manufacturing company is planning to introduce a new product in the market. The best competitor sells a similar product at \$420/unit. Other pertinent data are as follows:

Direct labor cost:	\$15.00/hour
Factory overhead:	120% of direct labor
Production materials:	\$300/unit
Packaging costs:	20% of direct labor

It has been found that an 85% learning curve applies to the labor required. The time to complete the first unit has been estimated to be 5.26 hours. The company decides to use the time required to complete the 20th unit as a standard for cost estimation purposes. The profit margin is based on the total manufacturing costs.

- a. Using the information given, determine the maximum profit margin that the company can have so as to remain competitive. (3.4, 3.5)

TABLE P3-29 Table for Problem 3-29

Equipment	Reference Size	Unit Reference Cost	Cost-Capacity Factors	New Design Size
Two boilers	6 MW	\$300,000	0.80	10 MW
Two generators	6 MW	400,000	0.60	9 MW
Tank	80,000 gal	106,000	0.66	91,500 gal

- b. If the company desires a profit margin of 15%, can the target cost be achieved? If not, suggest two ways in which the target cost can be achieved.

3-26. Given the following information, how many units must be sold to achieve a profit of \$25,000? [Note that the units sold must account for total production costs (direct and overhead) plus desired profit.] (3.4, 3.5)

Direct labor hours:	0.2 hour/unit
Direct labor costs:	\$21.00/hour
Direct materials cost:	\$4.00/unit
Overhead costs:	120% of direct labor
Packaging and shipping:	\$1.20/unit
Selling price:	\$20.00/unit

3-27. Today a proposed community college is estimated to cost \$34.6 million, which is \$127 per square foot of space multiplied by 272,310 square feet. If construction costs are expected to increase by 19% per year because of high demand for construction labor and materials, how much would a 320,000-square-foot community college cost five years from now? The cost capacity factor is 1.0. (3.3)

3-28. Your FICO score is a commonly used measure of credit risk (see www.myfico.com). A score of 850 is the best (highest) score possible. Thirty-five percent of the FICO score is based on payment history for credit cards, car loans, home mortgages, and so on. Suppose your current FICO score is 720 and you have just missed a credit card payment due date and have incurred a late-payment fee! If your FICO score will drop 10% in the “payment history” category because of the late payment on your credit card, what is your new FICO score? (3.3)

3-29. A small plant has been constructed and the costs are known. A new plant is to be estimated with the use of the exponential (power sizing) costing model. Major equipment, costs, and factors are as shown in Table P3-29. (Note MW = 10⁶ Watts.)

If ancillary equipment will cost an additional \$200,000, find the cost for the proposed plant. (3.4)

3-30. If 1,702.5 labor hours are required for the first production unit and 873.0 labor hours are required for the fifth production unit, determine the learning curve parameter s . (3.4)

Spreadsheet Exercises

3-31. Refer to Example 3-7. Construct a graph to show how the time to complete the 10th car changes as the learning curve slope parameter is varied from 75% to 95%. (3.4)

3-32. The Betterbilt Construction Company designs and builds residential mobile homes. The company is ready to construct, in sequence, 16 new homes of 2,400 square feet each. The successful bid for the construction materials in the first home is \$64,800, or \$27 per square foot. The purchasing manager believes that several actions can be taken to reduce material costs by 8% each time the number of homes constructed doubles. Based on this information,

- a. What is the estimated cumulative average material cost per square foot for the first five homes?

- b. What is the estimated material cost per square foot for the last (16th) home? (3.4)

3-33. Refer to Example 3-8. While cleaning out an old file, someone uncovers the first spacecraft manufactured by your company—30 years ago! It weighed 100 pounds and cost \$600. Extend the spreadsheet to include this data point. How does adding this observation affect R and the standard error? How about the regression coefficients? Should this new data point be included in the model used for predicting future costs? (3.4)

3-34. Refer to the throttle assembly problem described in Section 3.5.1. For a target cost of \$25.00, determine a production material cost goal for the throttle assembly. (3.5)

Case Study Exercises

3-35. What other cost factors might you include in such an economic analysis? (3.6)

3-36. What cost factor is the per unit demanufacturing cost most sensitive to and why? (3.6)

3-37. What is the projected impact on the per unit demanufacturing cost of a 50% increase in training costs coupled with a 90% increase in transportation costs? What is the revised cost reduction percentage? (3.6)

FE Practice Problems

3-38. Find the average time per unit required to produce the first 30 units, if the slope parameter of the learning rate is 92% and the first unit takes 460 hours.

- (a) $-3.30693E-11$ (b) 305.5404 (c) 245
(d) 347.3211

3-39. A student is considering the purchase of two alternative cars. Car A initially costs \$1,500 more than Car B, but uses 0.05 gallons per mile, versus 0.07 gallons per mile for Car B. Both cars will last for 10 years, and B's market value is \$800 less than A's. Fuel costs \$3.00 per gallon. If all else is equal, at how many miles driven per year does Car A become preferable to Car B?

- (a) 1,167 (b) 1,723 (c) 1,892
(d) 2,243

3-40. An automatic process controller will eliminate the current manual control operation. Annual cost of the current method is \$4,000. If the controller has a service life of 13 years and an expected market value of 11% of the first cost, what is the maximum economical price for the controller? Ignore interest.

- (a) \$28,869 (b) \$58,426 (c) \$26,358
(d) \$25,694 (e) \$53,344

3-41. A foreman supervises A, B, and eight other employees. The foreman states that he spends twice as much time supervising A and half as much time supervising B, compared with the average time spent supervising his other subordinates. All employees have the same production rate. On the basis of equal cost per unit production, what monthly salary is justified for B if the foreman gets \$3,800 per month and A gets \$3,000 per month?

- (a) \$3,543 (b) \$3,800 (c) \$3,000
(d) \$2,457 (e) \$3,400

3-42. A car rental agency is considering a modification in its oil change procedure. Currently, it uses a Type X filter, which costs \$5 and must be changed every 7,000 miles along with the oil (5 quarts). Between each oil change, one quart of oil must be added after each 1,000 miles. The proposed filter (Type Y) has to be replaced every 5,000 miles (along with 5 quarts of oil) but does not require any additional oil between filter changes. If the oil costs \$1.08 per quart, what is the maximum acceptable price for the Type Y filter?

- (a) \$12.56 (b) \$7.43 (c) \$11.48
(d) \$6.66