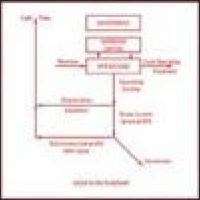
PROCESS ENGINEERING ECONOMICS



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PROCESS ENGINEERING ECONOMICS

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Preface

I have found through many years of experience in industry and academe that engineers, after having been promoted in the managerial ranks, are confronted with economic and financial terminology with which they are not familiar. Although in their education they may have encountered some of the principles presented in this text in engineering economics or business college courses, these courses, in general, do not include the broad coverage of topics presented herein. Some technical people will attempt to muddle through, not understanding which information is essential for management decisions. To accommodate this lack of understanding, some engineers have pursued night courses or on-line or self-study correspondence courses in accounting, finance, economics, cost estimation, and others in order to improve their qualifications for promotion.

This book was written to provide a fundamental understanding of these economic topics in one volume. It is designed to provide the engineer with the necessary tools and pertinent references for each of the topics. The text may be used by students enrolled in a two- or three-semester-hour, senior-level process engineering economics or process design course. Chapters 3 through 10 may be used for a two-semester-hour course. For a three-hour course, it is suggested that all the chapters be covered. The book may also be used as a text for continuing-education courses or as a self-study text for practicing engineers who feel they need to have a better understanding of engineering economics. The text contains information of interest to all plant managerial personnel in manufacturing, maintenance, or general management positions.

As may be seen from the table of contents, the material in this book moves from accounting and financial reports to cost estimating—of both capital costs and operating expenses—to economic analysis through time value of money, cash flow, depreciation, and taxes, and ultimately to profitability measures. For example in Chapter 4, "Estimation of Capital Requirements," there is a section on sizing equipment, which is an important step in obtaining equipment costs. To assist in sizing equipment, rules of thumb have been included in Appendix B. The depreciation rules are the latest as of manuscript preparation. Sensitivity and uncertainty analysis are presented in simplified form based on errors in forecasting and are treated from a practical industrial standpoint. A feasibility-analysis case study is presented to illustrate the combination of all the foregoing techniques. Chapter 12, "Choice Between Alternatives and Replacement," and Chapter 13, "The Economic Balance," will be of particular interest to design and plant engineering groups. The emphasis in these chapters is on the engineering trade-offs. The book includes the "traditional" time-tested techniques as well as "new" economy techniques where appropriate. At the end of each chapter are practice problems.

The English system of units was used throughout this book, since most of the major chemical, petroleum, petrochemical companies, and equipment manufacturers in the United States use the English system.

Appendix A is a glossary of terms used throughout the text. Rules of thumb for preliminary sizing of process equipment are found in Appendix B. Equipment costs in algorithm rather than graphical format are presented in Appendix C, thus eliminating the need for graphs. Also, the algorithm format is adaptable to computer programs for estimating capital costs.

The late Vincent W. Uhl encouraged me to join him in the presentation of continuing-education courses, the content of which ultimately led to the topics in this book. I acknowledge the advice and encouragement of two colleagues, Professor Jim Turpin and Professor W. Roy Penney of the University of Arkansas. I also express appreciation to my wife, Mary, for her patience, counsel, and advice in the preparation of this manuscript.

James R. Couper

Contents

1

Introduction

Economics is ever present in our lives because we earn money from our jobs and we spend money allocated by our personal budgets for housing, clothing, transportation, entertainment, etc. We spend money for these items based upon the perceived economic utility. Further, economics is the engine that drives industry.

Chemical engineering students in their formal education devote most of their efforts to the study of science and technology, including courses in chemistry, physics, mathematics, thermodynamics, kinetics, transport theory, unit operations, and design. The student learns how to utilize various physical phenomena in the design and operation of chemical plants. To function in industry today, the chemical engineer must understand and be able to apply more than just science and technology. Unlike many of the subjects studied in the chemical engineering curriculum, economics is not a science. In fact, it is more art than science but there are certain definitions, techniques, and principles that must be understood to use economics in a correct manner. The engineer must apply this entire body of knowledge to accomplish something of benefit to society.

Chemical engineering students in accredited programs take courses such as those shown in Figure 1.1, beginning in the lower right-hand corner of the triangular diagram with the technical/scientific courses [1]. As the student progresses in the program, basic chemical engineering courses cited in the previous paragraph are studied, culminating in the capstone process design course. Engineering students take at least one engineering economics course besides the classical economics course in business schools. Students may wish to

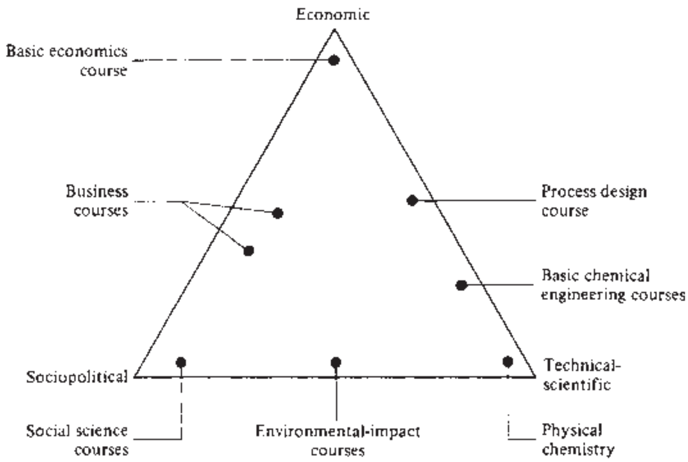

FIGURE 1.1 Decisive factors and university courses.

take other business courses such as accounting and finance to increase their knowledge of business. Of particular importance today are the humanities courses with special emphasis on the sociopolitical issues that form a basis for understanding political, environmental, health, and safety issues. These courses are important and give insights to chemical engineering students, helping them to appreciate the economic constraints affecting the application of technology that management encounters in making decisions about future projects.

Chemical engineers in the performance of their jobs will employ economics in the preparation of capital cost estimates, operating expense estimates, profitability analyses including the time value of money, feasibility studies, and to perform sensitivity and uncertainty analyses considering many alternatives. To move up the management ladder, they must have a working knowledge of balance sheets, income statements, and financial analyses of a corporate venture. This fundamental information in annual reports is covered in this text.

In the development of an industrial project, economics plays a significant role at various stages as the project progresses. Initially, an idea or need for the manufacture of a product may originate from customers, marketing, or research personnel. The development of the project is a team effort involving research and development, marketing, manufacturing, engineering, and management. Research and development and engineering personnel will evaluate the idea with thermodynamic and kinetic appraisals of the proposed process to determine if the product can be made in reasonable quantities and rates. Small amounts of the product may be made for customers to evaluate the product. If the product seems promising, crude estimates of the capital required and the operating expenses may be made. If on the other hand, this process is not feasible at this stage, it may be abandoned or alternate processes may be considered. As the number of technical alternatives are developed, economic issues become dominant. Some of these may be the availability and prices of equipment, sources of raw materials, plant size, etc. to determine which alternative is most efficient in the utilization of resources. Let's assume that the original idea seemed to be promising. A preliminary economic study of capital costs, operating expenses, and profitability will be prepared. Simultaneously, marketing personnel will conduct a domestic and global market survey to determine potential sales volume. The results are reported to management and if they are promising, large-scale laboratory or pilot plant studies are performed to obtain the required process engineering data for the proposed plant. Marketing needs to be involved at every stage in the development of the project, so further marketing information including potential price structure, competition, and share of the market is gathered. Again, if the results are not favorable, the project may be abandoned or recycled back to a previous step for further study. If the project appears to be feasible, then more detailed process engineering data, capital costs, operating expenses and market data are obtained to prepare a request for an appropriation to do definitive or detailed engineering. Once the appropriation meeting the criteria for a capital expenditure has been approved, the detailed engineering begins. Again there is the possibility that the economics may not be attractive and the project may be curtailed or recycled back to a previous step. It is apparent from the above project description that the overall procedure is an iterative one.

In today's economy many companies outsource the detailed engineering to consulting-design-engineering firms who have the dedicated staffs to perform these tasks, as many chemical companies do not have large numbers of personnel required due to downsizing. It should be pointed out that engineers continually monitor costs and economics at every stage of a project, including detailed design, construction, and startup of the facility. Once the unit comes on stream and the plant has been turned over to operating personnel for routine operation, economics are very important since the company is now committed to the process. The final step may be to fine-tune the process by making necessary process and plant improvements as more is learned during initial production.

At the initial stages of a project, there is a tendency to be optimistic about markets, product prices, capital costs, operating expenses, cash flow, and profitability. As the project proceeds through the various stages of development, the costs tend to escalate and the returns diminish. Of approximately, 100 project ideas, perhaps 2 of them may become operating plants.

Figure 1.2 depicts a typical career path irrespective of whether it is with one or several companies. A chemical engineer in the early years of a career is primarily concerned with the technical aspects of an assignment, but economics

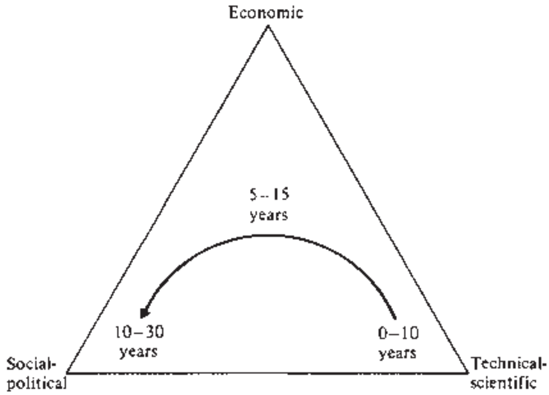

FIGURE 1.2 A typical career path.

quickly enters the picture. As a person enters the first level of management, 0–10 years, he or she is confronted with unfamiliar terminology used by corporate executives. A company's set of jargon is often foreign to a new employee. These new terms are confusing to a person whose experience has been in the engineering or scientific realm. As the young engineer advances up the corporate ladder, in perhaps 5–10 years, economics and financial matters play a significant role in his or her career. Further, the young engineer soon realizes the importance of marketing information and how that information may alter an investment decision. The chemical engineer in performance of the job will employ economics in the preparation of capital cost and operating expense estimates, profitability analyses including the time value of money, feasibility studies, and perhaps simple optimization studies. Further, there will be a need to understand balance sheets and income statements. The engineer, after 10–20 years, may move up to an upper-level managerial position in which the main requirements will necessitate the handling of personnel, economic, and sociopolitical issues. To learn the economics and financial terminology is not difficult, but the effective application of the information contained in this text takes time and experience. Economics underlies decisions in all these areas.

The chemical professional needs to master certain skills for a sucessful management career. This person should be able to read, analyze, perform, and comprehend financial reports to understand how management views a rational basis for decisions [2]. In addition to the classical approach to profitability, the new economy approach and terminology, e.g., value added (VA), economic value added (EVA), and market value added (MVA), are presented.

The fundamentals of process engineering economics are the focus of the material in this text. The book was written with the senior-level undergraduate student in mind and the contents are based upon pragmatic application of economics. The text also may be useful to the experienced engineer who needs a review or as a continuing education course text.

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2

Financing the Corporate Venture

Prior to World War I, most companies were small in comparison to companies today. They were often owned and operated by the founders [1]. The capital expenditures were for replacement of obsolete or worn-out equipment, or perhaps for modest plant expansions. The funds for these expenditures were, for the most part, obtained from company earnings.

Between World War I and II, industrial growth took place with plant acquisitions or mergers with other firms. Since these were often major expenditures, internal funds were not sufficient to meet company needs. Established companies, like Du Pont and Eastman, that in the past had relied on internally generated funds were forced to examine their policy in order to replace equipment and grow. External funding sources had to be obtained and the sources were banks, insurance companies, and investment banking houses.

In the period after World War II, growth was one of the management goals. For companies to maintain a regular dividend policy, external funding for ventures had to be sought. In very recent times, with the mergers, acquisitions, joint ventures, and alliances, and interest in megadollar projects, external sources were the only option for large-scale projects. Cash generated from internal sources alone could not begin to fund the capital-intensive projects.

2.1 BUSINESS PLANS

The planning function is essential for the growth of a successful, vigorous company. Two of the most important areas of management responsibilities are capital budgeting and planning. Committees within the firm are formed to plan for the future and prepare capital budgets.

A business plan must be developed before any funds are sought for a new product or venture. The capital budgeting function may be divided into several categories depending upon the time frame involved [1,2].

- Strategic planning involves setting the goals, objectives, and broad business plans for a 5- to 10-year time period in the future.
- Tactical planning involves the detailing of the strategic planning for say 2–5 years in the future.
- Capital budgeting involves a request, analysis, and approval of expenditures for the coming year.

Business plans minimally consist of the following information along with a projected timetable:

- Perceived goals and objectives of the company
- Market data
    - Projected share of the market
    - Market prices
    - Market growth
    - Markets the company serves
    - Competition, both domestic and global
    - Project and/or product life
- Capital requirements
    - Fixed capital investment
    - Working capital
    - Other capital requirements
- Operating expenses
    - Manufacturing expenses
    - Sales expenses
    - General overhead expenses
- Profitability
    - Profit after taxes
    - Cash Flow
    - Payout period
    - Rate of return
    - Returns on equity and assets
    - Economic value added
- Projected risk
    - Effect of changes in revenue
    - Effect of changes in direct and indirect expenses
    - Effect of cost of capital
    - Effect of potential changes in market competition

- Project life
  Estimated life cycle of the product or venture

The business plan is then submitted to the source of capital funding, e.g., investment banks, insurance companies.

2.2 SOURCES OF FUNDS

The funding available for corporate ventures may be obtained from internal or external sources.

2.2.1 Internal Sources

The capital from internal sources is from retained earnings or from an allowance known as *reserves*. Internal financing is "owned" capital, and it is argued that it could be loaned or invested in other ventures to receive a given return. In determining the cost of owned capital, interest to be paid on this capital is equal to the present return on all the company's capital [1–3].

2.2.1.1 Retained Earnings

Retained earnings of a company are the difference between the after-tax earnings and the dividends paid to stockholders. If a firm plans no growth, then theoretically all the after-tax earnings could be distributed as dividends to the stockholders. Management would not do this. The company retains a certain part of the profits, and a part is paid to the stockholders as dividends. That part retained may be used for research and development expenditures or for capital projects [1].

2.2.1.2 Reserves

Earlier in this section, reserves were mentioned as a possible source for internally generated funds. The reserves are to provide for depreciation, depletion, and obsolescence. Deprecation reserves seldom cover the replacement costs of equipment because improved technology results in more expensive, sophisticated equipment. Also, inflation severely cuts into reserves. Therefore, with the necessity of providing for dividends to stockholders and to purchase equipment, it is essential to seek external funding [1].

2.2.2 External Sources

There are three sources of external financing: *debt, preferred stock,* and *common stock*. These sources vary widely with respect to the cost and the risk the company assumes with each of these financing sources. The cheapest form of capital is the least risky. A general rule is the riskier the project, the safer should be the type of financing the capital used. A new venture with modest capital requirements could be funded by common stock. In contrast, a well-established business area may be financed by debt.

2.2.2.1 Debt

For discussion purposes, debt may be classified arbitrarily as follows:

Current debt—maturing up to 1 year
Intermediate debt—maturing between 1 and 10 years
Long-term debt—maturing beyond 10 years

2.2.2.1.1 Current Debt. Let's consider this case: A company has the opportunity of purchasing a raw material at a low price, but the company doesn't have ready cash. The company wants to pay off the debt in 90–120 days. There are three options available. First, it could be obtained from a bank by means of a *commercial loan* [1].

As an alternate, if the company has a good line of credit, it could borrow the money in the open market. It would draw a note to the order of the bearer of the note and have it discounted by a dealer in this type of note or by the purchaser of the note. This type of borrowing is a negotiable note known as *commercial paper*.

A third method is through what is known as *open-market paper* or *banker's acceptance*. If a raw material is to be purchased from a single source, the company could sign a 90-day draft on its own bank paid to the order of the vendor. The company will pay a commission to its own bank to accept in writing the draft and the company has an unconditional obligation to pay the full amount on the maturity date. Many chemical companies use this form of the 90-day note to the financial institution.

2.2.2.1.2 Intermediate Debt. This form of debt is retired in 1–10 years. This is usually the smallest form of debt based on the total debt. There are three types of intermediate debt, namely, *deferred-payment contract*, *revolving credit*, and *term loans*.

In the deferred-payment contract, the borrower signs a note that specifies a series of payments are to be made on a time schedule over a period of time, perhaps 5 or 10 years. This type of debt may be used for the purchase of equipment, the title of which rests with the note holder until the debt is retired. Institutional investors, banks, and insurance companies are examples of typical lenders.

Revolving credit is an agreement in which the lender agrees to loan a company an amount of money for a specified time period. A commission or fee is paid on the unused portion of the total credit. Banks usually are the lenders.

This form of credit is often used to purchase raw materials on a spot basis and for variable or recurring demands for funds for a specified time period. It is not intended to be a long-term loan. The duration of these agreements are of the order of 1–5 years [1].

Term loans are divided into installments that are due at specified maturity dates that may be as long as 10 years. There are a variety of arrangements that can be made, such as monthly, quarterly, semiannual, or annual payments. These obligations may be paid off prior to maturity, both with and without penalties, depending on how the agreement is drawn. Large commercial banks and insurance companies are typical lenders [1,2].

2.2.2.1.3 Long-Term Debt. Bonds or long-term notes are examples of this type debt. They are special kinds of promissory notes and are negotiable certificates that are issued at par values of $1000. They are securities promising to pay a certain amount of interest every 6 months for a number of years until the bond matures. There are four types of bonds in the market, namely, *mortgage, debenture, income*, and *convertible bonds* [1,2,4].

Mortgage bonds are backed by specific pledged assets that may be claimed if the terms of the indebtness are not met and particularly if the company issuing the bonds goes out of business. Utilities and railroads often use this type of debt.

Debenture bonds are only a general claim on the assets of a company. This type of bond is usually preferred by companies because it is not secured by specific assets but by the future earning power of the company and allows the company to buy and sell manufacturing facilities without being tied to specific assets.

Income bonds are different from other forms of long-term debt in that a company is obligated to pay no more of the interest charges that have accrued in a certain period than were actually earned in that period. These types of bonds find use when a company has, to recapitalize after bankruptcy and the company has uncertain earning power.

Convertible bonds are hybrids. In periods of inflation, an investor may become wary of putting funds in bonds that merely repay the principal in dollars that have deteriorated in purchasing power. To tempt the investor back into bonds, corporations resort to convertible bonds. If inflation sends stocks upward, one can convert the bonds to stocks and protect the rea purchasing power of the principal. In periods of low inflation or deflation, bonds are safe investments but in periods of inflation, stocks reflect the inflationary trend so that purchasing power may be retained.

2.2.2.2 Stockholders' Equity

This is the total equity interest that stockholders have in a corporation. There are two broad classes of equity: *preferred stock* and *common stock*. There may be several classes or types of each of these shares issued by a corporation and they have different attributes.

2.2.2.2.1 Preferred Stock. The word "preferred" means that these stockholders receive their dividends before common stockholders. In the event of company liquidation, preferred stockholders will recover funds from the company assets before common stockholders. Preferred stockholders generally have no vote in company affairs. Most preferred shares are issued by the company at a par value of $100 at a stated dividend rate, say 7%. This means that each shareholder is entitled to a $7 dividend when dividends are paid to stockholders. Most preferred stock offered today is *cumulative*, which means that if in any year no dividends are paid, the dividends accumulate in favor of the preferred stockholders. The cumulative dividends must be paid before any common stockholders receive dividends [1,4].

There is also a *convertible preferred stock* offered by companies. This stock, like a convertible bond, carries for a stated period of time the privilege of converting preferred stock to common stock. Usually, convertible preferred stock pays a lower dividend than preferred stock [4].

2.2.2.2.2 Common Stock. The holders of common stock are the source of venture capital for a corporation. As such, they are at the greatest risk because they are the last to receive dividends for the use of their money. When the company grows and flourishes and the earnings are high, they receive the greatest benefits in the form of dividends. An added feature is that the common stockholder has a voice in company affairs at the company annual meetings [1,2,4].

Venture capital firms fund start-up companies in return for common stock that someday might be offered as an initial public offering (IPO) that may be worth a lot of money. In some cases the venture capitalists seek positions in the start-up company. Normally, a venture capital firm doesn't put money in a firm and watch from afar to see what happens to the young firm. These firms are likely to stay active in the firm until the IPO is offered [5].

2.3 DEBT VERSUS EQUITY FINANCING

Various options for obtaining funds to finance capital projects were presented in Section 2.2. Top-level management is confronted with how a venture will be funded, considering the costs and risks involved. The capital requirements may vary from millions to billions of dollars.

The final decision is a complex one and significant questions must be addressed. For example, what is the state of the economy? Is it growing, static, or declining? What is the company's cost of capital, i.e., the cost of borrowing from all sources? What is the current level of indebtedness? Should the company incur more long-term indebtedness or should it seek venture capital through the issuance of stock? The answers to these questions are not simple [1].

A company must consider its position with respect to leverage. Does the company have a large proportion of its debt in bonds or preferred stock? If so, the common stock is said to be highly leveraged. If earnings decline by say 10%, this could wipe out dividends to the common stockholders. The company might also not be able to cover interest on bonds without using accumulated retained earnings. There is a great danger when companies have a high debt/equity ratio illustrating a weakness of companies with an unusually high ratio. Many capital-intensive industries like chemicals, petroleum, steel, etc. have ratios of 2 or 3 to 1. The danger is that they may be confronted with liquidating some of their assets to survive. On the other hand, if the ratio is of the order of 1 to 1, this strategy increases the chance of a takeover and does affect the stock price.

The strategies for financing a venture depend on a number of factors, some of which may have a synergistic effect and have to be evaluated from the standpoint of what is best for the company. A company must attempt to maintain a debt/equity ratio similar to successful companies in the same line of business.

2.4 CONCLUDING REMARKS

The largest holders of corporate securities are "institutional" investors. These include insurance companies; educational, philanthropic, religious organizations; and pension funds. These organizations may purchase securities as all or part of a new stock issue in what is called "private" placement or in contrast may purchase securities on the open market as initial public offerings (IPO).

There are many excellent texts on the subject of corporate finance as well as courses in business schools on this topic. In this chapter, the focus was to present general types of financing a venture available to corporations.

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3

Financial Statements

Some basic knowledge of accounting and financial statements is necessary for a chemical professional to be able to analyze a firm's operations, discover whether the firm is making a profit and whether a company will continue to make a profit. It is also essential to know how a firm's operation is reported to determine its role in a particular industry or in the national economy. Financial reports of a company are important sources of data used by management, owners, creditors, investment bankers, and financial analysts. Also, local and state governments and the federal government are interested in the information for tax purposes.

There are differences of opinion concerning how much information about the bookkeeping process an engineer should know to understand accounting reports and financial statements which would greatly enhance his or her knowledge of the company. He or she interfaces with the accounting department in the budgeting and control function, in the operation of a department, and in some instances, with input and feedback during stages of design and construction of facilities. Further, a general knowledge of accounting allows the engineer to communicate with accountants, financial personnel, and managers. Also, accounting records provide a source of historical information from actual projects that may be of value to the chemical professional in developing estimates.

The conventions governing accounting are fairly simple but their detailed application may be complex, requiring years of study and experience. In this chapter, it is the intent to acquaint the reader with the basic concepts of accounting and financial reporting by using simple examples and by analyzing a typical balance sheet and income statement from a company's annual report.

Accounting systems have as input business transactions in the form of receipts and invoices. These events are entered chronologically in a *journal* and

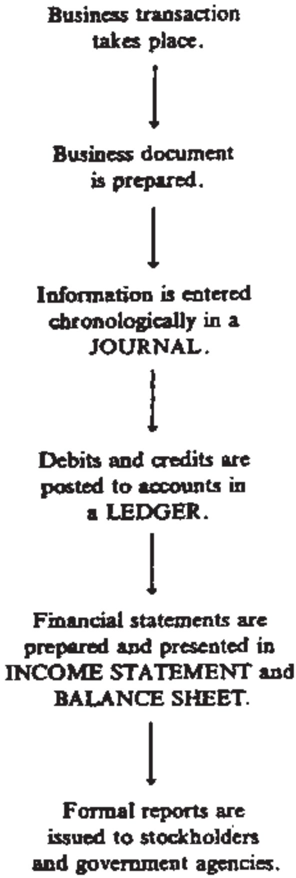

FIGURE 3.1 Flow of information through an accounting system.

are then classified and posted in an appropriate account in a *ledger*. Periodically, perhaps once a month but at least once a year, the accounts are closed and a summary is issued as an *income statement* and a *balance sheet*. An informational flow diagram is shown in Figure 3.1 [1–3].

3.1 ACCOUNTING CONCEPTS AND CONVENTIONS

There are a number of accounting texts which may be consulted for concepts of accounting and definitions [2,3].

3.1.1 The Accounting Equation

Accounting methods in use today had their origin in the 14th century in Italy. Fibonacci introduced the dual-aspect concept and the Medicis made the system more efficient. Their work led to the *double-entry bookkeeping* system, expressed as follows in simplest terms:

$$\text{Assets} = \text{Equities}$$

Assets are the economic resources a company owns and which are expected to benefit future operations. Assets are items of value and may be tangible, such as equipment, buildings, furniture, or intangible, like franchises, patents, trademarks. *Equities* are claims against the firm and may be divided into liabilities and owners' equity. The above equation then may be modified as follows:

$$\text{Assets} = \text{Liabilities} + \text{Owners' equity}$$

Liabilities are outside claims against the assets of a firm, e.g., accounts payable, borrowed funds, taxes owed. These obligations require settlement in the future. If liabilities are deducted from the assets, the difference is the amount belonging to the firm's owners, i.e., stockholders, and is called *owners' equity*.

Any transaction that takes place causes changes in the accounting equation. An increase in assets must be accompanied by one of the following:

- Increase in liabilities (e.g., money borrowed to purchase equipment)
- Increase in stockholders' equity
- Decrease in assets (perhaps money taken out of cash to purchase equipment; in this case, total assets do not change but there is a change in the distribution of the assets)

A change in one part of the equation due to an economic transaction must be accompanied by an equal change in another place—hence the term *double-entry bookkeeping*.

3.1.2 Debits and Credits

Whenever economic events occur, the accounting equation changes and the events are recorded in books. The left side of the account book page has been arbitrarily designated the *debit* side, and the right side the *credit* side. This convention is true regardless of the type of account.

3.1.3 Data Recording

Accounting today is performed by entering data into a computer using software packages to record, manipulate, and classify data. The accounting equation, business transactions, debits and credits, account books, journal and ledger information are all part of the modern accounting system.

3.1.4 The General Ledger

All transactions are recorded chronologically in a *general journal* similar to that shown in Table 3.1. The date of the transaction is shown in the first column. An account title and brief description of the transaction are found in the second column. The ledger page of each transaction is placed in the third column and serves as a cross-reference between the general journal and the various ledger accounts. The numbers in the column indicate the account to which the debit or credit has been transferred. The amount of each debit and credit entry is listed in the next two columns.

3.1.5 The Ledger

Journal entries are transferred to a ledger, a process called *posting*. Separate ledger accounts may be set up for each major type of transaction, such as asset account, liability account, revenue account, expense account. The number of ledger accounts depends on the information management needs to make decisions. Each debit entry to a ledger account is matched by a credit entry to another account. There is a one-to-one correspondence between journal entries and ledger entries—hence the term *double-entry bookkeeping*. The ledger page (LP) is the cross-reference.

Periodically, perhaps on a monthly basis but certainly on a yearly basis, the ledger sheets are closed and balanced. The ledger sheets are used as intermediate documents between journal records and balance sheets, income statements, retained earning statements, and provide information for various government reports. For example, a consolidated income statement can be prepared from the ledger revenue and expense accounts. From the asset and liability accounts, a company's balance sheet is prepared. Table 3.2 is the ledger obtained from the general journal, Table 3.1.

3.2 JOURNAL AND LEDGER EXAMPLE

The basic concepts of accounting are illustrated by the following simple example. The example illustrates the flow of information depicted in Figure 3.1.

On January 1, 20XX, three people agreed to start a business to manufacture a specialty solvent, Nusolv. Anderson, Burns, and Carter named the company Nuchem, Inc. and their contributions to the venture were:

Anderson: $5000 cash
Burns: $5000 cash
Carter: Basic process development information, a small reactor, and mixing vessels in addition to some raw materials

TABLE 3.1 Nuchem, Inc.: Page 1 of General Journal

Date	Account titles and explanation	LP[a]	Debit	Credit
1/1	Cash	10	5000	
	Stockholders' equity	50		5000
	Capital invested by Armstrong			
1/1	Cash	10	5000	
	Stockholders' equity	50		5000
	Capital invested by Bigelow			
1/1	Raw materials	11	1000	
	Stockholders' equity	50		1000
	Raw materials from Custer			
1/1	Equipment	12	3000	
	Stockholders' equity	50		3000
	Reactor and mixing vessels from Custer			

[a] The ledger page (LP) column is used as a cross-reference between the general journal and the various ledger accounts. The number in the column indicates the account to which the debit or credit has been transferred.

TABLE 3.2 Nuchem, Inc.: Ledger

Date		JP[a]	Debit	Credit
Asset accounts[b]				
1/1	Cash (10)	1	5,000	
			5,000	
	Ending balance		10,000	
1/1	Raw materials account (11)	1	1,000	
	Ending balance		1,000	
1/1	Equipment account (12)	1	3,000	
	Ending balance		3,000	
Liability accounts				
1/1	Stockholders' equity (50)	1		5,000
		1		5,000
		1		1,000
		1		3,000
	Ending balance			14,000

[a] Journal page.
[b] Ledger pages in parentheses.

The three decided to distribute 1000 shares of stock as follows:

Anderson: 300 shares
Burns: 300 shares
Carter: 400 shares

All these initial transactions are recorded in a general ledger similar to the one shown in Table 3.1. Note that each transaction appears twice, once as a credit and once as a debit.

A ledger, Table 3.2, was set up containing the necessary accounts to record the transactions of January 1, 20XX. The number of accounts in the ledger depends on the information required by management to make decisions. Initially, Nuchem, Inc. required only asset and liability accounts; however, as the firm grew, more accounts were established as necessary to record business transactions.

Table 3.3 is an illustration of how information from the general ledger and the ledger accounts was used to prepare a consolidated balance sheet. During the month of January, manufacturing began, so new asset and liability accounts were created to accommodate the new type of transactions. The general journal, Table 3.4, reflects the debits and credits with appropriate explanations and ledger page entries. For example, on January 26, there was a transfer of assets, namely, the transfer of $5000 in raw materials to $5000 of finished goods.

Temporary revenue and expense accounts are used to classify changes affecting stockholders' equity. Expense accounts, legal expense (40), depreciation expense (41), and interest expense (42) were created. A revenue account was not needed in January because there was no income. These accounts are used to prepare an income statement. The balance of revenue and expense accounts is reduced to zero through an *income summary* account at the end of the month. Table 3.4 is the general journal for the month of January and Table 3.5 is the corresponding ledger. A consolidated income statement, Table 3.6, is developed from income and expense accounts. Note that this statement reflects no income and that there was a loss of $1045 during that month. Table 3.7 is the consolidated

TABLE 3.3 Nuchem, Inc.: Consolidated Balance Sheet as of January 1, 20XX

Assets		Liabilities and stockholders' equity	
Cash (10)	$10,000	Current liabilities	$0
Inventory (raw materials) (11)	1,000	Stockholders' equity	
Plant and equipment (12)	3,000	(50)	$14,000
	$14,000		$14,000

TABLE 3.4 Nuchem, Inc.: Page 2 of General Journal

Date	Account titles and explanation	LP	Debit	Credit
1/3	Legal expense	40	1,000	
	Cash	10		1,000
	Paid lawyer to set up corporation			
1/4	Finished goods	14	1,000	
	Accrued wages payable	22		1,000
	Hired Davis as production labor and promised to pay him $1000 on 2/1[a]			
1/4	Prepared expenses	15	2,000	
	Cash	10		2,000
	Cash down payment on equipment to be delivered later			
1/10	Raw materials	11	10,000	
	Cash	10		4,000
	Accounts payable	24		6,000
	Purchased raw materials, paid $4000, balance of $6000 due in February			
1/17	Cash	10	2,000	
	Bank loan	21		2,000
	Obtained year loan from bank, interest at 12% per year			
1/26	Finished goods	14	5,000	
	Raw materials	11		5,000
	5000 liters of Nusolv manufactured using $5000 of raw materials[b]			
Adjusting entries				
1/31	Depreciation expense: Equipment	41	25	
	Equipment	12		25
	$3000 × 1/10 × 1/12 = $25 per month			
1/31	Interest expense	42	20	
	Interest payable	23		20
	To record bank loan interest for January			
1/31	Income summary	55	1,045	
	Legal expense	40		1,000
	Depreciation expense: equipment	41		25
	interest expense	42		20
	To close the expense and revenue accounts for the period			
1/31	Stockholder's equity	50	1,045	
	Income summary	55		1,045
	To close the income summary and transfer the gain (or loss) to the equity account			

[a] Notice from 1/26 entry that we have now in the inventory 5000 liters of Nusolv, incorporating $1000 of labor and $5000 of raw materials.

[b] Given the costs of labor (see 1/4 entry), inventory value of this batch of Nusolv is $6000/(5000 liters) or $1.20/liter.

TABLE 3.5 Nuchem, Inc.: Ledger

Date			JP	Debit	Credit
Asset accounts					
	Cash (10)				
1/1	Starting balance		1	10,000	
1/3			2		1,000
1/4			2		2,000
1/10			2		4,000
1/17			2	2,000	
		Ending balance		5,000	
	Raw materials (11)				
1/1	Starting balance		1	1,000	
1/10			2	10,000	
1/26			2		5,000
		Ending balance		6,000	
	Equipment (12)				
1/1	Starting balance		1	3,000	
1/31			2		25
		Ending balance		2,975	
	Finished goods (14)				
1/1	Starting balance			0	
1/4			2	1,000	
1/26			2	5,000	
		Ending balance		6,000	
	Prepaid expenses (15)				
1/1	Starting balance			0	
1/4			2	2,000	
		Ending balance		2,000	
Liability accounts					
	Bank loan (21)				
1/1	Starting balance				0
1/17			2		2,000
		Ending balance			2,000
	Accrued wages payable (22)				
1/1	Starting balance				0
1/4			2		1,000
		Ending balance			1,000
	Interest payable (23)				
1/1	Starting balance				0
1/30			2		20
		Ending balance			20

Table 3.5 Continued

Date		JP	Debit	Credit
	Accounts payable (24)			
1/1	Starting balance			0
1/10		2		6,000
	Ending balance			6,000
	Stockholder's equity (50)			
1/1	Starting balance	1		14,000
1/31		2	1,045	
	Ending balance			12,955
Expense accounts				
	Legal expense (40)			
1/1	Starting balance		0	
1/3		2	1,000	
1/31		2		1,000
	Ending balance		0	
	Depreciation expense: equipment (41)			
1/1	Starting balance		0	
1/31		2	25	
1/31		2		25
	Ending balance		0	
	Interest expense (42)			
1/1	Starting balance		0	
1/31		2	20	
1/31		2		20
	Ending balance		0	
	Income summary (55)			
1/1	Starting balance			0
1/31		2	1,000	
1/31		2	25	
1/31		2	20	
1/31		2		1,045
	Ending balance			0

balance sheet as of February 1, 20XX. If this balance sheet is compared with the January 1, 20XX sheet (Table 3.3), it will be noted that the stockholders' equity decreased on the February statement by $1045, reflecting the loss during January.

The same procedure is followed for each succeeding month with each transaction being entered in the general journal and then posted to the appropriate ledger account. At the end of February, an income statement and balance sheet may be prepared. In this manner, information for an annual report is assembled.

TABLE 3.6 Nuchem, Inc.: Consolidated Income Statement, January 1–31, 20XX

Revenue	$0
Legal expenses	$1000
Depreciation expense: equipment	25
Interest expense	20
Earnings (loss)	($1045)

Today, transactions are entered into a computer program, ledger accounts are assigned, and the data are manipulated electronically. Manual ledgers are no longer kept in modern business firms.

Up to this point in this chapter, "traditional" cost/managerial accounting has been presented. In the past, traditional methods helped finance departments to monitor operations and value inventory, but some people felt that this approach did not provide an accurate picture of a company's costs but focused more on direct costs and relied on arbitrary cost allocations such as labor-based overhead rates [4].

In the late 1980s with the restructuring and downsizing of companies, new management tools were introduced. With these new tools, new accounting concepts were developed [4]. One of these new accounting systems is believed to provide useful information about direct and indirect expenses of a production unit or a service, provide tracking cost-contributing activities as well as separating and identifying value-added activities from non-value-added ones that contribute to current expenses. Major corporations in the United States are using this system and proponents believe that it will allow managers to make better decisions about

TABLE 3.7 Nuchem, Inc.: Consolidated Balance Sheet, February 1, 20XX

Assets		Liabilities and stockholders' equity	
Cash (10)	$ 5,000	Accrued wages (22)	$ 1,000
Prepaid expense (15)	2,000	Short-term borrowing:	
Inventory:		Accounts payable (24)	6,000
Raw materials (11)	6,000	Bank loan (21)	2,000
Finished goods (14)	6,000	Interest payable (23)	20
Plant and equipment (12)	2,975	Total liabilities	$ 9,020
		Stockholders' equity	$12,955
Total assets	$21,975	Total liabilities and stockholders' equity	$21,975

what products and services to offer and what are the "real" expenses. This approach may affect how accounting information is handled and perhaps alter company financial reporting. It will be interesting to see how traditional accounting will withstand the test of time.

3.3 FINANCIAL REPORTS

A financial report, sometimes called an *annual report*, contains a large amount of information and is designed to tell the reader how well a company performed in the previous year and how this performance compared with various standards. An annual report for a fictitious company, Archem, Inc., will be used to explain the terminology and construction of a balance sheet, an income statement, and a retained earnings statement.

The contents of a financial report may be classified into three distinct parts. The written part, mostly prose, is cast in simple language although there may be some words or phrases new to the reader; financial jargon will be discussed in this chapter. In this section of the report, activities for all company divisions are presented, including any new ventures as well as old ones discontinued or sold to other companies. There will also be statements regarding how the company is meeting environmental, safety, health, and product liability problems. The purpose of these statements is to demonstrate that the company is a good citizen. Photographs, which comprise another part of the report, augment the prose and show what equipment, buildings, plants, and company personnel do for the company. The third part contains the financial figures that are usually the most difficult part of the report for the average reader to comprehend.

Footnotes, which are referenced and included with the financial figures, are one of the most important parts of the third section. When reading a financial report, one should always read these footnotes because they explain from where the numbers are derived. Although the style of a financial report has changed through the years, these three major sections have remained intact.

A financial report contains two significant documents—the *balance sheet* and the *income statement*. Two ancillary documents are the *accumulated retained earnings* and the *changes in working capital*. In some annual reports, the accumulated retained earnings are included in the *statement of consolidated stockholders' equity*. All four documents will be discussed in the following sections and it would be advisable to have Tables 3.8 and 3.9 available as one reads the subsequent sections.

3.3.1 The Balance Sheet

The balance sheet represents the financial status of a company on a particular date. The date frequently used is December 31 of any given year, although some

TABLE 3.8 Archem, Inc.: Consolidated Balance Sheet as of December 31[a]

Assets	200X	2000
Current assets		
Cash	$ 63,000	$51,000
Marketable securities	41,000	39,000
Accounts receivable[b]	135,000	126,000
Inventories	149,000	153,000
Prepaid expenses	3,200	2,500
Total current assets	$391,200	$371,500
Fixed assets		
Land	35,000	35,000
Buildings	101,000	97,500
Machinery	278,000	221,000
Office equipment	24,000	19,000
Total fixed assets	$438,000	$372,500
Less accumulated depreciation	128,000	102,000
Net fixed assets	$310,000	$270,500
Intangibles	4,500	4,500
Total assets	$705,700	$ 646,500

Liabilities	200X	2000
Current liabilities		
Accounts payable	$ 92,300	$ 81,300
Notes payable	67,500	59,500
Accrued expenses payable	23,200	26,300
Federal income taxes payable	18,500	17,500
Total current liabilities	$201,500	$184,600
Long-term liabilities		
Debenture bonds, 10.3% due in 2015	110,000	110,000
Debenture bonds, 11.5% due in 2007	125,000	125,000
Deferred income taxes	11,600	10,000
Total liabilities	$448,100	$429,600
Stockholders' equity		
Preferred stock, 5% cumulative		
$5 par value—200,000 shares	$ 10,000	$ 10,000
Common stock, $1 par value		
2000 28,000,000 shares	32,000	28,000
200X 32,000,000 shares		
Capital surplus	8,000	6,000
Accumulated retained earnings	207,600	172,900
Total stockholders' equity	$257,600	$216,900
Total liabilities and stockholders' equity	$705,700	$646,500

[a] All amounts in thousands of dollars.
[b] Includes an allowance for doubtful accounts.

Table 3.9 Archem, Inc.: Consolidated Income Statement as of December 31[a]

	200X	2000
Net sales (revenue)	$932,000	$850,000
Cost of sales and operating expenses		
Cost of goods sold	692,000	610,000
Depreciation and amortization	40,000	36,000
Sales, general, and administrative expenses	113,500	110,000
Operating profit	$ 86,500	$ 94,000
Other income (expenses)		
Dividends and interest income	10,000	7,000
Interest expense	(22,000)	(22,000)
Income before provision for income taxes	$ 74,500	$ 79,000
Provision for federal income taxes	24,500	26,000
Net profit for year	$ 50,000	$ 53,000
Accumulated retained earnings statement[a]		
Balance as of January 1	$172,900	$141,850
Net profit for year	50,000	53,000
Total for year	$222,900	$194,850
Less dividends paid on		
Preferred stock	700	700
Common stock	14,600	21,250
Balance December 31	$207,600	$172,900

[a] All amounts in thousands of dollars.

companies use June 30. It is as if the firm's operation is "frozen" in time on that date [5].

In Table 3.8, a "consolidated" balance sheet appears. This means that all the financial data for the parent company as well as the financial data for all subsidiary firms, if there are any, are consolidated in this document.

A balance sheet contains some real figures (e.g., cash and marketable securities), some estimated numbers or allowances (e.g., inventories and accounts receivable), as well as some fictitious numbers (e.g., intangibles for which numbers are difficult to assess).

The balance sheet consists of two parts: the *assets*, which are what the company owns, and the *liabilities* and *stockholders' equity*, which are what the company owes. The total assets must equal the total liabilities plus the stockholders' equity for both sides of the sheet to balance.

3.3.1.1 Assets

The assets of a company are divided into three broad categories: *current assets*, *fixed assets*, and *intangibles*.

3.3.1.1.1 Current Assets. The *current assets* are those that may be converted to cash within a year from the date of the balance sheet. The current assets include *cash* such as petty cash and money on deposit in a bank, while *marketable securities* are usually commercial paper and government bonds that can be readily converted to cash. *Accounts receivable* are goods sold to customers on a 30-, 60-, or 90-day basis for which full payment has not been received as of the date of the balance sheet. An allowance is made for uncollected bills because some customers are unable to pay. *Inventories* consist of raw materials on hand, goods in process, supplies, and finished goods ready for shipment to customers. Raw materials and supplies are carried at cost, and goods in process at the raw material cost plus one-half the conversion cost; finished goods are valued at the market price. Frequently, inventory costs are carried at slightly less than these figures to allow for deterioration, decline in prices, obsolescence, and so on.

Prepaid expenses include prepaid insurance premiums as well as leases for equipment, computers, and office machinery. These expenses are listed under current assets because although the full benefit has not been received, the company has paid for the assets and expects to receive full benefit within the year.

3.3.1.1.2 Total Current Assets. The sum of cash, marketable securities, inventories, accounts receivable, and prepaid expenses is called *total current asset*.

3.3.1.1.3 Fixed Assets. A company's *fixed assets* include land, buildings, manufacturing equipment, office equipment, automobiles, trucks, and so on that the company owns. These items are carried on the books at cost less the accumulated depreciation. Land value is entered at the same value year to year. The sum of these items is the *net fixed assets*.

Other assets include *intangibles*. They are assets that have substantial value to the company (patents, licenses, franchises, trademarks, goodwill, etc.). There is no consistent way to evaluate these assets, so the company often balances both sides of the balance sheet by making this value "close" the sheet. On occasion, other assets, such as investments in affiliates or deferred charges for which the full benefit has not been received, may be included before the total assets are summed.

3.3.1.2 Total Assets

The sum of current assets, fixed assets, deferred charges, and intangibles is called *total assets*.

3.3.1.3 Liabilities

The *liabilities* are what a company owes, divided into current and long-term liabilities.

3.3.1.3.1 Current Liabilities. *Current liabilities* are debts that must be paid within a year from the date of the balance sheet. They are paid from the current assets. Current liabilities include accounts payable, notes payable, accrued expenses payable, and income taxes payable.

Accounts payable are such items as invoices for raw materials and supplies that a company has purchased from suppliers for which payment is usually due within 30, 60, or 90 days.

Notes payable include money owed to banks and other creditors. Promissory notes are in this category.

Accrued expenses payable are in addition to accounts payable. They may include such items as salaries, wages, interest on borrowed funds, insurance premiums, and pensions.

The liability known as *income taxes payable* is the debt due to various taxing authorities such as federal, state, and local governments. It is common practice to isolate this item from other expenses. These taxes are usually paid quarterly.

3.3.1.3.2 Total Current Liabilities. The sum of the accounts payable, notes payable, accrued expenses payable, and income taxes payable is called *total current liabilities*.

3.3.1.3.3 Long-term Liabilities. *Long-term liabilities* are debts due more than a year from the date of the financial report.

3.3.1.3.4 Bonds and Loans. *First mortgage bonds* are issued at a stated interest rate due in a stated year. They are backed by the company's property. *Debenture bonds*, on the other hand, are backed by the general credit of the company rather than by company property. *Long-term loans* from insurance companies and investment houses are another form of long-term liability.

3.3.1.3.5 Deferred Income Taxes. *Deferred income taxes* are encouraged by the government as a tax incentive that will benefit the economy. An example of such an incentive is accelerated depreciation, which provides rapid write-off in the early years of an investment. The net effect is to reduce what the company will pay in current taxes, but the full amount must be paid in the future. To smooth out wide fluctuations in a company's earnings, an entry is made for deferred taxes. This entry shows what the taxes would be without accelerated depreciation write-offs.

3.3.1.4 Total Liabilities

The sum of current and long-term liabilities constitutes *total liabilities*.

3.3.1.5 Stockholders' Equity

This is the total interest that the stockholders have in the business. The *stockholders' equity* is the net worth of the company, namely, total assets minus total liabilities. For convenience, stockholders' equity is divided into three categories: *capital stock*, *capital surplus*, and *accumulated retained earnings*.

3.3.1.5.1 Capital Stock. *Capital stock* is classified into broad groups: preferred stock and common stock.

The stockholders who have *preferred stock* have a preference over the shareholders regarding dividends and/or the distribution of assets. Some preferred stock is called *cumulative* which means that if in any given year the company does not pay dividends, the unpaid dividends accumulate, and when these obligations are paid, the preferred stockholders receive stock dividends before the holders of common stock. Preferred stockholders do not normally have a voice in company affairs or voting rights unless the company fails to pay them dividends. Preferred stock is carried on the company books at a stated par value.

On the other hand, there are no limitations on the dividends paid to holders of *common stock*. If the company's earnings are high, dividends are paid, but if the earnings are low, dividends may not be paid at all. Common stock is valued at stated par value.

3.3.1.5.2 Capital Surplus. *Capital surplus* is the amount of money stockholders paid for stock over and above the par value of the stock.

3.3.1.5.3 Accumulated Retained Earnings. This term is sometimes referred to as *earned surplus*. The *accumulated retained earnings* are calculated by subtracting the dividends paid to stockholders from the net profit. If all the profits in one year are not distributed, they are retained by the firm and added to next year's earnings. They may be used, for example, for research and development activities, and/or for the purchase of capital equipment.

3.3.1.6 Total Stockholders' Equity

The *total stockholders' equity* is the sum of the preferred stock, common stock, capital surplus, and accumulated retained earnings.

3.3.1.7 Total Liabilities and Stockholders' Equity

The sum of the total liabilities and the stockholders' equity is what the company owes. For the balance sheet to "balance," the sum must equal the total assets.

3.3.2 The Income Statement

The income statement is also known as the profit and loss statement, the earnings statement, or the statement of operations. It displays the financial operating activities of a firm for the year and may be an indication of the company's future performance. A typical statement will show figures for the current year as well as one or two previous years' activities. Frequently, an annual report will include a 5- or 10-year summary near the end of the report. The term "consolidated" may appear, indicating that all the financial activities of the company and its subsidiary operations are reported in a single statement (Table 3.9) [5].

3.3.2.1 Net Sales

The *net sales* is the amount of money received for the goods sold less the amount of returned goods and allowances for reduction in prices (e.g., allowing for freight on goods shipped).

3.3.2.2 Cost of Goods Sold and Operating Expenses

This item includes all the expenses in converting raw materials into finished products, including depreciation, as well as sales, administration, research, and engineering expenses.

3.3.2.2.1 Cost of Goods Sold. The *cost of goods sold* represents the cash operating expenses for raw materials, labor, utilities, supplies, supervision, maintenance, waste disposal, plant indirect expenses, and so on.

3.3.2.2.2 Depreciation, Amortization, and Depletion. The federal government allows a company to charge off a portion of an asset due to wear and tear as well as obsolescence each year as an operation expense. This is known as *depreciation*; it is a paper transaction and is not a cash item. *Amortization* is the decline in useful value of a tangible asset such as a patent. *Depletion* is the diminution of a natural resource, such as coal in a mine. All these paper allowances appear as one item in most income statements.

3.3.2.2.3 Sales Administration, Research, and Engineering Expenses (SARE). These are expenses associated with maintaining sales offices, paying the corporate officers and their staffs, as well as research and engineering expenses not attributable to a specific project.

3.3.2.3 Operating Profit (Operating Income)

This entry is the difference between net sales and all operating expenses.

3.3.2.3.1 Other Income. *Other income* may be derived from dividends or interest received by the company in other investments, patents and licenses, and additional sources.

3.3.2.3.2 Income Before the Provision for Federal Income Taxes. When *other income* is subtracted from operating profit, the result is the *income before the provision for federal income taxes*.

3.3.2.3.3 Federal Income Taxes. Every company has a basic tax rate that it must pay. Because of tax incentives, tax credits, depreciation write-offs, capital gains, and so on, the actual taxes paid may be less than the basic rate.

3.3.2.4 Net Profit for the Year After Income Taxes

This entry is obtained by subtracting the provision for federal income taxes from the income before provision for federal income taxes.

3.3.3 Accumulated Retained Earnings

Accumulated retained earnings is an important part of the financial report because it shows how much money the company has retained for growth and how much is paid out as dividends to stockholders. When the accumulated retained earnings increase, the company has more value [5].

To obtain the value of the retained earnings, the company starts at the beginning of the year with the previous year's balance. To that figure the *net profit after taxes for the year* is added. The dividends paid to the preferred and common stockholders are subtracted. The result is the retained earnings at the end of the year.

3.3.4 Changes in Financial Position

If one inspects the balance sheet and the income statement, it is easy to see how much money passed through the company. How much profit was made? Did the working capital change and, if so, where did it go? (Working capital is the difference between the total current assets and the total current liabilities.) How were funds obtained from various sources like net profit, depreciation, and the sale of common stock used? How did cash generated affect the company operations? By careful tracking of changes through the changes in financial position, the reader can determine how the company managed its funds.

Excerpts from the 1999 Dow Company Annual Report [6] have been included as an example of a typical report from a chemical company (see Tables 3.10–3.12). It is useful to compare the entries in this report with those in the fictitious company Archem, Inc. (Tables 3.8 and 3.9). You will note that there are some differences in nomenclature and entries, but overall the income statement and the balance sheets are similar in style.

TABLE 3.10 Dow Consolidated Balance Sheet (1999 Annual Report. See Notes to Financial Statements.)[a]

	December 31	
	1999	1998
Assets		
Current assets		
Cash and cash equivalents	$ 506	$ 123
Marketable securities and interest-bearing deposits	706	267
Accounts and notes receivable		
Trade (net of allowance for doubtful receivables—1999: $107: 1998: $93)	2,631	2,787
Other	1,983	1,750
Inventories		
Finished and work in process	2,264	2,245
Materials and supplies	522	565
Deferred income tax assets—current	235	303
Total current assets	8,847	8,040
Investments		
Investment in nonconsolidated affiliates	1,359	1,311
Other investments	2,872	2,191
Noncurrent receivables	390	424
Total investments	4,621	3,926
Property		
Property	24,276	24,435
Less accumulated depreciation	15,786	15,988
Net property	8,490	8,447
Other assets		
Goodwill (net of accumulated amortization—1999: $351; 1998: $246)	1,834	1,641
Deferred income tax assets—noncurrent	597	684
Deferred charges and other assets	1,110	1,092
Total other assets	3,541	3,417
Total Assets	$ 25,499	$ 23,830

(continued)

TABLE 3.10 Continued

	December 31	
	1999	1998
Liabilities and stockholders' equity		
Current liabilities		
Notes payable	$ 692	$ 1,526
Long-term debt due within 1 year	343	300
Accounts payable		
Trade	1,782	1,682
Other	1,087	981
Income taxes payable	178	290
Deferred income tax liabilities—current	38	71
Dividends payable	213	192
Accrued and other current liabilities	1,962	1,800
Total current liabilities	6,295	6,842
Long-term debt	5,022	4,051
Other noncurrent liabilities		
Deferred income tax liabilities—noncurrent	839	747
Pension and other postretirement benefits—noncurrent	1,843	1,903
Other noncurrent obligations	2,219	2,283
Total other noncurrent liabilities	4,901	4,933
Minority interest in subsidiaries	408	532
Preferred securities of subsidiary	500	
Temporary equity		
Preferred stock at redemption value (authorized 250,000,000 shares of $1.00 per value each; issued Series A—1999; 1,316,440; 1998: 1,360,813)	114	117
Guaranteed ESOP obligation	(64)	(74)
Total temporary equity	50	43

TABLE 3.10 Continued

	December 31	
	1999	1998
Stockholders' equity		
Common stock (authorized 500,000,000 shares of $2.50 per value each; issued 1999 and 1998: 327,125,854)	818	818
Additional paid-in capital	1,321	718
Retained earnings	13,445	12,887
Accumulated other comprehensive income	(251)	(347)
Treasury stock at cost (shares 1999: 103,844,216; 1998: 106,749,081)	(7,010)	(6,647)
Net stockholder's equity	8,323	7,429
Total liabilities and stockholders' equity	$ 25,499	$ 23,830

[a] Amounts in millions except per share.

3.3.5 Independent Accountant's Certification

When reading an annual report, one should look at the independent accountant's statement (Table 3.13). The certificate will state that the auditing steps used in the verification of the figures meet the accounting world's approved standards of practice, and that the financial statements contained in the annual report were prepared in conformance with generally accepted accounting practices [5].

The two statements assure the reader that the figures in the annual report fairly represent the data they purport to describe. Occasionally, "subject to" or "except for" appear. This should alert the reader to dig further to find out what necessitated these qualifying statements. The answers are frequently found in the notes of the annual report that is one of the most important sections of the annual report.

3.3.6 Relationship Between the Balance Sheet and the Income Statement

Someone inexperienced in reading a financial report may believe that there is no relationship between the balance sheet and the income statement. However, this is not the case because information obtained from each is used to calculate the return on assets and the return on equity, which are of significance to financial people as we shall see in Section 3.4, Financial Ratios. Figure 3.2, the operating profitability tree for Archem, contains the fixed and variable expenses as reported

TABLE 3.11 Dow Consolidated Statement of Income (1999 Annual Report. See Notes to Financial Statements.)[a]

	1999	1998	1997
Net Sales	$18,929	$18,441	$20,018
Cost of sales	14,302	13,799	14,679
Research and development expenses	845	807	785
Selling, general, and administrative expenses	1,530	1,666	1,880
Amortization of intangibles	146	88	61
Purchased in-process research and development charges	6	349	—
Special charges	94	458	—
Insurance and finance company operations, pretax income	127	112	113
Equity in earnings of nonconsolidated affiliates	82	64	75
Sundry income—net	261	916	436
Earnings before interest, income taxes, and minority interests	2,476	2,366	3,237
Interest income	121	139	182
Interest expense and amortization of debt discount	431	493	471
Income before income taxes and minority interests	2,166	2,012	2,948
Provision for income taxes	766	685	1,041
Minority interests' share in income	69	17	99
Preferred stock dividends	5	6	6
Net income available for common stockholders	$ 1,326	$ 1,304	$ 1,802
Share data			
Earnings per common share—basic	$ 6.02	$ 5.83	$ 7.81
Earnings per common share—diluted	5.93	5.76	7.70
Common stock dividends declared per share	3.48	3.48	3.36
Weighted-average common shares outstanding—basic	220.1	223.5	230.6
Weighted—average common shares outstanding—diluted	224.4	227.3	234.8

[a] Amounts in millions except per share.

TABLE 3.12 Dow Consolidated Statement of Stockholders' Equity (1999 Annual Report. See Notes to Financial Statements.)[a]

	1999	1998	1997
Common stock			
Balance at beginning and end of year	$ 818	$ 818	$ 818
Additional paid-in capital			
Balance at beginning of year	718	532	307
Issuance of treasury stock at more than cost	550	121	162
Proceeds from sales of put options and other	53	65	63
Balance at end of year	1,321	718	532
Retained earnings			
Balance at beginning of year	12,887	12,357	11,323
Net income before preferred stock dividends	1,331	1,310	1,808
Preferred stock dividends declared	(5)	(6)	(6)
Common stock dividends declared	(768)	(774)	(768)
Balance at end of year	13,445	12,887	12,357
Accumulated other comprehensive income			
Unrealized gains on investments			
Balance at beginning of year	130	316	192
Unrealized gains (losses)	160	(186)	124
Balance at end of year	290	130	316
Cumulative translation adjustments			
Balance at beginning of year	(414)	(429)	(363)
Translation adjustments	(64)	15	(66)
Balance at end of year	(478)	(414)	(429)
Minimum pension liability			
Balance at beginning of year	(63)	(33)	(22)
Adjustments	—	(30)	(11)
Balance at end of year	(63)	(63)	(33)
Treasury stock			
Balance at beginning of year	(6,647)	(5,935)	(4,301)
Purchases	(429)	(742)	(1,655)
Sales of treasury shares in open market	39	—	—
Issuance to employees and employee plans	27	21	30
Reclassification related to put options	—	9	(9)
Balance at end of year	(7,010)	(6,647)	(5,935)
Net stockholders' equity	$ 8,323	$ 7,429	$ 7,626

[a] Amounts in millions except per share.

TABLE 3.13 Dow Independent Auditors' Report (1999 Annual Report)

Management Statement of Responsibility and Independent Auditors' Report

Management Statement of Responsibility
The management of The Dow Chemical Company and its subsidiaries prepared the accompanying consolidated financial statements and has responsibility for their integrity, objectivity and freedom from material misstatement or error. These statements were prepared in accordance with generally accepted accounting principles. The financial statements include amounts that are based on management's best estimates and judgments. Management also prepared the other information in this annual report and is responsible for its accuracy and consistency with the financial statements. The Board of Directors, through its Audit Committee, assumes an oversight role with respect to the preparation of the financial statements.

Management recognizes its responsibility for fostering a strong ethical climate so that the Company's affairs are conducted according to the highest standards of personal and corporate conduct. Management has established and maintains internal controls that provide reasonable assurance as to the integrity and reliability of the financial statements, the protection of assets from unauthorized use or disposition, and the prevention and detection of fraudulent financial reporting.

Internal controls provide for appropriate division of responsibility and are documented by written policies and procedures that are communicated to employees with significant roles in the financial reporting process and updated as necessary. Management continually monitors internal controls for compliance. The Company maintains a strong internal auditing program that independently assesses the effectiveness of the internal controls and recommends possible improvements.

Deloitte & Touche LLP, independent auditors, with direct access to the Board of Directors through its Audit Committee, have audited the consolidated financial statements prepared by the Company, and their report follows.

Management has considered recommendations from the internal auditors and Deloitte & Touche LLP concerning internal controls and has taken actions that are cost-effective in the circumstances to respond appropriately to these recommendations. Management further believes the controls are adequate to accomplish the objectives discussed herein.

Table 3.13 Continued

Independent Auditors' Report

To the Stockholders and Board of Directors of
The Dow Chemical Company:

We have audited the accompanying consolidated balance sheets of The Dow Chemical Company and its subsidiaries as of December 31, 1999 and 1998, and the related consolidated statements of income, stockholders' equity, comprehensive income and cash flows for each of the three years in the period ended December 31, 1999. These financial statements are the responsibility of the Company's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with generally accepted auditing standards. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, such consolidated financial statements present fairly, in all material respects, the financial position of The Dow Chemical Company and its subsidiaries at December 31, 1999 and 1998, and the results of their operations and their cash flows for each of the three years in the period ended December 31, 1999, in conformity with generally accepted accounting principles.

DELOITTE & TOUCHE LLP
Midland, Michigan
February 9, 2000

in internal reports such as the manufacturing expense sheet. This information is fed into the income statement as the cost of goods sold along with selling expenses, general overhead expenses, and depreciation, resulting in the operating expenses. The operating profit is calculated by subtracting the operating expenses from sales. (The total assets are obtained from the balance sheet. Some of the data in the income statement flowsheet boxes may be found in the income statement, Table 3.9.) The return on assets is calculated by dividing the net income after taxes by the total assets.

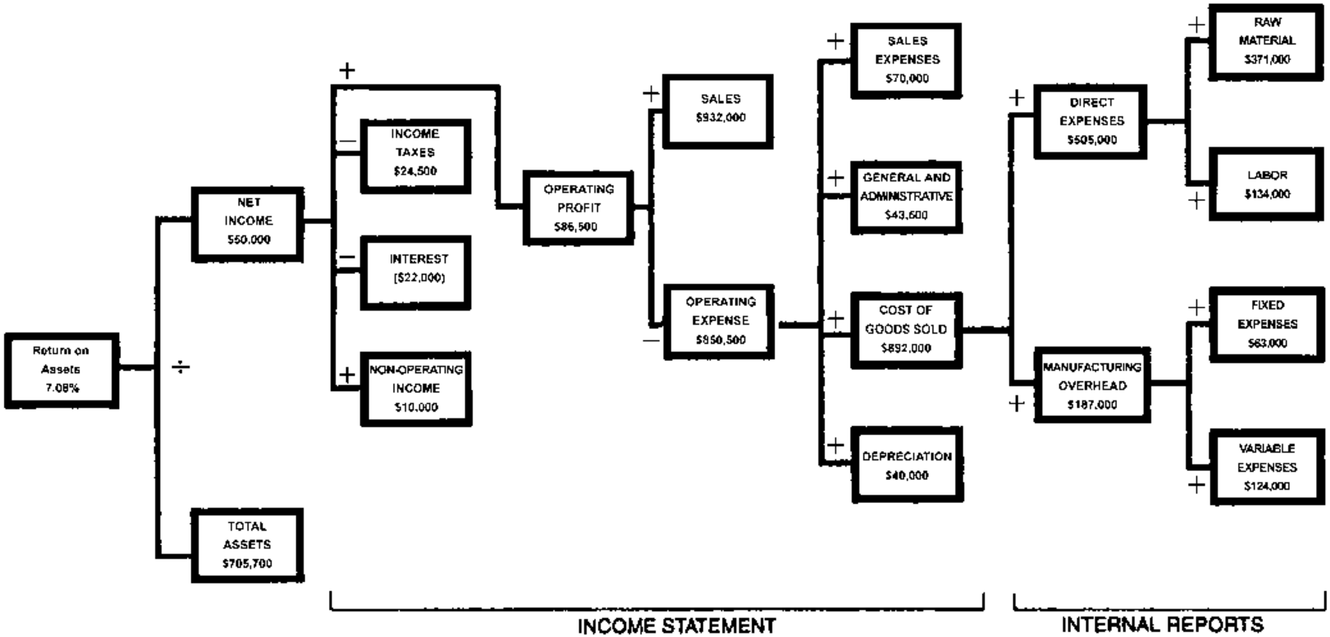

Figure 3.2 Operating profitability tree for Archem, Inc.

For a broader perspective (see Figure 3.3), the financial family tree ties together the income statement and the balance sheet for Archem. The upper part of the figure includes information obtained from the income statement, while the lower part contains information from the balance sheet, namely, the total assets and total liabilities. The difference between these latter two figures is the stockholders' equity from which the return on equity is calculated. The net income found in the income statement divided by the stockholders' equity is the return on equity. Figures 3.2 and 3.3 therefore, depict how the income statement and the balance sheet are related.

3.3.7 The 10K Report

Every year, every public corporation in the United States is required to file a report, known as the 10K report, with the Securities and Exchange Commission. When one requests a copy of a company's annual report, the 10K report frequently accompanies or is bound with it. The 10K report is a more thorough presentation and discussion of the details found in the annual report. Over the past decade, the format of the 10K report has been modified to eliminate redundancy and repetition of data in the annual report.

The 10K report consists of four parts. In Part 1, the company presents the corporate structure, describing the nature of the business and providing details about acquisitions, mergers, raw material sources, environmental affairs, patents, licenses, as well as research and development activities. Data on foreign, domestic, and discontinued operations are included. Properties, plants, and leases including transportation and marketing information are also presented, if the company is engaged in petroleum operations. Any legal proceedings brought by states, federal government, foreign governments, or individuals are also noted in Part 1. The subject of any litigation is stated in clear and concise terms. Also discussed in this part of the report are matters submitted to security holders. The concluding section of Part 1 contains the name, position, and date of appointment of each corporate officer.

Part 2 consists of the financial position, capital expenditures, funds availability, and results of operations. Consolidated balance sheets, income statements, and selected quarterly data, as well as stock prices and dividends per share, may be found in Part 2. Any disagreements on accounting and financial disclosure are explained in narrative format.

Part 3 contains a listing of nominees for election as directors as distributed in a proxy statement for the annual stockholders' meeting. Security ownership of voting securities and the principal holders are found in the proxy statement and only referenced in Part 3. Any related financial transaction not included in one or more of the foregoing sections is presented here.

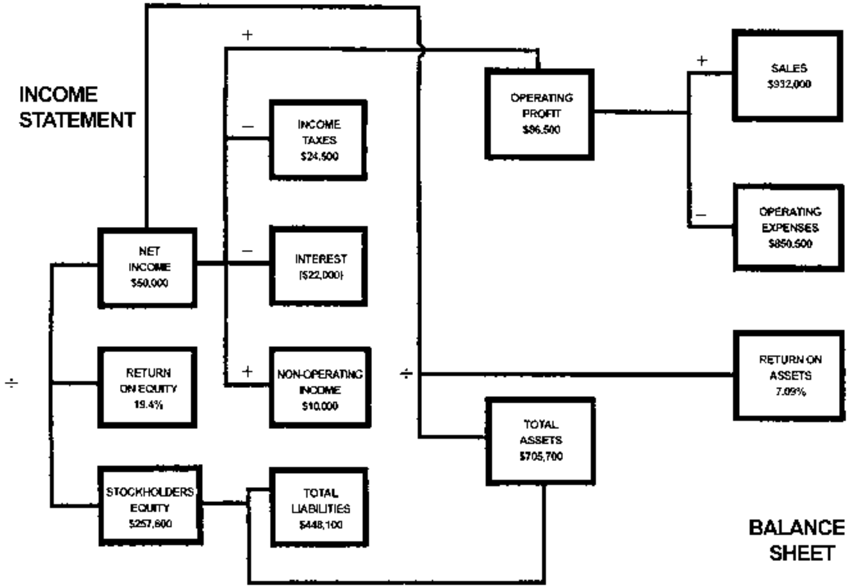

FIGURE 3.3 Financial family tree for Archem, Inc.

Part 4 contains all financial statements and pertinent schedules referring to specific pages in the annual report. A statement concerning whether the registrant has filed any other reports is mentioned. A statement by the certified public accountants concerning their consent to include the annual report with the 10K report is made. An index to financial statements and financial schedules over the past three years is included as follows:

Properties, plant, and equipment
Accumulated depreciation, depletion, and amortization
Valuation of accounts and reserves
Short-term borrowing

Finally, a signature page for all corporate officers to sign is included.

3.4 FINANCIAL RATIOS

The sports and business worlds use statistics as a measure of performance. There are many financial ratios of interest to financial analysts. A summary of the definitions of financial ratios used in this text and chemical process industry

TABLE 3.14 Summary of Selected Financial Ratios

Ratio	Equation for calculation	Industry average
Liquidity		
Current	Current assets/current liabilities	1.5–2.0 times
Cash or quick cash	Current assets—inventory/current liabilities	1.0–1.5 times
Leverage		
Debt-to-total assets	Total debt/total assets	30–35%
Times interest earned	Profit before taxes plus interest charges/interest charges	7.0–8.0 times
Fixed-charge coverage	Income available for meeting fixed charges/fixed charges	5.5 times
Activity		
Inventory turnover	Sales or revenue/inventory	7.0 times
Average collection period	Receivables/sales per day	45–60 days
Fixed assets turnover	Sales/fixed assets	2–3 times
Total assets turnover	Sales/total assets	1–2 times
Profitability		
Gross profit margin	Net sales—cost of goods sold/sales (revenue)	Varies
Net operating margin	Net operating profit before taxes/sales (revenue)	Varies
Profit margin on sales	Net profit after taxes/sales (revenue)	5–8%
Return on net worth (return on equity)	Net profit after taxes/net worth	15%
Return on total assets	Net profit after taxes/total assets	10%

average values are found in Table 3.14. Only the following common financial ratios are presented in this section:

Liquidity ratios: A measure of the company's ability to pay its short-term debts when due

Leverage ratios: A measure of the company's overall debt burden

Activity ratios: A measure of how effectively a company manages its assets

Profitability ratios: An indication of a firm's total operating performance, which is a combination of asset and income management

3.4.1 Liquidity Ratios

Two measures of a firm's liquidity are the *current ratio* and the *cash (quick) ratio*.

The *current ratio* is defined as the current assets divided by the current liabilities. It is a measure of the company's overall ability to meet obligations from current assets. Today a "comfortable" level of between 1.5 and 2.0 is considered adequate. (*Note*: Numbers presented in this section are typical as of 2000 but will vary depending on a company's style of management. Some companies operate with a current ratio nearer to 1.0, believing that their assets must be made to work for the firm. This can be dangerous because that ratio leaves little margin for financial surprises).

The *cash (quick) ratio* expresses the ability of a company to cover from its assets in an emergency. It is the cash plus marketable securities divided by the current liabilities. A typical figure is slightly greater than 1.0.

3.4.2 Leverage Ratios

The leverage ratios are an indication of the company's overall debt burden.

The *debt-to-total assets ratio* is determined by dividing the total debt by the total assets expressed as a percentage. An all-industry average is about 35%. Another measure is the *debt-to-equity ratio* also expressed as a percentage. Both these ratios are used to measure the amount of debt that a company maintains. The higher the ratio, the greater the financial risk. If an economic turndown occurred, it might be difficult for a company with high debt levels to meet creditor's demands.

The *times-interest-earned ratio* is a measure of the extent to which profits could decline before a company is unable to pay interest charges. This ratio is calculated by dividing the earnings before interest and taxes (EBIT) by interest charges.

The *fixed-charge coverage* is obtained by dividing the income available for meeting fixed charges by the fixed charges. Many firms lease assets and incur long-term obligation under lease contracts. The lease contracts are part of the fixed cost and the cost of doing business. The numerator of this ratio is the operating profit before deducting the interest expense, lease costs, and income taxes divided by lease costs and interest expenses.

3.4.3 Activity Ratios

Activity ratios are a measure of how effectively a firm manages its assets. They are based on the assumption that there are proper relationships between a company's assets and the sales and income that the assets generate. Different methods are used to generate these ratios, and they depend on how a person wants to use the ratios. Most analysts compile average ratios from balance sheet data, which are end-of-year data. In this section and in the financial ratio example that follows, this method is used.

There are two *inventory/turnover ratios* in common use today. The *inventory/sales ratio* is found by dividing the sales by the inventory. Another method is to divide the cost of sales by the inventory. In either case, all-industry averages are between 7.0 and 9.0.

The *average collection period* measures the number of days that customers' invoices remain unpaid. This figure is found by dividing the annual sales by 365 to obtain the daily sales, and then dividing this figure into the accounts receivable balance. The average period for the CPI is about 45 days.

Fixed-assets and *total-assets turnover* indicate how well the fixed and total assets of the firm are being used. These figures are determined by dividing the annual sales by the fixed assets or the total assets, respectively.

3.4.4 Profitability Ratios

Activity ratios are used to determine the management of the company's assets, while profitability ratios are used to evaluate its income management.

The *gross profit margin* is found by dividing the gross profits by the net sales, and the result is expressed as a percentage. This ratio is an indication of the effectiveness of a company's pricing, purchasing, and production policies.

The *net operating margin* is equal to earnings before interest and taxes (EBIT) divided by the net sales, again expressed as a percentage. This is a measure of a firm's income performance before interest and taxes.

Another measure is the *profit margin on sales*, which is calculated by dividing the net profit after taxes by the net sales, expressed as a percentage. Industry averages vary but 5% is a reasonable figure for the CPI.

The *return-on-total-assets ratio* is the net profit after taxes divided by the total assets, expressed as a percentage. It reflects the overall return a company has earned on its assets. The average for all industries is about 10%, but figures vary widely depending on the industry.

The *return-on-equity ratio* is the net income after taxes and interest divided by the stockholders' equity. It measures the return on equity capital invested in the firm. Since one of management's objectives is to earn the highest return for stockholders, this ratio is probably the best measure of management's performance.

In evaluating a company's performance, one should compare it with data from other companies in the same line of business. Thus a chemical company's performance should be compared with that of other chemical companies. Companies in the same line of business frequently use the same style of management.

3.4.5 Economic Value Added

In the mid-1990s, a management concept, *economic value added* (EVA), was moved from a buzzword to an important financial tool. EVA is the after-tax net operating profit minus the cost of capital. It measures whether a business earns more than the cost of capital. EVA is being used as a performance measure, as an analytical financial tool, and as a management discipline measure. Various economic sectors like manufacturing industries, health-care companies, and the postal service are among the enterprises using EVA to help manage their operations. It is an indication of how efficient management is at turning investor money, namely capital, into profits [7,8].

In periods when the economy is strong and sales are growing, the bottom line still might not show good results. EVA analysis helps companies identify waste and inefficiency in their daily operations and in the use of capital. It also aids in identifying high inventories as well as the need to reduce accounts receivable. In other words, EVA is a tool to improve overall efficiency. In some instances, EVA has demonstrated that debt capital is cheaper than equity capital. It gives management a clearer idea of whether they are increasing or decreasing stockholders' wealth. Stockholders can benefit from EVA analysis if it results in higher dividends and permits stick share repurchases. Further, some companies are tying EVA to salaries and bonuses of upper-level company executives.

3.4.6 Other Financial Information

In this section, additional terms and information found frequently in financial reports are presented.

Profit margin is the ratio of net income to total sales expressed as a percentage or sometimes quoted as the ratio of profit before interest and taxes to sales expressed as a percentage.

Gross margin is the ratio of cost of goods sold to revenue expressed as a percentage.

Operating margin is obtained by subtracting the operating expenses from the gross profit expressed as a percentage of sales (operating profit as a percentage of sales)

Net worth, the difference between total assets and total liabilities, is the same as stockholders' equity.

Working capital is calculated by subtracting the total current liabilities from the total current assets.

Earnings per share is of interest to owners of common stock and stockbrokers. It is found by dividing the net profit after taxes by the number of shares of common stock.

After-tax cash flow is defined as the net profit after taxes plus depreciation. This item is important to management because it is the amount of money available for operating the company. With the advent of accelerated depreciation, the cash flow in the early years of an asset tends to increase, when a plant is being brought on stream and markets are being developed.

LIFO–FIFO valuation of raw materials and supplies inventory is an important consideration for management. *LIFO* means last material in, first material out, referring to the purchase of materials inventory. *FIFO* means first material in, first material out. The method selected is reflected not only in the operating expenses but also in the income statement and the balance sheet. At different times it may be more advantageous financially to use one instead of the other.

3.4.7 *Z* Scores

Charles Kyd [9] developed an equation that measures how closely a firm's financial statements resemble those of companies that have gone bankrupt. The equation is as follows:

$$Z = 1.2\left(\frac{\text{working capital}}{\text{total assets}}\right) + 1.4\left(\frac{\text{retained earnings}}{\text{total assets}}\right) + 3.3\left(\frac{\text{EBIT}}{\text{total assets}}\right) + 0.6\left(\frac{\text{market value of equity}}{\text{total liabilities}}\right) + \left(\frac{\text{sales}}{\text{total assets}}\right)$$

The five ratios displayed help one to evaluate how changes in the ratios produce changes in values of Z. A Z score of less than 1.80 implies that the firm is economically bankrupt. A firm on a sound financial footing generally will have a score greater than 3.0. A score between these two values indicates some uncertainty about the company's prospects.

3.5 A FINANCIAL RATIO EXAMPLE

3.5.1 Problem Statement

To illustrate the use of the balance sheet and the income statement in determining the financial soundness of a company, an example of a fictitious company, Archem, Inc., will be presented. It was formed over a period of about 15 years through acquisitions, mergers, and buyouts of several small companies. Archem manufactures specialty and fine chemicals. We shall use their balance sheet and income statement for 200X as a typical set of data, Tables 3.8 and 3.9. Determine the liquidity, leverage, activity, and profitability performance of Archem.

Calculate the Z score for this firm. You may assume that the stock is selling at \$10 per share. What do you conclude about the financial performance of this firm?

3.5.2 Problem Solution

The financial ratios for Archem are found in Table 3.15. If these are compared with the CPI averages found in Table 3.14, one can draw the following conclusions:

From the liquidity ratios, the company is able to pay its short-term debts when due.

From the leverage standpoint, the "fixed charge coverage" and the "times interest earned" are a bit low. The debt-to-asset ratio is about average. The company needs to reduce fixed or interest charges or increase profit or income.

The activity ratios are about average for a company in the CPI, and the company manages its assets effectively.

The profitability ratios are about average, although the return on total assets is low.

Overall, the operating performance appears to be satisfactory. The management seems to operating the company in a satisfactory manner despite some areas as cited above that bear some watching.

The Z score for Archem, Inc., obtained by substituting the appropriate values, is 3.06 (see Table 3.15). The firm is safe from bankruptcy at this time but management must continually monitor the Z score.

3.6 SUMMARY

This chapter introduced the basic elements of accounting that readers are likely to encounter in industry. From accounting records and internal reports, the financial data ultimately become part of the balance sheet or the income statement. The various terms in the balance sheet and the income statement were defined, and an illustration of these documents for a typical company was presented. This information should allow one to determine how well a firm has done and is doing. All annual reports contain footnotes, which explain how changes in financial information and pending litigation could affect the financial performance of a company. The 10K report was mentioned because it provides the source of detailed backup information not in the annual report.

Financial ratios often used by analysts were introduced because they are indicators of how well the company uses its asset and how well management performs. An equation for determining the Z score was introduced as it measures the financial position of the firm with respect to bankruptcy.

Table 3.15 Financial Ratios for Archem, Inc.

Liquidity
Current ratio = \$391,200/\$201,500 = 1.94
Cash ratio = \$391,200 − 149,000/\$201,500 = 1.20
Leverage
Debt-to-assets = [(\$448,100 − 201,500)/\$705,700] × 100 = 35%
Times interest earned = \$74,500 − 22,000/\$22,000 = 4.39
Fixed-charge coverage = \$86,500/\$22,000 = 3.93
Activity
Inventory turnover = \$932,000/\$149,000 = 6.25
Average collection period = \$135,000/(\$932,000/365) = 52.8 days
Fixed-assets turnover = \$932,000/\$438,000 = 2.13
Total-assets turnover = \$932,000/\$705,700 = 1.32
Profitability
Gross profit margin = [(\$932,000 − 692,000)/\$932,000] × 100 = 25.8%
Net operating margin = \$74,500/\$932,000 × 100 = 7.99%
Profit margin on sales = \$50,000/\$932,000 × 100 = 5.36%
Return on net worth (return on equity) = [\$50,000/(\$705,700 − 448,100)] × 100 = 19.4%
Return on total assets = (\$50,000/\$705,700) × 100 = 7.09%
Z score
Z = 1.2 (working capital/total assets) + 1.4 (retained earnings/total assets) + 3.3 (EBIT/total assets) + 0.6 (market value of equity/total liabilities) + (sales/total assets)
Z = 1.2 (\$391,200 − \$201,500)/\$705,700 + 1.4 (\$268,400/\$705,700) + 3.3(\$96,500/\$705,700) + 0.6 (\$320,000/\$448,100) + \$932,000/\$705,700
Z = 0.323 + 0.532 + 0.451 + 0.429 + 1.321 = 3.056

The principles and definitions of terms presented in this chapter will appear many times throughout the text to explain how financial data affect the marketing, manufacturing, engineering, research and development, and administration of a company.

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PROBLEMS

3.1 From the transactions in the general journal, prepare a ledger, a balance sheet, and an income statement for the month of February for Nuchem, Inc. (See Table 3.16.)

3.2 From the following transactions for Nuchem, Inc. (see Table 3.17), construct the journal, ledger, balance sheet, and income statement for March. Do not forget to include previous commitments (interest, depreciation, Custer's salary, etc.).

3.3 In April, the price of Nusolv drops to 50 cents/liter. Nuchem decides not to sell any product but continues to produce Nusolv at 1,000 liters/month. To keep everything running, Custer makes a deal with a bank to borrow \$5,000 a month on a continuous basis. Would the income statement and the balance sheets look very bad? What kind of troubles would Nuchem eventually encounter?

3.4 Old Smooky McCarthy was drilling wildcat holes in northern Michigan when he struck oil. The find is estimated at 2 million producible barrels of oil. The cost of drilling the well was \$1.5 million; royalty to the owner is \$2.50/barrel plus a bonus of \$5,000 for signing the agreement last year. Oil currently sells for \$18/barrel. What should the asset value of this property be on the balance sheet?

3.5 Chuck Adamson built a new indigo plant at a cost of \$2 million to capitalize on the world craze for blue denim. He managed to convince the IRS that the craze would last only 2 years so that he should be able to depreciate the plant in 2 years by straight line, even though the plant will physically last 15 years. Let's assume the blue denim craze lasts strongly into the third year. Will Adamson operate without a plant listed on the balance sheet? Will he have no depreciation expense on this product cost? Can he undersell any would-be newcomers to the market?

TABLE 3.16 Page 3 of Nuchem General Journal: For Problem 3.1

Date	Account titles and explanation	LP	Debit	Credit
2/1	Accrued wages payable	22	1,000	
	Cash	10		1,000
	Finished goods	14	1,000	
	Accrued wages payable	22		1,000
	Back wages to Davis, owe for February			
2/7	Equipment	12	5,000	
	Prepaid expense	15		2,000
	Cash	10		3,000
	Equipment arrives, $3000 balance paid in cash			
2/10	Accounts payable	24	6,000	
	Cash	10		6,000
	Pay outstanding raw materials account upon delivery			
2/20	Finished goods	14	4,000	
	Raw materials	11		4,000
	Make 5000 liters of Nusolv using $4000 of raw materials[a]			
2/25	Cash	10	2,000	
	Bank loan	21		2,000
	Take out another $2000 loan at 12% interest; promise to pay back after 1 year			
2/26	Cost of goods sold	44	1,000	
	Finished goods	14		1,000
	Cash	10	3,000	
	Revenue	30		3,000
	Sell 1000 liters of Nusolv at $3/liter[b]			
2/28	Salaries expense	43	1,500	
	Salaries payable	26		1,500
	Owe Custer his salary			
Adjusting entries				
2/28	Depreciation expense: equipment	41	66.67	
	Equipment	12		66.67
	$8,000 × 1/12 = $66.67 per month			
2/28	Interest expense	42	40.00	
	Interest payable	23		40.00
	To record bank loan interest for February			

(*continued*)

TABLE 3.16 Continued

Date	Account titles and explanation	LP	Debit	Credit
2/28	Revenue	30	3,000.00	
	Income summary	55		3,000.00
	To close the revenue account			
2/28	Income summary	55	2,606.67	
	Salaries expense	43		1,500.00
	Depreciation expense: equipment	41		66.67
	Interest expense	42		40.00
	Cost of goods sold	44		1,000.00
	To close the expense accounts			
2/28	Income summary	55	393.33	
	Stockholders' equity	50		393.33
	To close out the income summary			

[a] The book value of the second batch of finished goods is \$5000/(5000 liters) or \$1/liter.
[b] This firm uses the LIFO method, where the goods sold are evaluated at the cost of the last batch manufactured, or \$1/liter. So the credit side of the "Finished goods" account shows a withdrawal of 1000 liters at \$1/liter. The debit side of the "Cost of goods sold" account records the \$1000 cost of the 1000 liters.

3.6 Sharppencil & Associates, Inc. is a consulting firm operating from rented office space and furniture. It spent \$200,000 in the past 2 years developing a set of computer programs for the control of batch-processing chemical plants. It hopes to sell them to domestic as well as foreign CPI firms. How should the firm list this set of programs on the balance sheet? Suppose two buyers, each paying \$500,000, could be found each year for the next 3 years. How should these transactions be listed on the books? Should the firm amortize the programs over a period of time? On the other hand, suppose no buyers can be located for 3 years. How would the programs be entered then?

TABLE 3.17 March Nuchem Data for Problem 3.2

Date	Account titles and explanation
3/1	Pay \$1000 to Davis, give him a raise, owe him \$1500 for March
3/10	Pay \$360 for advertisement in a chemical trade journal
3/11	Buy \$5500 of raw materials, pay \$4000 now, owe \$1500 due in April
3/15	Borrow \$5000 from bank at 12% interest; promise to pay back after 1 year
3/15	Sell 3000 liters of Nusolv at \$3.50/liter

3.7 Inflation has suddenly doubled the cost of all Nusolv raw materials and tripled machinery costs. How is this likely to affect Nuchem's evaluation of assets under raw materials, plants, and finished goods? The price of Nusolv has also doubled. What will happen to the profit margin? Should the company use LIFO or FIFO accounting? Is it dangerous and unrealistic to keep depreciation charges at the original machine cost once replacement machinery cost has tripled?

3.8 From the 1999 Dow Company Annual Report (*Tables 3.10–3.12*), answer as many of the following questions as possible:

a. What was the year's income?
b. What was the net income as a percentage of sales?
c. What was the income tax as a percentage of pretax income?
d. What percentage of the cost of plants and properties was shown as depreciation and obsolescence?
e. What percentage of sales was shown as depreciation and obsolescence?
f. What percentage of sales comprised selling, general, and administrative expenses?
g. What was the total revenue from net sales and other income?
h. What percentage of total revenue was spent for materials and services?
i. What percentage of total revenue was spent for wages, salaries, and related expenses?
j. What percentage of total revenue was paid out as dividends?
k. How much was retained for use in the business, including depreciation "set asides"?
l. How much did it cost to construct (or acquire in other ways) the company's existing plants and properties?
m. How much of the cost of plants and properties have been charged to date as an operating expense?
n. What percentage of the cost of plants has been charged to cost?
o. What percentage of total assets is in each of the following: cash, marketable securities, accounts receivable, and inventories?
p. What were the total liabilities, excluding stockholders' equity?
q. What was the stockholders' equity?
r. How much cash and marketable securities were on hand at the beginning of the year?
s. During the year, the cash and marketable securities increased and decreased. What was the increase due to the sum of net income and depreciation?
t. What were the dividends as a percentage of net income plus depreciation?
u. What were construction expenditures as a percentage of net income plus depreciation?

v. How much cash and marketable securities were left at the end of the year?

3.9 Using data from the 1999 Dow Annual Report, calculate the company's liquidity, leverage, activity, and profitability ratios. What was the *Z* score?

4

Estimation of Capital Requirements

A company that manufactures a product has funds invested in land, buildings, and equipment. Some industries require very large capital investments as reflected in their assets per employee. These industries have a high degree of large, expensive equipment and automatic control equipment and are said to be "capital intensive." Examples of such industries are crude-oil production, energy, petroleum refining, chemicals, and pharmaceuticals. Other industries that require a large amount of labor to manufacture or sell a product are said to be "labor intensive." Examples are merchandising, textiles, and food consumer products. National magazines occasionally publish information listing the assets and the number of employees so that the capital or labor intensiveness may be determined [1]. Table 4.1 is a list of assets per employee for selected industrial sectors.

Total capital investment includes funds required to purchase land, design, purchase, and install equipment and buildings, as well as to bring the facility into operation [2].

A list of these items includes:

- Land
- Fixed capital investment
- Offsite capital
- Allocated capital
- Working capital
- Other capital items
  - Interest on borrowed funds prior to startup
  - Catalyst and chemicals
  - Patents, licenses, and royalties

Table 4.1 Assets per Employee

Industry sector	Assets/employee
Mining, crude oil production	$2,203,000
Energy	1,978,000
Petroleum refining	1,373,000
Motor vehicles and parts	446,000
Chemicals	416,000
Pharmaceuticals	394,000
Forest and paper products	360,000
Semiconductors and electronic components	341,000
Beverages	304,000
Computers and office equipment	304,000
Metals	286,000
Soaps, cosmetics	235,000
Aerospace and defense	216,000
Food consumer products	131,000
Rubber and plastics	131,000
General merchandise	79,000
Textiles	75,000

Source: Compiled from Ref. 1.

Each of the above items will be discussed in detail in this chapter. Not every item in the list appears in every estimate.

4.1 LAND

Although land is a small part of the total capital investment, it should be included. Companies will frequently purchase a tract of land for a future plant location and will allocate a parcel of this land at cost to a project when the project is authorized. Other companies consider land as a sunk cost and since it is small will eliminate it from economic evaluation considerations.

Land costs may be obtained by checking with the firm's real estate department (if it has one). Local chambers of commerce or real estate agents may be able to give information on land costs. In the absence of such data, and for preliminary estimates only, about 3% of the fixed capital investment may be used to estimate land costs.

4.2 FIXED CAPITAL INVESTMENT

The fixed capital investment for a plant includes the manufacturing equipment, piping, ductwork, automatic control equipment, structures, insulation, painting, site preparation, and environmental control equipment, as well as engineering and contractor's costs. One may think of it as that part of the total investment pertinent to the manufacturing of a product; it is "fixed" to the land. It is the depreciable part of the total capital investment. Land is not a part of the fixed capital investment and is not depreciable. Numerous techniques are available for estimating the fixed capital investment and shall be discussed in detail in following sections.

4.2.1 Capital Cost Estimates

When a firm considers a project to manufacture a product, a capital cost estimate is prepared. An in-house engineering staff may develop the estimate, if the staff is large enough, or the estimate may be outsourced to an engineering or consulting company.

4.2.1.1 Classification of Estimates

There are two broad classes of cost estimates: *grass-roots* and *battery-limits* estimates. The former, also called a *green-field* estimate, is a descriptive term. It means the entire facility is estimated starting with site preparation and includes building and structures, processing equipment, utilities, service facilities, storage facilities, railroad yards, and docks. A *battery-limits* estimate is one in which there is an imaginary boundary drawn around the facility to be estimated. It is assumed that all raw materials, utilities, services, etc. are available at the boundary in the proper quantity and with the desired quality to manufacture the product in question. Only costs within this boundary are estimated—hence the name *battery-limits* estimate.

4.2.1.2 Quality of an Estimate

Capital cost estimation is more an art than a science. An estimator must use a great deal of judgment in the preparation of an estimate. As the estimator gains experience, the accuracy of the estimate improves.

Estimates may be classified further based upon the quality and the amount of required information. In an attempt to bring order to the types of estimates, The American Association of Cost Engineers [3] has proposed the following:

Estimate type	Accuracy range
Order of magnitude	-30 to $+50\%$
Budget	-15 to $+30\%$
Definitive	-5 to $+15\%$

Many companies have a fourth type between the budget and the definitive type called an *authorization* estimate which has an accuracy range of -10% to

+20%. Still other companies may have a fifth category called *detailed* estimate that has a purported accuracy range of −5% to +10%. The five-category breakdown is as follows:

Estimate type	Accuracy range
Order of magnitude	−30% to +50%
Study	−25% to +30%
Preliminary	−20% to +25%
Definitive	−10% to +20%
Detailed	−5% to +10%

During inflationary periods, there is an overlap in the accuracy range and therefore the distinction between estimates may be blurred. Figure 4.1 shows the relationship between the two estimating procedures.

In this text, the five-category estimate shall be used. Nichols [4] in 1951 prepared an estimating guide of information required to prepare capital cost estimates. A similar guide, Figure 4.2 [5], based upon the Nichol's chart, will be

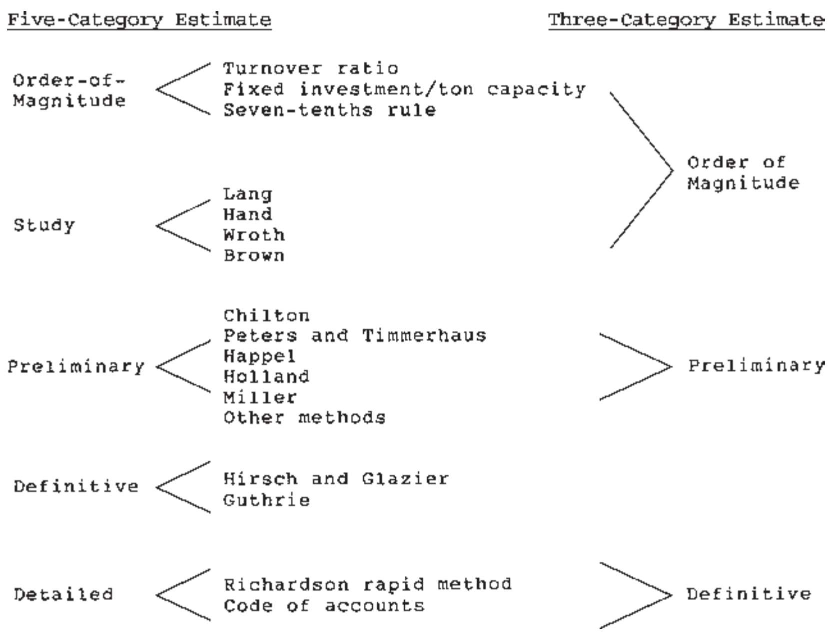

FIGURE 4.1 Relationship between two estimating procedures. (From Refs. 2, 3.)

ESTIMATING INFORMATION GUIDE

INFORMATION EITHER REQUIRED OR AVAILABLE

ESTIMATE TYPES: DETAILED (FIRM); DEFINITIVE (PROJECT CONTROL); PRELIMINARY (BUDGET AUTHORIZATION); STUDY (FACTORED); ORDER OF MAGNITUDE (RATIO)

		ORDER OF MAGNITUDE (RATIO)	STUDY (FACTORED)	PRELIMINARY (BUDGET AUTHORIZATION)	DEFINITIVE (PROJECT CONTROL)	DETAILED (FIRM)
SITE	LOCATION		•	•	•	•
	GENERAL DESCRIPTION		•	•	•	•
	SITE SURVEY			•	•	•
	GEOTECHNICAL REPORT			•	•	•
	SITE PLOT PLAN AND CONTOURS				•	•
	WELL-DEVELOPED SITE FACILITIES					•
PROCESS FLOW	ROUGH SKETCHES		•			
	PRELIMINARY			•		
	ENGINEERED				•	•
EQUIPMENT	ROUGH SIZES AND CONSTRUCTION		•	•		
	ENGINEERED SPECIFICATIONS				•	•
	VESSEL DATA SHEETS				•	•
	GENERAL ARRANGEMENT			•	•	
	FINAL ARRANGEMENT					•
BUILDINGS AND STRUCTURES	ROUGH SIZES AND CONSTRUCTION		•	•		
	FOUNDATION SKETCHES			•	•	
	ARCHITECTURAL AND CONSTRUCTION			•	•	•
	PRELIMINARY STRUCTURAL DESIGN			•	•	
	GENERAL ARRANGEMENTS AND ELEVATIONS				•	•
	DETAILED DRAWINGS					•
UTILITIES AND SERVICES	ROUGH QUANTITIES		•			
	PRELIMINARY HEAT BALANCE			•		
	PRELIMINARY FLOW SHEETS			•		
	ENGINEERED HEAT BALANCE				•	•
	ENGINEERED FLOW SHEETS				•	•
	DETAILED DRAWINGS					•
PIPING AND INSULATION	PRELIMINARY FLOW SHEETS		•	•		
	ENGINEERED FLOW SHEETS				•	•
	PIPING LAYOUTS AND SCHEDULES					•
	INSULATION ROUGH SPECIFICATIONS			•		
	INSULATION APPLICATIONS				•	•
	INSULATION DETAILS					•
INSTRUMENTATION	PRELIMINARY LIST			•		
	ENGINEERED LIST				•	•
	DETAIL DRAWINGS					•
ELECTRICAL	ROUGH MOTOR LIST AND SIZES		•	•		
	ENGINEERED LIST AND SIZES				•	•
	SUBSTATION NUMBER AND SIZE			•	•	•
	PRELIMINARY SPECIFICATIONS			•	•	
	DISTRIBUTION SPECIFICATIONS					•
	PRELIMINARY INTERLOCKS AND CONTROLS				•	
	ENGINEERED SINGLE-LINE DIAGRAMS				•	•
	DETAILED DRAWINGS					•
WORK-HOURS	ENGINEERING AND DRAFTING		•	•	•	•
	CONSTRUCTION SUPERVISION					•
	CRAFT LABOR				•	•
PROJECT SCOPE	PRODUCT, CAPACITY, LOCATION, UTILITIES, AND SERVICES; BUILDING REQUIREMENTS, PROCESS, STORAGE, AND HANDLING	•	•	•	•	•

FIGURE 4.2 Information guide for capital cost estimates. (Adapted from Ref. 5.)

TABLE 4.2 Cost of Preparing a Capital Cost Estimate

Type of estimate	Cost (% of capital cost)
Order of magnitude	0.01–0.05
Study	0.10–0.20
Preliminary	0.20–0.50
Definitive	0.40–1.50
Detailed	1.00–5.00

Source: Refs. 2, 3.

used in this text. From the guides, it is apparent that the more information available, the better the accuracy of the estimate.

An estimate might be prepared and used as follows:

To select a business opportunity from alternative proposals
To select a process design from a number of alternatives
To prepare feasibility studies
To appropriate funds for construction
To present and select engineering bids
To facilitate cost control of a project during implementation

Before preparing an estimate, it is advisable to consider carefully the purpose for which the estimate is to be used. For example, in the early stages of process development, an order-of-magnitude estimate may suffice for screening ideas whereas study estimates may be used for preparing preliminary economics. If the results appear promising, then perhaps a preliminary estimate with bids on selected major equipment items might be prepared. Preliminary estimates are often used for economic planning, refining economics, and perhaps requesting authorization from management to do further engineering. If the project economics are still promising, a definitive estimate may be prepared to seek project fund and construction authorization. Ultimately, a definitive or detailed estimate for plant construction and budget control will be prepared. The cost of preparing estimates increases according to the type of estimate, as shown in Table 4.2.

Anyone concerned with the results of estimates should recognize the degrees of variability inherent in an estimate basis. A widely accuracy range indicates that there is a strong possibility that there would be a large degree of uncertainty and an overrun, especially if a preliminary estimate is used for appropriation of funds. Sometimes this fact is not made clear to management and no one should risk an appropriation based upon preliminary figures although there may be pressure to obtain numbers quickly.

4.2.1.3 Equipment Cost Data

The foundation of a fixed capital investment estimate is the equipment cost data. From these data, through the application of factors or percentages based upon experience, a fixed capital investment estimate may be prepared. It is essential to have reliable equipment cost data but the engineer preparing the estimate must exercise good judgment in the selection and application of the data. There are many sources of data listed in the literature [6–12], but some are old and the latest data published was in 1990 [12]. There has been no significant cost data published in the open literature since that date. It is essential for the estimator to know:

- Source of the data
- Basis for the cost data
- Date of the cost data
- Potential errors in the cost data
- Range over which the cost data apply

Most data clearly state the date of the data but should the source be a textbook, it is advisable that if no date is given, deduct 2 years from the publication of the text for a base date. One should seek the latest cost data since the data reflect new technology and improved designs. Old cost data, 10 or more years old, should be suspect and if no new data are available, the judicious application of cost indexes may be used as a last resort to update costs. It is true that some equipment item designs have not changed in 15–20 years.

In order to obtain current cost data, one should solicit bids from equipment vendors. It is essential to impress on the vendor that the information is to be used for preliminary estimates. One disadvantage of using the vendor source is that there is a chance of compromising proprietary information.

4.2.1.3.1 Data Presentation. Cost data are stated as *purchased, delivered,* or *installed* costs. *Purchased cost* is the price of the equipment FOB (free on board) at the manufacturer's plant. *Delivered cost* is the price of the equipment plus delivery charges to the purchaser's plant FOB. For estimating purposes, delivery charges east of the Mississippi River range from 3 to 5% of the purchased cost and these charges are 7–10% of the purchased costs on the West coast.

Some cost data are reported as *installed cost*. This means the equipment item, for instance, a centrifugal pump has been purchased, delivered, uncrated, and placed on a foundation in an operating department but does not include piping, electrical, insulation costs. Perhaps a more accurate term would be *set-in-place cost.*

Equipment cost data are correlated as a function of equipment parameters. This correlation technique is used whether the costs are purchased, delivered, or installed equipment costs. Typical capacity parameters are presented in Table 4.3.

TABLE 4.3 Cost-Capacity Parameters[a]

Equipment	Capacity factors[b]
Heat exchangers	Surface area, number of passes, pitch, type head, pressure
Tanks, receivers	Volume, pressure, vertical or horizontal
Pumps	Head, capacity, type of pump, motor size
Blowers, fans	Flow rate, pressure, motor size
Compressors	Capacity, discharge pressure, number of stages, motor size
Towers	Height, diameter, internals (plates or packing), operating pressure
Filters	Filter area, pressure, type
Dust collectors	Flow rate, pressure, type
Wet scrubbers	Flow rate
Cyclone separator	Flow rate, type
Cooling towers	Capacity, approach temperature
Conveyors	Length, type
Dryers	Drying area, or volume
Evaporators	Heat exchanger area, type
Furnaces	Heat transferred, type
Mills	Mill capacity, type
Reactors	Reactor volume, pressure, type

Source: Ref. 2.
[a] Cost data are frequently expressed as a function of equipment factors.
[b] Materials of construction is a variable in all the above equipment.

A simple convenient method of presenting cost data is by an equation:

$$C_2 = C_1 \left(\frac{S_2}{S_1} \right)^n \tag{4.1}$$

where

C_1 = cost for equipment capacity S_1
C_2 = cost for equipment capacity S_2
n = an exponent that varies between 0.30 and 1.20 depending on the type of equipment

Equation (4.1) is known as the *six-tenths* or *0.6*, *rule*. This equation permits the user to obtain a cost for an equipment item of a different size when the cost for given size is known. For most process equipment, the exponent varies between 0.4 and 0.8 with an average value of about 0.6. When the exponent is unknown, this value may be used. Typical equipment cost-capacity exponents are found in Table 4.4. An extensive list of cost-capacity exponents was published by Remer and Chai in 1990 [6].

Example 4.1 is an example of the application of the 0.6 rule.

TABLE 4.4 Cost-Capacity Exponents[a]

Equipment group	Average exponent
General equipment	0.68
Heat exchange equipment	0.68
Fluid-moving equipment	0.63
Tanks, vessels, and towers	0.63
Environmental equipment	0.82

Source: Ref. 6.
[a] Average cost-capacity exponents for equipment groups are presented in this table. For a detailed listing of exponents by specific equipment, see Appendix D.

Example 4.1

Problem Statement:

Recently a cast iron leaf pressure filter with 100 ft^2 was purchased for clarifying an inorganic liquid stream for $15,000. In a similar application, the company will need a 450 ft^2 cast iron leaf pressure filter. The size exponent for this type filter is 0.6 (see Appendix D). Estimate the purchased price of the 450 ft^2 unit.

Solution:

$$\begin{aligned} \text{Cost}_{450} &= \text{cost}_{100}\left(\frac{\text{capacity}_{450}}{\text{capacity}_{100}}\right)^{0.6} \\ &= \$15,000\left(\frac{450}{100}\right)^{0.6} = \$15,000(2.47) = \$37,050 \end{aligned}$$

Graphical Presentation. Equipment cost data are presented in the literature by Guthrie [7], Hall et al. [8], Hall et al. [9], Peters and Timmerhaus [10], Garrett [11], and Page [12] as logarithmic plots of cost as a function of equipment capacity. Figure 4.3 is a typical example of a cost-capacity plot. Special attention must be paid to the cost, be it purchased, delivered, or installed.

Although some cost-capacity plots indicate a straight-line relationship, these lines are not straight. They are slightly curved at both the low-capacity and high-capacity ends of the plot, and therefore large errors may be produced at either end of the capacity scale. Actually, the exponent is not a constant in any given case and the manner in which it varies may not be known. The cost-capacity plot, Figure 4.4, shows that n could vary from 0.4 to 0.9 over the desired range. If possible, before using any cost-capacity data, it is advisable to determine how the data were obtained and correlated. The data accuracy may

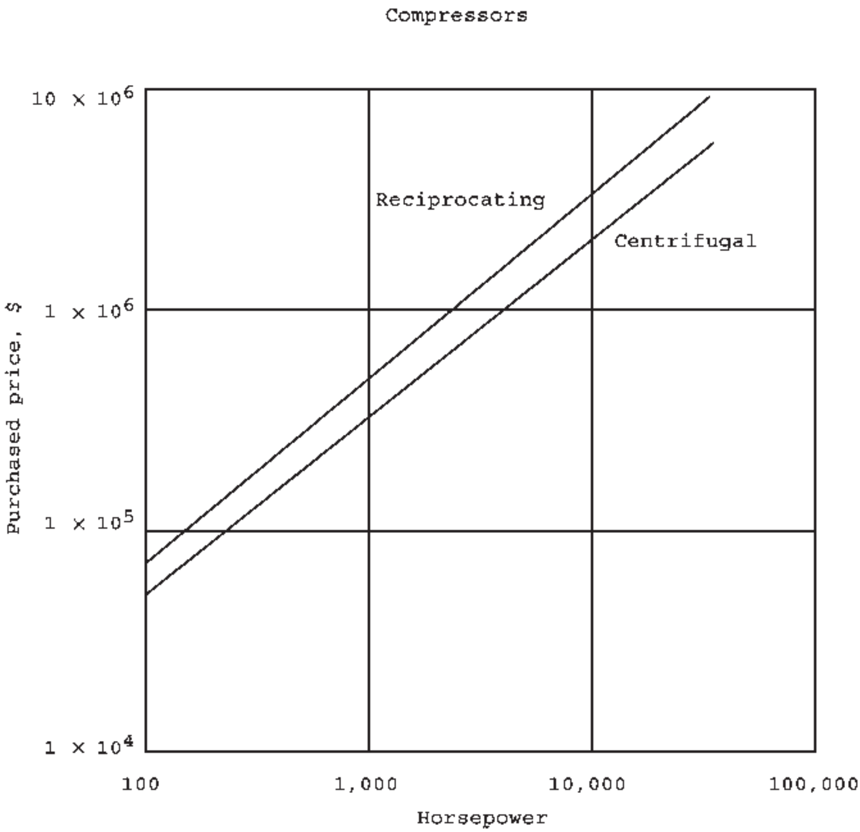

FIGURE 4.3 Typical equipment cost-capacity plot. (From Ref. 2.)

be high over a very narrow range of capacity, usually in the middle of the range. C. A. Miller [13] reported that errors are introduced:

- If one attempts to correlate cost data with one independent variable, especially when more than one variable is needed to represent the data
- If attempts are made to correlate cost with capacity when pressure and temperature, materials of construction, and design features vary considerably
- If one line is drawn through smoothed data when more than one line, perhaps a curve, is needed.
- If technological advances in equipment design take place or no consideration is given to the "learning curve" in presenting cost correlations

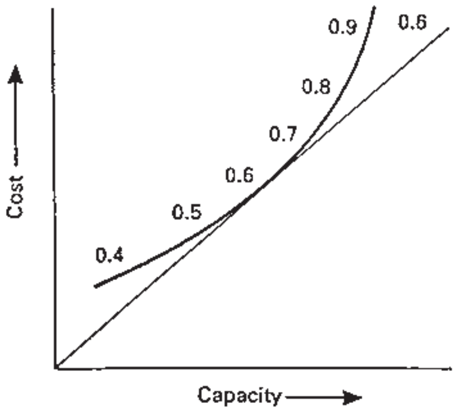

FIGURE 4.4 Variations of *n* in a cost-capacity plot.

If we assume that for an equipment item, a cost-capacity exponent is 0.6, doubling the capacity will increase the cost about 50–60%, not 100%. The economy of scale is reflected in the exponent. If the exponent is less than 1.0, there is an economy of scale. As n approaches the value of 1, the economy of scale disappears. An exponent greater than 1.0 is a negative economy of scale and multiple equipment units should be used. This is true not only for equipment items but also for cost data for entire plants.

Algorithm Format. A more convenient way to display cost-capacity data is by an algorithm. They are readily adaptable in computer cost-estimating programs. Cost data may be represented by using an equation with equation modifiers to account for pressure, temperature, materials of construction, equipment design type, etc. For example, a shell-and-tube heat exchanger cost developed for ASPEN [14] may be estimated from the following basic equation:

$$C_E = 1.218\, C_B F_D F_{\mathrm{MC}} F_P \tag{4.2}$$

where

C_E = exchanger cost
C_B = base cost of a carbon steel, floating-heads exchanger, 150 psig design pressure
F_D = design-type cost factor if different from that in C_B
F_{MC} = material of construction cost factor
F_P = design pressure cost factor

Correlations for base cost, design type factor, material of construction factor, and design pressure factor can be developed as secondary algorithms:

Base cost:

$$C_B = \exp\,[8.821 - 0.30863\ln(A) + 0.0681(\ln A)^2] \tag{4.3}$$

where A is the heat transfer area between 150 and 12,000 ft^2

Design type, F_D:

Fixed head	$\exp\,[-1.1156 + 0.0906(\ln A)]$
Kettle reboiler	1.35
U tube	$\exp\,[-0.9816 + 0.0830(\ln A)]$

Design pressure range (psig), F_P:

100–300	$0.7771 + 0.04981(\ln A)$
300–600	$1.0305 + 0.07140(\ln A)$
600–900	$1.1400 + 0.12088(\ln A)$

Material of construction:

$$F_{MC} = g_1 + g_2(\ln A) \tag{4.4}$$

Material	g_1	g_2
Stainless steel 316	0.8603	0.23296
Stainless steel 304	0.8193	0.15984
Stainless steel 347	0.6116	0.22186
Nickel 200	1.5092	0.60859
Monel 400	1.2989	0.43377
Inconel 600	1.2040	0.50764
Incoloy 825	1.1854	0.49706
Titanium	1.5420	0.42913
Hastlelloy	0.1549	0.51774

Material

Shell/tube	f_m
cs/cs	1.0
cs/304L stainless	1.9
cs/316 stainless	2.2

Pressure

Bars	f_p
<4	1.00
4–6	1.10
6–7	1.25

To bring the cost obtained from the above relationships to the present time (late 2002), it is necessary to multiply the cost by 1.25. Walas [15] published algorithms for a variety of equipment that may be found in Appendix C.

4.2.1.4 Equipment Sizing

Before equipment costs can be obtained, it is necessary to calculate equipment sizes, specify operating temperatures and pressures as well as materials of construction. To size equipment, one must prepare material and energy balances to determine the quantities of material processed and the amount of energy transferred. With the above information, preliminary equipment sizes may be determined. In this text, it shall be assumed that a preliminary cost of equipment is to be developed. To assist the reader in the sizing task, heuristics or rules of thumb may be used for a preliminary estimate. Rules of thumb published by Walas [15] may be used to size equipment and they are found in Appendix B. Other rules of thumb may be found in Refs. 16–19.

Example 4.2 is an example of how a rule of thumb is used to size an equipment item for a preliminary estimate.

Example 4.2

Process design of a shell-and-tube heat exchanger

Problem Statement:

An oil at a rate of 490,000 lb/hr is to be heated from 100 to 170 F with 145,000 lb/hr of kerosene at initially at 390 F from another plant unit. The oil stream enters at 20 psig and the kerosene stream at 25 psig. The physical properties are:

Oil 0.85 sp. gr.; 3.5 cP at 135 F; 0.49 sp.ht.
Kerosene 0.82 sp.gr.; 0.4 cP; 0.61 sp.ht.

Estimate the cost of an all carbon steel exchanger in late 2002. Assume a counterflow 1–2 shell-and-tube heat exchanger.

$$\begin{aligned}\text{Energy required to heat oil stream} &= (490,000)(0.49)(170 - 100\,\text{F})\\ &= 16,807,000\,\text{Btu/hr}\end{aligned}$$

$$\text{Exit kerosene temperature } T = 390 - \left(\frac{490{,}000}{145{,}000}\right)\left(\frac{0.49}{0.61}\right)(170 - 100\,\text{F})$$
$$= 200\,\text{F}$$

$$\text{LMTD} = \frac{220 - 100}{\ln 2.2} = \frac{120}{0.788} = 152.2\,\text{F}$$

Calculating the F factor for efficiency:

$$P = \frac{170 - 100}{390 - 100} = 0.241$$

$$R = \frac{390 - 200}{170 - 100} = 2.71$$

$$F = 0.88$$

(from Perry [5])

Since the F factor must be greater than 0.75, this exchanger is satisfactory. Then

$$\Delta T = (F)(\text{LMTD}) = (0.88)(152.2) = 133.9\,\text{F}$$

From Appendix B, a U_D of 50 Btu/hr ft^2 F is satisfactory.

$$Q = U_D A\,\Delta T = 16{,}807{,}000 = (50(A)(133.9)$$
$$A = 2510\,\text{ft}^2$$

Use the heat exchanger cost algorithm:

$$C_b = \exp\,[8.821 - 0.30863(\ln A) + 0.0681(\ln A)^2]$$
$$C_b = \exp\,[8.821 - 0.30863(7.83) + 0.0681(61.3)] = \$39{,}300$$

$$f_d = 1.0$$

$$f_m \text{ for cs/cs material} = 1.0$$

$f_p = 1.00$ (since this exchanger is operating below 4 bar).

Therefore,

$$C = f_d f_m f_p C_b = (1.0)(1.0)(1.0)(\$39{,}300) = \$39{,}300 \text{ in } 1986$$

CE Index 1986 = 318

CE Index late 2002 = 398

The cost of this heat exchanger in late 2001 is (\$39,300)(398/315) = \$49,200.

4.2.1.5 Cost Indexes

Cost data are presented as of a specific date. They are adjusted through the use of cost indexes that are based upon constant dollars in a base year and actual dollars in a specified year. The base year selected for each index was a period in which inflation was flat and the economy stable. Most published cost indexes are about 6 months behind. Projections of cost data into the near future have to take into account not only inflation rates but also short-term estimates of what an index might be. Correction for inflation is, at best, an estimate of what the economy might do. This topic will be discussed later in this chapter. Many cost indexes are published on a regular basis. Some indexes can be used for estimating equipment costs while other indexes apply only to labor and materials in specialized fields. Selected cost indexes are found in Table 4.5.

4.2.1.5.1 Marshall and Swift Cost Index (M&S). The Marshall and Swift Index, originally known as the Marshall and Stevens Index, was established in the base year, 1926, with a value of 100. The index is reported as a composite of two

TABLE 4.5 Cost Indexes

Year	M&S Index(1)(2)a	CE Index(1)(2)	Nelson–Farrar Index(1)(3)
Base	1926 = 100	1957–1959 = 100	1946 = 100
1980	675	261	823
1985	813	325	1074
1990	915.1	357.6	1225.7
1991	930.6	361.3	1252.9
1992	943.1	358.2	1277.3
1993	964.2	359.2	1310.8
1994	993.4	368.1	1349.7
1995	1027.5	381.1	1392.1
1996	1039.1	381.7	1418.9
1997	1056.8	386.5	1449.2
1998	1061.9	389.5	1477.6
1999	1068.3	390.6	1497.2
2000	1089.0	394.1	1542.7
2001	1094.3	396.8	1574.2
2002	1104.2	398.1	——
	3Q	Sept.	June

Sources: (1) Ref. 2. (2) From 1990 on, the M&S and CE indexes are from *Chemical Engineering* [20]. (3) The Nelson–Farrar indexes from 1990 on are found in *Oil and Gas Journal* [22].

[a] Process industry average instead of all-industry average.

major components, namely, a process-industry equipment average and all-industry equipment average. The process-industry equipment average is based upon selected process industries. The percentages used for this average are cement, 2; chemicals, 48; clay products, 2; glass, 3; paint, 5; paper, 10; petroleum products, 22; and rubber, 8. Related industries such as electric power, mining and milling, refrigeration, and steam power are also included. The M&S Index tracks equipment costs and installation labor, thereby reflecting changes in installed equipment costs. The all-industry average is a simple arithmetic average of individual indexes for 47 different types of industrial, commercial, and housing equipment. Included in the Marshall and Swift Index is a correction for changes in labor productivity. This index is found in each issue of *Chemical Engineering,* on the pages entitled *Economic Indicators* [20].

4.2.1.5.2 Chemical Engineering Index (CE). The Chemical Engineering Index was established in the early 1960 s using a base period of 1957–1959 as 100. The index consists of four major components:

Component	Weight factor, %
Equipment, machinery, and supports	61
Construction labor	22
Building materials and labor	7
Engineering and supervision	10
Total	100

The dominant components, equipment, machinery, and supports consist of the following subcomponents:

Subcomponent	Weight factor, %
Heat exchangers and tanks	37
Process machinery	14
Pipe, valves, and fittings	20
Process instruments	7
Pumps and compressors	7
Electrical equipment	5
Structural supports and miscellaneous	10
Total	100

This index is intended for use in escalating process plant construction costs and is designed to reflect trends in chemical process equipment costs. In determining the value of the index, prices for the above components were obtained from the Bureau of Labor Statistics Producer Price Index [21]. The CE Index is updated monthly and reflects short-term changes in chemical industry plant costs, although it lags in time by about 3 months. In 1982, a correction was introduced to reflect changes in labor productivity; in January 2002, it was revised by updating the components making up the index and in revising the productivity factor. Like the M&S Index, the CE Index is found in *Chemical Engineering* under *Economic Indicators* [20].

4.2.1.5.3 Nelson–Farrar Indexes (NF). The Nelson–Farrar Indexes were originally known as the Nelson Refinery Construction Indexes [22]. These indexes are calculated and published in the first issue each month of the *Oil and Gas Journal* with quarterly summaries in January, April, July, and October. The original indexes were established in 1946 with a value of 100 and are heavily weighted towards the petroleum and petrochemical industries. The NF Indexes are based upon the following components:

Pumps, compressors, etc.	Heat exchangers
Electrical machinery	Miscellaneous equipment, average
Internal combustion engines	Materials
Instruments	Labor

A more detailed breakdown of each of the above components may be found in annual index summaries and how the index was determined may be found in the November 29, 1978 issue of the *Oil and Gas Journal*. This index does account for changes in labor productivity.

4.2.1.5.4 Engineering News Record Index (ENR). The Engineering News Record Index is the oldest cost index. It was established in 1913 with an arbitrarily set value of 100 and has been adjusted twice as a result of inflation in 1926 and in 1949. The 1913 index today (late 2001) is 6391. The ENR Index is more suitable for the general construction business than for the CPI. It is based upon labor craft rates, the cost of lumber, steel and other construction materials based upon a 46-city average. This index does not account for adjustment in labor productivity, and, therefore has a tendency to increase more rapidly than other indexes. The ENR Index may be found weekly in *Engineering News Record* [23].

4.2.1.5.5 Vatavuk Air Pollution Control Cost Index (VAPCCI). This index is applicable only to air pollution control equipment. The time base is the first quarter of 1994 with a value of 100. Air pollution control devices presented are:

Carbon absorbers	Mechanical collectors
Catalytic incinerators	Refrigeration systems
Electrostatic precipitators	Regenerative thermal oxidizers
Fabric filters	Thermal incinerators
Flares	Wet scrubbers
Gas absorbers	

A detailed explanation of the development and use of the VAPCCI may be found in the *Economic Indicators* section of *Chemical Engineering* [20].

4.2.1.5.6 Bureau of Labor Statistics (BLS). The Bureau publishes information on material and labor indexes for various industries. The best-known and most useful information is found as the Producer Price Index; see also information in the *Monthly Labor Review* [24].

4.2.1.5.7 Mining and Metallurgical Index. This is an index that is specific to the mining and metallurgical industries. It is found frequently in *Cost Engineering* [25].

4.2.1.5.8 EPA–STP Treatment Plant Index. This index is intended for escalating prices in the primary and secondary waste treatment facilities. The base period is 1957–1959 and the index value is 100. Monthly summaries are found in the *Journal of Water Pollution Control Foundation* [26].

4.2.1.5.9 OFJ–Morgan Pipeline Index. As the name of the index implies, it is specific to the pipeline industry. It is published every 2 months in the *Oil and Gas Journal* [22].

4.2.1.5.10 Foreign Indexes. Occasionally, cost indexes for foreign countries, e.g., Great Britain, Netherlands, France, Germany, and Australia, are published in *Cost Engineering* [25]. In using the foreign indexes, one should determine if the money exchange rate has been taken into account.

4.2.1.5.11 Company Indexes. Companies that have the manpower, experience, and records should develop their own indexes. These will be more realistic for a specific site when weighted properly to reflect local equipment and labor and material costs rather than using a national average.

4.2.1.6 Which Index to Use

The choice of the index to use is based upon the industry in which the person works. If it is general construction, the ENR Index is the best. An engineer in the petroleum or petrochemical business might find the NF Index suitable. In the chemical process industries, either the CE or the M&S are adequate. Although these latter two indexes have different bases, they give similar results. Some companies have a preference of one over the other because in their locale experience has shown that one index is more consistent with company experience. In this text, the appropriate index will be identified.

One large chemical company located on the Gulf Coast has found that the M&S Index is more suitable for their operation. The CE Index is more general for the chemical industry as a whole since it is strongly based upon equipment costs. For the period from the late 1970s to the late 1980s, the two indexes tracked well but as equipment prices increased they went their own way. These two indexes should not be used interchangeably.

4.2.1.7 Use of a Cost Index

A cost index as mentioned earlier is used to project a cost from a base year to another selected year. The following equation is used:

$$\text{Cost at } \theta_2 = \text{cost at } \theta_1 \left[\frac{\text{index at } \theta_2}{\text{index at } \theta_1}\right] \tag{4.5}$$

where

θ_1 = base year
θ_2 = selected year

Example 4.3

Problem Statement:

A stainless steel centrifuge cost \$85,000 in 1990. What is the cost of that same centrifuge in 2001? Use the CE Index.

Solution:

$$\text{CE Index in 1990} = 357.6$$

$$\text{CE Index in 2001} = 396.8$$

$$\text{Cost in 2001} = \text{cost in 1990}\frac{\text{CE Index in 2001}}{\text{CE Index in 1990}}$$

$$\text{Cost in 2001} = \$85{,}000\left(\frac{396.8}{357.6}\right)$$

$$\text{Cost in 2001} = \$94{,}318$$

4.2.1.8 Effect of Inflation and Escalation

Projection of costs to some future date is a highly speculative exercise, but it is necessary to estimate investment costs and operating expenses for developing profitability estimates and corporate business plans. Inflation refers to the increase in the price of goods without a corresponding increase in productivity. This means that there is a tendency for prices in the economy to increase.

Escalation is a more all-inclusive term used to reflect price increases due not only to inflation but also due to supply–demand factors and engineering advances. Projected escalation factors are based on past inflation rates and estimates of where these rates might be in the future.

An effective way is to estimate what the inflation rate might be 1, 2, 3, etc. years in the future and then adjust the rates later as more reliable data become available [2]. For example, initially a cost escalated for a 3-year period from the present might be

$$C_{esc} = (1 + f')(1 + f'')(1 + f''')(C_{present}) \tag{4.6}$$

where $f', f'', f''' =$ inflation rates expressed as a decimal in 3 years.

These factors must be reviewed periodically to reflect changes in inflation. This information may be obtained from newspapers, federal economic reports, and from financial sources such as banks, investment houses, etc.

Example 4.4

Problem Statement:

A drier today costs \$221,000. The estimated inflation rates are expected to be:

$$\text{First year} = 3.5\%$$

$$\text{Second year} = 4.2\%$$

$$\text{Third year} = 4.7\%$$

What is the cost of that drier 3 years hence?

Solution:

$$\begin{aligned} C_{esc} &= (1 + f')(1 + f'')(1 + f''')(C_{present}) \\ &= (1.035)(1.042)(1.047)(\$221,000) \\ &= \$249,500 \end{aligned}$$

4.3 ESTIMATION OF FIXED CAPITAL INVESTMENT

Numerous techniques are available for estimating the fixed capital investment. The methods vary from a simple single factor to a detailed method using a code of accounts that involves item-by-item costing. The estimating methods presented in the following sections are some of but not all the methods available. The methods will be discussed according to the estimate type.

4.3.1 Order-of-Magnitude Estimates

A project scope is essential before preparing an estimate irrespective of the quality of the estimate. The scope defines the basis for the estimate and the information required to prepare the estimate. Such information is found in Figure 4.2. As the project moves from an order-of-magnitude to a detailed estimate, the scope will increase in detail. At best the accuracy range for these estimates may vary from -30% to $+50\%$. As is noted from Figure 4.2, the minimum information required is a project scope, including location, utilities, and services, etc., but a preliminary flowsheet with simple material and energy balances and a general design basis would increase the accuracy of the estimate. The name of this category of estimates is misleading in that the accuracy is better than the literal interpretation of the term order of magnitude. These estimates are used for screening processes, rough business plans, or long-range planning at the inception of a proposed project.

4.3.1.1 Turnover Ratio

This is a rapid, simple method for estimating the fixed capital investment but is one of the most inaccurate. The turnover ratio is defined as

$$\text{Turnover ratio (TOR)} = \frac{\text{annual gross sales}}{\text{fixed capital investment}} \tag{4.7}$$

The annual gross sales figure is the product of the annual production rate and the selling price per unit of production. A basic assumption is that all product made is sold. For a large number of chemical processes operating near ambient conditions, the turnover ratio is near 1.0. These ratios may vary from 0.2 to 5.0. Values less than 1.0 are for large volume, capital-intensive industries and those greater than 1.0 are for processes with a small number of equipment items. Factors affecting the TOR may be temperature, pressure, materials of construction, the amount of equipment required, plant operating rate. Inflation affects the ratio because both the numerator and denominator will vary but not necessarily in the same ratio. A list of turnover ratios is found in Table 4.6.

Financial analysts use the reciprocal of the turnover ratio, called the *capital ratio*, to compare companies in the same line of business. Example 4.5 is an application of the TOR method.

Example 4.5

Problem Statement:

Estimate the fixed capital investment for a 1500 ton/day ammonia plant using the turnover ratio. The current gross selling price of ammonia is \$150/ton. The plant will operate at a 95% stream time.

Solution:

$$\text{TOR} = \frac{\text{annual gross sales}}{\text{fixed capital investment}}$$

Table 4.6 Turnover Ratios[a]

Product	TOR
Acetic acid	1.70
Acrylonitrile	1.55
Ammonia	0.65
Ammonium sulfate	3.82
Benzaldehyde	1.00
Benzene	8.25
Butadiene	1.68
Butanol	1.10
Carbon tetrachloride	1.00
Ethylene dichloride	0.51
Ethylene glycol	1.10
Ethyl ether	6.05
Methanol	1.00
Methyl chloride	2.95
Methyl isobutyl ketone	2.10
Maleic anhydride	4.82
Nitric acid	3.95
Phthalic anhydride	3.12
Polyethylene	0.40
Polypropylene	0.35
Sodium carbonate	0.39
Styrene	5.21
Sulfuric acid	0.63
Urea	2.36
Vinyl chloride	3.40

Sources: Refs. 2, 11.

[a] $\text{Turnover ratio (TOR)} = \dfrac{\text{annual gross sales, \$}}{\text{fixed capital investment, \$}}$

From Table 4.6, the TOR for an ammonia plant is 0.65.

$$\text{Annual gross sales} = \$150/\text{ton} \times 365 \times 0.95 \times 1500\ \text{ton/day}$$

$$= \$78{,}000{,}000$$

$$\text{FCI} = \frac{\text{annual gross sales}}{0.65} = \frac{\$78{,}000{,}000}{0.65} = \$120{,}000{,}000$$

TABLE 4.7 Fixed Investment per Annual Ton of Capacity

Product	Capacity M tons/year	Fixed investment, $/annual ton capacity
Acetaldehyde	50	400
Ammonia	350	120
Butadiene	240	150
Carbon dioxide	550	80
Ethylene oxide	200	700
Ethyl ether	40	170
Maleic anhydride	60	270
Methanol	300	120
Nitric acid	175	50
Phenol	180	275
Phthalic anhydride	185	220
Polyethylene	20	1800
Propylene	25	210
Sulfuric acid	350	90
Vinyl chloride	500	300

Sources: Refs. 2, 11.

4.3.1.2 Fixed Investment per Annual Ton of Capacity

Fixed capital investments may be calculated in an approximate manner using this method. The data for this method are often in the open literature or from information that will allow one to calculate this information. *Chemical Week* or *Hydrocarbon Processing* are potential sources. The user must be careful in using this information because it may be old or may have been obtained from foreign sources. Salem [27] and Guthrie [7] have reported data from which this ratio may be calculated.

One should recognize that these data are based on a given process, so projecting costs must be via that same process and for a similar plant size. Cost indexes may be used to bring the fixed investment up to date. Table 4.7 is a list of typical values for the fixed investment per annual ton of capacity. An example of this method is found in Example 4.6.

Example 4.6

Problem Statement:

Estimate the fixed capital investment of a 75,000 ton/yr maleic anhydride plant using the data for fixed investment per annual ton capacity in Table 4.7.

Solution:

From Table 4.7 a 60,000 ton/yr plant is \$270 investment per annual ton capacity. Therefore, the fixed capital investment of the plant is 75,000 ton/yr × \$270 per annual ton, or \$20,300,000.

Since this method is sensitive to time and the data presented in Table 4.7 was based on 1986 information, cost indexes must be applied to get a 2001 cost.

$$\text{CE Index for 1986} = 331$$
$$\text{CE Index for late 2001} = 396.8$$

Therefore, the cost in 2001 is estimated to be (\$20,300,000)(396.8/331), or \$24,335,000.

4.3.1.3 Seven-Tenths Rule

It has been found that cost-capacity data for process plants may be correlated using a logarithmic plot similar to the 0.6 rule. Remer and Chai [28] have compiled exponents for a variety of processes and most are between 0.6 and 0.8. The use of an average value 0.7 is the name of this method. Table 4.8 and Appendix E contain appropriate data. The equation is

$$\text{Cost plant } B = \text{cost plant } A\left(\frac{\text{capacity plant } B}{\text{capacity plant } A}\right)^{0.7} \tag{4.8}$$

where cost plant A is the cost of that plant with capacity A and cost plant B is the cost of that plant at capacity B.

In order to use this method, the estimator must have the fixed capital investment for another plant using the same process but at a different capacity. Cost indexes may be used to correct costs for time changes. Example 4.7 is an application of this method.

Example 4.7

Problem Statement:

A company is considering the manufacture of ethylene oxide as an intermediate for its polymer division. The process to be used is the direct oxidation of ethylene. The company built a similar unit in 1997 that had a rated capacity of 100,000 tons annually for \$66,000,000. The projected production of the new facility is to be 150,000 tons annually. Estimate the fixed capital investment in late 2001 dollars to produce the required ethylene oxide.

Solution:

$$\text{CE Index for 1997} = 386.5$$
$$\text{CE Index for late 2001} = 396.8$$

TABLE 4.8 Seven-Tenths Rule

Compound	Process	Size range	Unit	Exponent
Acetaldehyde	Ethylene	25–100	1000 tons/yr	0.70
Acetylene	Natural gas	4–37	1000 tons/yr	0.73
Ammonia	Natural gas	37–110	1000 tons/yr	0.63
Benzene				0.61
Cyclohexane	Benzene, H_2	15–365	1000 tons/yr	0.49
Ethanol	Ethylene by direct hydration			0.72
Ethylene	Refinery gas or hydrocarbons			0.71
Ethylene oxide	Direct oxidation of ethylene			0.67
Methanol	Natural gas			0.71
Phthalic anhydride	Naphthalene or *o*-xylene	21–365	1000 tons/yr	0.72
Propylene				0.70
Sulfuric acid	Contact, sulfur	7–256	1000 tons/yr	0.63
Urea		20–200	1000 tons/yr	0.70
Vinyl chloride	Ethylene, Cl_2 or HCl	27–365	1000 tons/yr	0.88

$$\text{Cost plant } B = \text{cost plant } A\left(\frac{\text{capacity plant } B}{\text{capacity plant } A}\right)^{0.7}$$

Source: Ref. 28.

Equation (4.8) can be modified to include the cost indexes.

$$\text{Cost}_{150}(2001) = \text{cost}_{100}(1997)\left(\frac{\text{capacity } 150}{\text{capacity } 100}\right)^{0.67}\left(\frac{\text{CEI } 2001}{\text{CEI } 1997}\right)$$

$$\text{Cost}_{150}(2001) = (\$60{,}000{,}000)\left(\frac{150}{100}\right)^{0.67}\left(\frac{396.8}{386.5}\right)$$

$$\text{Cost}_{150}(2001) = (\$60{,}000{,}000)(1.31)(1.027)$$

$$= \$80{,}722{,}000, \text{ say } \$80{,}700{,}000$$

4.3.2 Study Estimates

The information needed to prepare a study estimate includes a project scope, preliminary material and energy balances, preliminary flowsheets, rough sizes of equipment, rough quantities of utilities, rough sizes of building and structures, etc. (see Figure 4.2). Study estimates have an accuracy of -30% to $+40\%$.

4.3.2.1 Lang Method

Lang [29] developed a method for obtaining quick estimates of the capital investment based upon information gathered on 14 processing plants of various sizes and types. He recommended that the delivered equipment cost be multiplied by a factor based upon the type of processing plant to obtain the fixed capital investment. These factors include process equipment, instrumentation and automatic control equipment, piping, insulation, electrical, engineering costs, etc., but do not include a contingency factor. The Lang factor method has a tendency to produce high results. The factors are found in Table 4.9.

The Lang factor method is illustrated in Example 4.8.

TABLE 4.9 Lang Factors

Type of plant	Factor
Solids processing	3.10
Solids–fluid processing	3.63
Fluid processing	4.74

Source: Ref. 29.

Example 4.8

Problem Statement:

A small fluid processing plant is considered for construction adjacent to a larger operating unit at a large plant site. The present delivered equipment costs are as follows:

Equipment	Delivered cost
Distillation tower	$500,000
Trays and internals for tower	435,000
Receivers	320,000
Accumulator drum	175,000
Heat exchangers	620,000
Pumps and motors	215,000
Automatic control equipment	300,000
Miscellaneous equipment	150,000

Estimate the battery-limits fixed capital investment, assuming a 15% contingency factor.

Solution:

Sum of the delivered equipment cost = $2,715,000

Because this is a fluid processing plant, the Lang factor is 4.74.

$$\text{Battery-limits fixed capital investment} = (\$2{,}715{,}000)(4.74)(1.15)$$

$$= \$14{,}799{,}000, \text{ or } \$14{,}800{,}000$$

(All calculations will be rounded to three significant figures.)

4.3.2.2 Hand Method

The Hand method [30] is a refinement of the Lang method for quick estimates. The method begins with purchased equipment costs, FOB at the factory. Hand recommended that equipment be grouped by type, such as heat exchangers, pumps, compressors, with an appropriate factor applied to each type for installation. Hand determined these multipliers by analyzing several detailed estimates of plants of the same type. The categories and factors are included in Table 4.10. The justification for different factors is that not all equipment requires the same amount of foundations, piping, electrical, insulation, etc. for installation. For example, the major cost of a compressor installation is in the first cost of the equipment that is a higher percentage of the installed cost compared to that of a pump, since it does not require 3 or 4 times the purchased cost to install the compressor.

TABLE 4.10 Hand Factors

Equipment type	Factor
Fractionating columns	4
Pressure vessels	4
Heat exchangers	3.5
Fired heaters	2
Pumps	4
Compressors	2.5
Instruments	4
Miscellaneous equipment	2.5

A process flowsheet is essential, along with sizes of major plant items, to produce the batter-limits fixed capital investment by this method. The purchased equipment cost is multiplied by an appropriate factor to obtain the investment cost. The Hand method does not include a contingency factor, so the user should apply an appropriate figure. Like the Lang method, accounting for material of construction differences requires experience. To improve the accuracy of this method, factors must be derived from recent installations or from detailed estimates for a given location. Further, this method does not include a contingency factor that must be applied by the user.

The Hand method has a tendency to produce lower results than the Lang method. Example 4.9 is an illustration of this method.

Example 4.9

Problem Statement:

Solve Example 4.8 for the battery-limits fixed capital investment using the Hand method and a 15% contingency.

Solution:

Equipment	Delivered costs ($)
Distillation tower and internals	935,000
Receivers	320,000
Accumulator drum	175,000
Heat exchangers	620,000
Pumps and motors	215,000
Automatic control equipment	300,000
Miscellaneous equipment	150,000

Applying the appropriate Hand factor to each of the above items,

Distillation tower	$935,000 × 4.0 =	$3,740,000
Receivers*	320,000 × 2.5 =	800,000
Accumulator drum*	175,000 × 2.5 =	438,000
Heat exchangers	620,000 × 3.5 =	2,170,000
Pumps and motors	215,000 × 4.0 =	860,000
Automatic controls	300,000 × 4.0 =	1,200,000
Miscellaneous equipment	150,000 × 2.5 =	375,000
	Subtotal =	$9,583,000

*Since there was no information to indicate these units were pressure vessels, they shall be categorized as noted. Had they been pressure vessels, a factor of 4.0 might be appropriate; then

$$\text{Receivers} = \$320{,}000 \times 4.0$$

$$= \$1{,}280{,}000 \text{ or } \$480{,}000 \text{ additional cost}$$

$$\text{Accumulator drum} = \$175{,}000 \times 4.0$$

$$= \$700{,}000 \text{ or } \$262{,}000 \text{ additional cost}$$

Therefore, $9,583,000 + $480,000 + $262,000 = $10,950,000 and when the contingency is applied, the battery-limits fixed capital investment is $10,950,000 × 1.15, $12,184,000, or $12,200,000.

$$\text{Battery-limits fixed capital investment} = \$9{,}583{,}000 \times 1.15$$

$$= \$11{,}020{,}000, \text{ or } \$11{,}000{,}000$$

4.3.2.3 Wroth Method

A more detailed list of equipment installation factors was compiled by Wroth [31]. The data were obtained from production, construction, accounting, etc. records. The factors are presented in Table 4.11. They include the cost of site development piping, electrical installations, painting, foundations, structures, contractor's fees, engineering, overhead, and supervision.

The Lang and Hand methods start with delivered equipment costs, but the Wroth method begins with purchased costs so delivery charges must included. Wroth suggested that if an equipment item is not found in the list, then "use or modify a factor for a similar unit." Although the Wroth method is not as quick as the Lang or Hand method, the results obtained are more accurate. It does have the same disadvantages the Lang and Hand methods have with respect to equipment

TABLE 4.11 Wroth Factors

Equipment	Factor
Blender	2.0
Blowers and fans (including motor)	2.5
Centrifuge (process)	2.0
Compressors	
Centrifugal (motor driven, less motor)	2.0
Centrifugal (steam driven, incl. turbine)	2.0
Reciprocating (steam and gas)	2.3
Reciprocating (motor driven, less motor)	2.3
Ejectors (vacuum units)	2.5
Furnaces (packaged units)	2.0
Heat exchangers	4.8
Instruments	4.1
Motors, electric	3.5
Pumps	
Centrifugal, (motor driven, less motor)	7.0
Centrifugal (steam driven, incl. turbine)	6.5
Positive displacement (less motor)	5.0
Reactor (factor as appropriate, equivalent type equipment)	—
Refrigeration (packaged units)	2.5
Tanks	
Process	4.1
Storage	3.5
Fabricated and field erected	2.0
50,000 + gal	
Towers (columns)	4.0

Source: Ref. 31.

sizes and materials of construction. An example of how to apply this method is presented in Example 4.10.

Example 4.10

Problem Statement:

Solve Example 4.8 for the battery-limits fixed capital investment using the Wroth method. Assume that the delivery charges are 5% of the purchased equipment cost. A 15% contingency factor is to be used.

Solution:

Since the Wroth method begins using purchased equipment costs, the delivered equipment costs will have to be converted.

Equipment	Delivered costs	Purchased costs
Distillation tower, internals	\$935,000	\$890,000
Receivers	320,000	305,000
Accumulator drum	175,000	167,000
Heat exchangers	620,000	590,000
Pumps and motors	215,000	205,000
Automatic controls	300,000	286,000
Miscellaneous equipment	150,000	143,000

Applying the Hand factors to each item:

Distillation tower, internals	$\$890{,}000 \times 4.0 =$	\$3,560,000
Receivers	$305{,}000 \times 3.5 =$	1,068,000
Accumulator drum	$167{,}000 \times 3.5 =$	585,000
Heat exchangers	$590{,}000 \times 4.8 =$	2,832,000
Pumps and motors	$205{,}000 \times 7.7^{a} =$	1,579,000
Automatic controls	$300{,}000 \times 4.1 =$	1,230,000
Miscellaneous equipment	$150{,}000 \times 4.0^{b} =$	600,000
	Subtotal =	\$11,454,000

where

a = average installation value for pumps and motors
b = assumed factor of 4.0

Therefore

$$\text{Battery-limits fixed capital investment} = \$11{,}454{,}000 \times 1.15$$
$$= \$13{,}200{,}000$$

The results of the three methods are:

Lang	\$14,800,000
Hand	11,000,000
Wroth	13,200,000

The Lang method, in general, has a tendency to produce high figures. Whatever figure is reported to management, there should be a statement about the potential accuracy of these study methods, namely, −25% to +30%.

4.3.2.4 Brown Method

Brown [32] developed guidelines for the preparation of order-of-magnitude and study capital cost estimates using a modified modular method. Further, he modified the Lang and Hand methods for materials of construction, instrumentation, and plant location. He then compared the results of the modified Lang and Hand estimates with his method using the module factors of Garret [11] (see Table 4.12). Brown found that the modified Hand and the module factor methods gave results within 3.5%, whereas the results of the modified Lang method were over 30% higher; see the example below.

Brown's material of construction factor F_m is obtained from a plot of F_m versus a material cost ratio, namely, alloy cost/carbon steel cost (see Figure 4.5). For fully instrumented processes F_i a factor of 1.2 is used. If the process is to be built in the US, the location factor F_p is 1.0. The instrumentation and location factors are presented in Table 4.13.

An illustration of the application of the Brown method is found in Example 4.11.

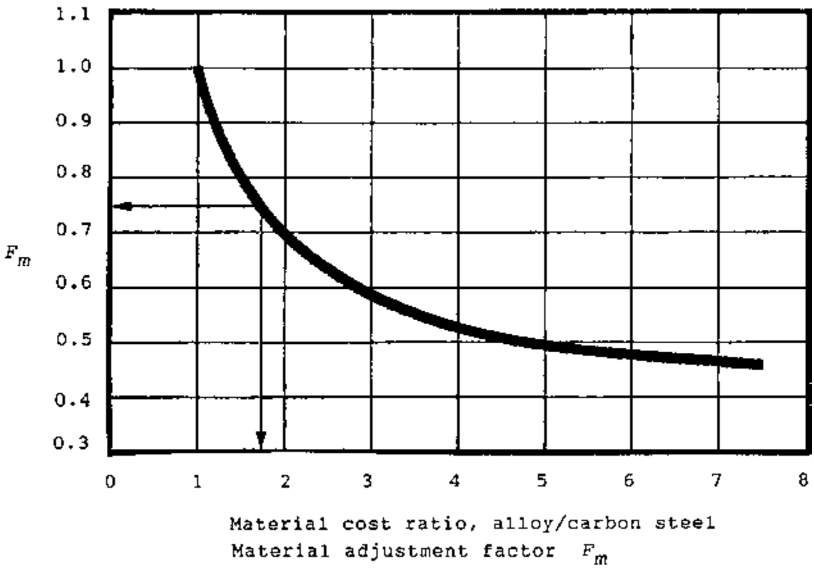

FIGURE 4.5 Brown's material of construction plot. (From Ref. 32.)

Table 4.12 Garrett's Module Factors

Equipment type (carbon steel, unless noted)	Module factor
Agitators: dual-bladed turbines/single-blade propellers	2.0
Agitated tanks	2.5
Blowers, centrifugal	2.5
Centrifuges: solid-bowl, screen-bowl, pusher, stainless steel	2.0
Columns: distillation, absorption, etc.	
Horizontal	3.1
Vertical	4.2
Compressors: low, medium, high pressure	2.6
Cooling towers	1.7
Drives/motors	
Electric for fans, compressors, pumps	1.5
Electric for other units	2.0
Gasoline	2.0
Turbine: gas and steam	3.5
Dryers	
Fluid bed, spray	2.7
Rotary	2.3
Evaporators, single effect-stainless steel	
Falling film	2.3
Forced circulation	2.9
Fans	2.2
Filters	
Belt, rotary drum and leaf, tilting pan	2.4
Others	2.8
Heat exchangers	
Air-cooled	2.2
Double-pipe	1.8
Shell-and-tube	3.2
Pumps	
Centrifugal	5.0
Chemical injection	2.8
Reciprocating	3.3
Turbine	1.8
Pressure vessels	
Horizontal, spherical	3.1
Vertical	4.2
Vacuum equipment	2.2

Source: Adapted from Ref. 11.

Example 4.11

Problem Statement:

Estimate the fixed capital investment for the following list of equipment, using the Hand method and the Brown method.

Solution:

Equipment	Description	Material ratio alloy/C steel	Purchased cost
1. Vacuum dryer heater	200 ft^2 U tube, 304 SS tubes and shell, 150 psig	3.5	$26,000
2. Vacuum dryer	2 ft diameter, 6 ft high, 304 SS, full vacuum, 150 psig	1.7	1,900
3. Vacuum dryer ejector	2 stage, 50 mmHg absolute pressure, 100 lb/hr air flow, 304 SS	2.0	9,900
4. Vacuum dryer pump	240 gpm, 130 psi TDH, 304 SS	2.0	12,800
5. Still heater	U tube, 450 ft^2, 304 SS tubes and shell, 800 psig	3.5	50,700
6. Fatty acid still	10 ft diameter, 35 ft high, 304 SS, heating coil and internals included	1.7	55,000
7. Still bottoms pump	100 gpm, 50 psi, 304 SS	2.0	4,000
8. Overhead condenser	U tube, 570 ft^2, 304 SS	3.5	54,000
9. Overhead surge tank	2 ft diameter, 4 ft high, 304 SS, 50 psig	1.7	1,600
10. Overhead pump	150 gpm, 120 psig TDH, 304 SS	2.0	6,000
11. Still steam ejector	3 stages, ejector and 15 mmHg abs, 20 lb/hr, 304 SS	2.0	124,300

Hand method:

Equipment	Purchase	Hand factor	F_m	
1. Heat exchanger	$26,000	3.5	0.55	$50,200
2. Pressure vessel	1,900	4.0	0.75	5,700

(*continued*)

TABLE 4.12. Continued

Equipment	Purchase	Hand factor	F_m	
3. Steam ejector	17,100	2.5	0.69	17,100
4. Pump	12,800	4.0	0.69	35,300
5. Heat exchanger	50,700	3.5	0.55	97,600
6. Pressure vessel	55,000	4.0	0.75	165,000
7. Pump	4,000	4.0	0.69	11,000
8. Heat exchanger	54,000	3.5	0.55	104,000
9. Pressure vessel	1,600	4.0	0.75	4,800
10. Pump	6,000	4.0	0.69	16,600
11. Steam ejector	124,300	2.5	0.69	214,400
		Total		$721,700

F_m found in Figure 4.5
F_i, process fully instrumented—1.2
F_p, process in the US—1.0
Capital cost, ($721,700)(1.2)(1.0) = $866,000

Module factor method:

This method used the modular factors of Garret [11] found in Table 4.12. Capital cost $=$ Σ(purchased equipment cost $\times$ module factor $\times F_m) \times F_i \times F_p$.

TABLE 4.13 Brown's Location Factors (1993)

Country	Factor
Australia	1.60
Belgium	1.26
Canada	1.32
Denmark	1.46
France	1.64
Germany	1.19
Italy	2.15
Japan	0.95
Netherlands	1.04
Spain	2.32
Sweden	1.79
United Kingdom	1.76

Source: Ref. 32.

Equipment	Purchase	Module factor	F_m	
1. Heat exchanger	$26,100	3.2	0.55	$ 45,900
2. Pressure vessel	1,900	4.2	0.75	6,000
3. Steam ejector	9,900	2.2	0.69	15,200
4. Pump	12,800	5.0	0.69	44,200
5. Heat exchanger	50,700	3.2	0.55	89,200
6. Pressure vessel	55,000	4.2	0.75	173,300
7. Pump	4,000	5.0	0.69	13,800
8. Heat exchanger	54,000	3.2	0.55	95,000
9. Pressure vessel	1,600	4.2	0.75	5,000
10. Pump	6,000	5.0	0.69	20,700
11. Steam ejector	124,300	2.2	0.69	188,700
	Total			$696,900

Again, F_i and F_p are 1.2 and 1.0, respectively. The capital cost is (\$696,900)(1.2)(1.0) = \$836,000. The Lang method modified for instrumentation and materials of construction resulted in a capital cost of \$1,126,000, or 32% higher than the other two methods.

4.3.3 Preliminary Estimates

This quality estimate has many purposes, namely, to screen further processing methods in the research and development stages, to compare in–house technology with purchased technology, to uncover those areas of the process where important design data are missing, and to serve as a basis for an appropriation request.

During a recent literature survey, the author found 25 methods that were classified as preliminary. The methods were divided roughly into two categories. One group consists of factored methods in which a series of factors are applied to items in each method beginning with purchased or delivered equipment costs. The other group consists of *functional units* or *step-counting methods*. Bridgwater [33] reviewed a number of these methods in considerable detail. Because of the great number of methods, it will be necessary to limit those presented here.

The information required to prepare a preliminary estimate is found in Figure 4.2. A great deal of judgment in using factors or in defining a module depends upon the information provided and the experience of the estimator. The accuracy of the various techniques presented in this section will vary from −15% to +25%.

4.3.3.1 Chilton Method

Chilton used multiple factors to obtain a battery-limits fixed capital investment. The method is an extension of previously discussed factored methods. Chilton

TABLE 4.14 Chilton Method

Item	Factor	% of item
1. Delivered equipment cost	1.0	1
2. Installed equipment cost	1.43	1
(or directly from cost data)		
3. Process piping		
Type of plant		
Solid	0.07–0.10	2
Solids–fluid	0.10–0.30	2
Fluid	0.30–0.60	2
4. Instrumentation		
Amount		
None	0.03–0.05	2
Some	0.05–0.12	2
Extensive	0.12–0.20	2
5. Buildings and site development		
Type of plant		
Outdoor	0.10–0.30	2
Outdoor–indoor	0.20–0.60	2
Indoor	0.60–1.00	2
6. Auxiliaries		
Extent		
Existing	0	2
Minor addition	0–0.05	2
Major addition	0.05–0.75	2
New facilities	0.25–1.00	2
7. Outside lines		
Average length		
Short	0–0.05	2
Intermediate	0.05–0.15	2
Long	0.15–0.25	2
8. Total physical plant costs		
Σ of items 2–7		
9. Engineering and construction		
Complexity		
Simple	0.20–0.35	8
Difficult	0.35–0.60	8
10. Contingencies		
Process		
Firm	0.10–0.20	8
Subject to change	0.20–0.30	8
Speculative	0.30–0.50	8

(continued)

Table 4.14. Continued

Item	Factor	% of item
11. Size factor		
Size of plant		
Large commercial unit $>$\$10MM	0–0.05	8
Small commercial unit \$0.5MM to \$10MM	0.05–0.15	8
Experimental unit $<$\$0.5MM	0.15–0.35	8
12. Total fixed plant cost (Σ items 8–11)		

Sources: Refs. 2, 34.

developed this method years ago based upon long experience in chemical process plants [34]. For many years, this was the only method reported in the open literature and as a result became popular. The author through various consulting contacts is acquainted with several companies that have expanded the Chilton concept for their own in-house needs. The Chilton method is found in Table 4.14 and requires some interpretation to use. Suggestions will be given.

To calculate a fixed capital investment by this method, the user may start with purchased, delivered, or installed costs. If purchased costs are available, then a delivery charge must be included resulting in item 1 in Table 4.14. To obtain the installed equipment cost, a factor of 1.43 is applied to the delivered equipment cost. Various sources in the literature have noted that installation costs may vary from 35 to 100% of the delivered equipment costs, with 43% being an average value. Then individual factors are applied to the installed equipment cost to obtain process piping, instrumentation, etc. as shown in Table 4.14. Certain modifications to the original factored method are necessary to update it. Process piping includes piping, valves, and fittings associated with the process equipment, including utility lines and lines carrying process materials. For very high pressure and unusually corrosive or erosive conditions in a fluid processing plant, the 0.6 factor may approach 1.0. This part of the piping is confined to the "building" although it may be an open structure. Costs of service piping not associated with the process, like steam for heating, drinking water, etc., are included in the building costs. All piping outside the building is classified as outside lines, including piping supports. When this method was developed, instrumentation was not as sophisticated as it is today and as such was not a major part of the fixed capital cost. Today, with data loggers and computer-controlled processes, those items should be included in the delivered equipment costs and 0.20–0.25 used for extensive instrumentation. Even though the "building" may be an open structure like most refineries and petrochemical plants, the "building" costs include service facilities such as heating, plumbing, lighting.

In the manufacture of food products, pharmaceuticals, and cosmetics, a building is essential and the factor may be as high as 1.00 times item 2. All piping external to the building area is classified as "outside" lines and the costs include the piping supports. Occasionally, outside lines need to be extended to the battery limits of the proposed plant. Motors, starters, and wiring for process equipment are included in the installed equipment costs. Electrical services within the building or structure are part of the building costs. Outside feeder lines are part of the outside lines. Substations and transformer costs are under auxiliary facilities.

The sum of items 2–7 is called the "total physical plant", item 8. The rest of the items in this method are factors that are applied to item 8. Engineering and construction are estimated on the basis of a project's complexity. If it is relatively simple, then 20–35% is reasonable. But if the engineering is difficult, first of its kind, or new to the company, a percentage selected in the difficult range is appropriate. Contingencies are based upon process information. If the data are firm and similar to other processes, then 10–20% of item 8 is satisfactory. If the process is speculative and subject to change, a higher percentage should be used. Small process plants seem to have a variety of problems that larger plants don't. The "size" factor is included to account for this fact.

Items 8–11 are summed to give the total battery-limits fixed capital investment. Example 4.12 is an illustration of how the Chilton method is used to prepare a preliminary estimate.

Example 4.12

Problem Statement:

A small fluid processing plant is to be built at an existing plant site. The delivered equipment costs are:

Equipment	Delivered costs
Distillation tower	$500,000
Trays and internals	435,000
Receivers	320,000
Accumulator drum	175,000
Heat exchangers	620,000
Pumps and motors	215,000
Automatic controls	300,000
Miscellaneous equipment	150,000

The equipment is to be installed in an outdoor structure. The process is heavily instrumented, and auxiliary services and outside lines are minimal. The process is well defined and is based upon a similar unit built at another company location. Estimate the battery-limits fixed capital investment using the Chilton method.

Solution:

The total delivered equipment cost is $2,715,000.

Item description	Factor	Item no.	M$
1. Delivered equipment cost	1.0	1	2,715
2. Installed equipment cost	1.47	1	3,991
3. Process piping (high-fluid plant)	0.60	2	2,395
4. Instrumentation (extensive)	0.20	2	798
5. Building and site development (average, outdoor)	0.20	2	798
6. Auxiliaries (minimal)	0.02	2	80
7. Outdoor lines (minimal)	0.02	2	80
8. Total physical plant costs			8,142
9. Engineering and construction (simple)	0.30	8	2,443
10. Contingencies (firm)	0.15	8	1,221
11. Size factor (>$2 million)	0.02	8	163
12. Total fixed capital investment			11,969 (say $12,000,000)

4.3.3.2 Peters and Timmerhaus Method

This method begins with purchased equipment costs delivered and combines some of the features of the Lang and Chilton methods [10]. A process is classified according to whether it is a solid, solid–fluid, or fluid processing plant like the Lang method, and then 12 factors for direct and indirect costs are applied is in the Chilton method. The authors state that the method applies to an existing plant site and therefore have included land. They also include 15% of the total capital investment for working capital so that the bottom line is the total capital investment. A word of caution, for depreciation calculations: land and working capital must be subtracted to give the fixed capital investment since land and working capital are not depreciable items. The factors are found in Table 4.15. Example 4.13 is an illustration of this method.

Example 4.13

Problem Statement:

The problem statement is the same as for Example 4.12. Use the Peters and Timmerhaus method to estimate the battery-limits fixed capital investment.

Solution:

Direct Costs	Factor	Cost, $M
1. Delivered equipment cost	1.00	$2,715
2. Equipment installation	0.47	1,276
3. Instrumentation and controls	0.18	489
4. Piping (installed)	0.66	1,792
5. Electrical (installed)	0.11	299
6. Building (including services)	0.18	489
7. Yard improvements	0.10	272
8. Service facilities (installed)	0.70	1,901
9. Land (omit)		
10. Total direct plant costs		9,283
11. Engineering and supervision	0.33	896
12. Construction expense	0.41	1,113
13. Total direct and indirect plant costs		11,242
14. Contractor's fee	0.21	570
15. Contingency (10% of item 13)		1,124
16. Total battery-limits fixed capital investment		12,936 (say $12,900,000)

4.3.3.3 Holland Method

Holland et al. [35] proposed a method that combine features of the Lang, Chilton, and Peters and Timmerhaus methods. In Table 4.16 equipment installation factors are presented depending upon the type of processing plant beginning with delivered equipment costs. The reader will note the similarity between the methods mentioned above.

4.3.3.4 Happel Method

Another method for estimating the fixed capital investment for fluid processing plants using multiple factors was developed by Happel [36]. The method begins with delivered equipment costs. Factor ranges for installation labor, insulation, piping, foundations, buildings, structures, fireproofing, electrical, painting, overhead, contractor's fees, and contingencies are applied. As in the Chilton method, the estimator must exercise some judgment in selecting the appropriate factors. The details of this method are presented in Table 4.17.

4.3.3.5 Miller Method

Miller [37] analyzed a large number of plants of widely different chemical production and developed factors for all components, e.g., piping, foundations, insulation, instrumentation, within the battery limits. All factors were given a range, minimum, most likely, and maximum values, but in practice selection must

TABLE 4.15 Peters and Timmerhaus Method

Direct costs	Solid	Solid–fluid	Fluid
1. Purchased equipment delivered including fabricated equipment and process machinery	100	100	100
2. Purchased equipment installation	45	39	47
3. Instrumentation and controls (installed)	9	13	18
4. Piping (installed)	16	31	66
5. Electrical (installed)	10	10	11
6. Building (including services)	25	29	18
7. Yard improvements	13	10	10
8. Service facilities (installed)	40	55	70
9. Land (if purchase is required)	6	6	6
10. Total direct plant costs	264	293	346
Indirect costs			
11. Engineering and supervision	33	32	33
12. Construction expenses	39	34	41
13. Total direct and indirect costs	336	359	420
14. Contractor's fee (about 5% of the direct and indirect plant costs	17	18	21
15. Contingency (about 10% of the direct and indirect plant costs)	34	36	42
16. Total fixed capital and land	387	413	483

Sources: Refs. 2, 10.

be based on knowledge of the project as well as experience of the estimator. This three-point method was the introduction of a three-point uncertainty analysis in the preparation of a capital cost estimate. In the hands of an experienced estimator and with reliable equipment costs, an appropriation grade estimate is possible.

4.3.3.6 Miscellaneous Preliminary Methods

4.3.3.6.1 Other Factor Methods. Kharbanda and Stallworthy [38] have noted that there are many other methods employing factors and various plots to obtain preliminary estimates with varying degrees of accuracy. Hill [39], Stallworthy [40], Wilson [41], Allen and Page [42], and Cran [43] developed factored methods drawing frequently upon techniques previously presented in this section. Vatavuk [44] presented a factor-type estimating procedure for air pollution control equipment.

Table 4.16 Holland Method

$$C_{tc} = \phi_1\phi_2\phi_3C_{eq}$$
C_{tc} = fixed capital cost of plant
C_{eq} = major process equipment cost, delivered
$\phi_1 = 1.45$ for solids processing
$\phi_1 = 1.39$ for mixed solids–fluid processing
$\phi_1 = 1.47$ for fluid processing
$\phi_2 = 1 + f_1 + f_2 + f_3 + f_4 + f_5$
$\phi_3 = 1 + f_6 + f_7 + f_8$
Process piping factor range:
$f_1 = 0.07–0.10$ for solids processing
$f_1 = 0.10–0.30$ for solids–fluid processing
$f_1 = 0.30–0.60$ for fluid processing
Instrumentation factor ranges:
$f_2 = 0.02–0.05$ for little automatic control
$f_2 = 0.05–0.10$ for some automatic control
Buildings factor ranges:
$f_3 = 0.05–0.20$ for outdoor units
$f_3 = 0.20–0.60$ for mixed indoor outdoor units
$f_3 = 0.60–1.00$ for indoor units
Facilities factor range:
$f_4 = 0–0.05$ for minor additions
$f_4 = 0.05–25$ for major additions
$f_4 = 0.25–1.00$ for a new site
Outside lines factor ranges:
$f_5 = 0–0.05$ for existing plant
$f_5 = 0.05–0.15$ for separated units
$f_5 = 0.15–0.25$ for scattered units
Engineering and construction factor ranges:
$f_6 = 0.20–0.35$ for straightforward plants
$f_6 = 0.35–0.50$ for complex plants
Size factor ranges:
$f_7 = 0–0.05$ for large plants
$f_7 = 0.05–0.15$ for small plants
$f_7 = 0.15–0.35$ for experimental units
Contingency factor ranges:
$f_8 = 0.10–0.20$ for a firm process
$f_8 = 0.20–0.30$ for a process subject to change
$f_8 = 0.30–.50$ for a tentative process

Source: Ref. 35.

TABLE 4.17 Happel Method

Delivered equipment costs	Factor I_E
Additional direct costs as a fraction of I_E	
Labor for installing major equipment	0.10–0.20
Insulation	0.10–0.25
Piping (carbon steel)	0.50–1.00
Foundations	0.03–0.13
Buildings	0.07
Structures	0.05
Fireproofing	0.06–0.10
Electrical	0.07–0.15
Painting and cleanup	0.06–0.10
f_i	1.09–2.05
Total direct cost $(1 + f_i)\ I_E$	
Indirect costs as a fraction of direct costs	
Overhead, contractor's costs and profit	0.30
Engineering fee	0.13
Contingency	0.13
Total	0.56
$f_I = 1 + 0.56$	
Total cost	$I_F = (1 + \Sigma f_i) f_I f_E = (3.1–4.8)\mathrm{I_E}$

Source: Ref. 26.

One must be careful in using any of the factored methods because they might apply only to certain type of chemical processing plants. Also, it is unwise to extend the factor methods beyond their intended application.

4.3.3.6.2 Step-Counting Methods. Step counting and a similar method known as "functional unit method" are discussed in Ref. 38. In these methods, a unit operation or unit process roughly constitutes a "step" or "functional unit." For example, a distillation step might include a fractionating column, condenser(s), reboiler, pumps, and receivers. These equipment items are regarded as a functional unit. A fixed capital investment figure is determined for the equipment in the unit. A process then consists of a number of steps each containing more than one equipment item. Certain modifiers like materials of construction, pressure, temperature, etc. are applied to each step.

Zevnik and Buchanan [45] were among the early investigators to recognize the functional unit approach. Unfortunately, they based their method on limited historical data and the data are old, but they were the first to introduce correction factors such as temperature, pressure, process complexity, materials of construction. Other step-counting methods were introduced by Taylor [46], Bridgwater [47], Viola [48], and Klumpar et al. [49]. These methods also incorporate Zevnik and Buchanan's concept of various modifications.

The most serious disadvantage is in defining a step or functional unit. This takes practice and experience. If equipment has been inadvertently omitted from a step, the resulting estimate may be seriously affected. These methods are reported to yield estimates in the 30–40% accuracy range.

4.3.3.6.3 Thermodynamic Method. This unique method was introduced by Tolson and Sommerfeld [50]. The premise is that the relative ease or difficulty associated with the manufacture of a chemical product is related to the free energy of the reaction and is reflected in the capital investment. Sommerfeld and White [51] published information on 55 industrial inorganic and organic compounds. According to the authors, this method has accuracies between 30 and 40% accuracy. One disadvantage of this method is that it can only be used on processes in which a chemical reaction takes place and for which thermodynamic information may be calculated.

4.3.4 Definitive Methods

The methods mentioned in this section can produce accuracies from −10% to +20%, depending upon the quality of the data available. Figure 4.2 details the information available to develop a definitive estimate. A detailed scope is essential in order to provide product capacity, location, utility and service requirements, building requirements for process storage, and handling. Process flowsheets, material and energy balances, site information, piping and instrumentation diagrams, utility requirements, equipment and instrumentation and electrical specifications, should be firm. Bids for all equipment and instrumentation should be on hand.

Two methods are presented in this section in an abbreviated form, but references are given so the user can find the details of each method.

4.3.4.1 Hirsch and Glazier Method

The authors of this method reported costs of some 42 refining, petrochemical, and synthetic fuel plants [52]. They developed algorithms and auxiliary plots consisting of a series of installation factors that permit the user to obtain a battery-limits fixed capital investment cost with accuracies near the upper limit of those in the definitive estimate range. The procedure is structured to begin with purchased equipment cost. The factors and algorithms are found in Table 4.18.

Table 4.18 Hirsch and Glazier Method

$$I = EA(1 + F_L + F_P + F_M) + B + C$$

where
I = total battery-limits investment, \$
A = total purchased equipment cost FOB less incremental cost for corrosion-resistant alloys, \$
B = cost of all equipment estimated on an erected basis, such as furnaces, tanks, cooling towers, etc., company, erected equipment
C = incremental cost of alloy materials used only for their corrosion-resisting properties, \$
E = indirect factor for contractor's overhead and profit, engineering, supervision, and contingencies, \$ (normally 1.4).
F_L = cost of field labor, $F_L A$ is the total field labor costs, less supervision and excluding the labor charges in item B, \$
F_M = cost factor of miscellaneous item; $F_M A$ includes material cost for insulation, instruments, foundations, structural steel, buildings, wiring, painting, and the cost of freight and supervision, \$
F_P = cost factor for piping materials; $F_P A$ is the total cost of piping materials, including pipe, fitting, valves, hangers, and support, but excluding insulation and installation charges, \$

The F_L, F_M, and F_P factors are not simple ratios but are defined by equations.

$$\log F_L = 0.635 - 0.154 \log A_o - 0.992\left(\frac{e}{A}\right) + 0.506\left(\frac{f}{A}\right)$$

$$\log F_P = -0.266 - 0.014 \log A_\rho - 0.156\left(\frac{e}{A}\right) + 0.556\left(\frac{p}{A}\right)$$

$$F_M = 0.344 + 0.033 \log A_o + 1.194\left(\frac{t}{A}\right)$$

where $A_o = \dfrac{A}{1000}$, expressed in \$M
e = total heat exchanger cost, less incremental cost of alloys, \$
f = total cost of field-fabricated vessels, less incremental cost of alloy, \$ (vessels larger than 12 ft in diameter are usually field erected)
p = total pump plus driver cost less incremental alloy, \$
t = total cost of tower shells less incremental cost of alloy, \$

In the reference, there are plots for

$$\log F_L = f\left[\left(\frac{e}{A}\right)\left(\frac{f}{A}\right)\right]$$

$$\log F_P = f\left[\left(\frac{e}{A}\right), \left(\frac{p}{A}\right)\right]$$

$$F_M = f\left[(A_o), \left(\frac{t}{A}\right)\right]$$

Source: Ref. 52.

4.3.4.2 Guthrie Method

Guthrie [53] developed a method based upon the modular concept using data from 42 chemical process plants. All major cost elements are grouped into six modules:

Chemical processing
Solids handling
Site development
Industrial buildings
Offsite facilities
Project indirects

In the chemical processing module, there are 7 primary cost elements and 14 secondary cost elements. These are found in Table 4.19. A module represents a group of cost elements that have similar characteristics and relationships. The total module cost then is the sum of the direct material cost M (as purchased equipment items E and as material for field labor m) and field labor costs L for each equipment item. These are then gathered to form a total module cost that accounts for the indirect costs. In order to obtain the total fixed capital investment, extra costs for adjuncts and auxiliaries are added to the sum of the total module costs. The Guthrie references [7,53] provide values for equipment costs and the factors to compute the required installation materials M and the field labor costs.

As an example, there is a module for shell-and-tube heat exchangers which includes bare equipment cost-capacity plot, adjustment factors for design pressure, materials of construction, as well as piping, concrete, steel, instruments, electrical, painting, material erection, equipment setting, etc. When these costs are summed, the result is the bare module cost. At this point in the method, a lumped indirect cost factor may be applied to each of the equipment modules, and indirect cost factors may be calculated from an indirect cost module, Table 4.19. The sum of each bare module cost, indirect costs as well as contingency and contractor's fees, give the total module cost.

Because a process consists of a group of equipment items, each being a module, when all the modules are summed, the fixed capital investment results. Baasel [54] illustrated the use of the Guthrie method using a polyvinyl chloride plant. A user could provide up-to-date cost data and use the method successfully to prepare a definitive cost estimate.

Garrett [11] presented updated (1986) module costs similar to Guthrie's, including installation factors, materials of construction, and pressure corrections for a variety of equipment items.

Table 4.19 Guthrie Method

The schedule for the Guthrie method was developed from seven cost elements:

Equipment cost, FOB	E
Auxiliary material	M
Direct (field) material	$m \qquad M = E + m$
Direct (field) labor	L
Direct M and L costs	$E + M + L = \mathrm{DC}$
Indirect costs	IC
Bare module costs	$\mathrm{IC} + \mathrm{DC} = \mathrm{BMC}$
Total module costs	I_F

The direct field material m consists of:

Piping Concrete Steel Instrumentation Electrical Insulation Paint	(m ranges from 40 to 125% of E or a norm of 62%. Multiply E by 1.40 to 2.25 to get M, the total of all direct material costs.)

The direct field labor L applies to:

Material erection Equipment setting	(L ranges from 50 to 70% of E or a norm of 58%.)

The sum of $M + L$ comprises the total direct costs. The sum of the values of the $M + L$ for all major plant items, and indirect items are applied to account for these three items:

Freight, insurance, sales tax Construction overhead Engineering	[Indirect cost ranges from 25 to 45% of $M + L$; multiply $M + L$ by 1.34 to bare module cost.]

The total module cost is obtained by applying the following factors to the bare module cost:

Contingency	(8–20% of the bare module cost, or a norm of 15%)
Contractor's fee	(2–7% of the bare module cost)

If adjuncts or auxiliaries like solids-handling facilities, site development, industrial buildings, and offsite facilities are required, then the extra investment for them must be added. Guthrie presented tables listing the details of each of these latter item in Ref. 7.

Source: Refs. 7, 53.

TABLE 4.20 Richardson System

The Richardson system is presented in seven volumes that cover all the detailed estimating elements:

Civil engineering work	Excavation, backfill, and earthmoving
Concrete	Forming, pouring, reinforcing, equipment foundations, treatment plants, etc.
Structural steel	Building, process equipment supports, platforms, handrails, and ladders
Electrical work	Conduit, wire, switchgear for buildings, process equipment, power distribution, etc.
Mechanical work	Piping, instrumentation, plumbing
Process equipment	Pressure vessels, tanks, compressors, motors, freight
Indirect costs	Jobsite and home office overhead, supervision, rental equipment and tools

A detailed fixed capital investment may be prepared from the volumes for the cost of a process plant. The cost data are updated on an annual basis.

Source: Ref. 55.

4.3.5 Detailed Estimates

The detailed estimating methods are beyond the scope of this book; however, a brief discussion of each will be presented. Figure 4.2 lists the information required to prepare this type of estimate. Detailed estimating procedures should yield an accuracy of −5% to 10%.

4.3.5.1 Richardson Rapid Estimating Method

This estimating method was developed by Richardson Engineering Services, Inc. [55]. The system is presented in seven volumes that cover the detailed estimating elements found in Table 4.20. The process equipment volume is of interest to chemical engineers since it contains actual equipment costs from manufacturers with equipment models identified. But as can be seen, estimates for elements of construction are found in other volumes. By following the instructions in the manuals, a detailed estimate can be prepared. Preparing an estimate using this method takes time and the detail required is considerable. One of the disadvantages is that some items of equipment are of small to moderate size. Today the trend is for larger equipment so Richardson's data may not extend as far as the user desires, like cooling towers, boilers, and electrical substations.

4.3.5.2 Code of Accounts Method

Companies have a codified system called “code of accounts.” This code is essentially a listing of all the elements in a detailed estimate so that no pertinent items have been omitted [56]. A typical code of accounts is found in Table 4.21. Experienced personnel are required to prepare this quality estimate. Each item in the code is explained in detail with respect to what is included under the item. The code is used to note only estimate costs, but later when the plant is being built it is used to control costs.

4.3.6 Commercial Computerized Estimating Procedures

With the advent of the personal computer, numerous computer estimating software packages were developed for cost estimation and economic evaluation. The software programs vary from fairly simple programs to elaborate ones. Also, there are some companies that will perform computerized capital cost estimates on a contact basis.

Several of the commercial software packages are CHEMCAD, SUPER-PRO Designer 4.5 (Intelligen, Inc.), ASPEN, and ICARUS. Although advertising information of packaged software programs are not intentionally misleading, any given program may not yield the type estimate the user desires. These programs are often more expensive than colleges may be able to afford and maintain. On the other hand, it is very expensive and time consuming to develop a program for specific use, if a purchased software package can be modified for the user’s needs. Often companies like those listed above will work with a customer on program modifications. An elaborate software program may be loaded on a minicomputer or a large main frame and the program may be accessed via a network for local users within a company.

There are many reasons for computer cost estimations and economic evaluations, such as saving time on repetitive calculations and reducing mathematical errors. Whatever package is used, or if an estimate is prepared by an outsourced firm, it is wise to spot-check the estimate by selected hand calculations. The author is aware of several instances in which cost estimates were prepared by competing engineering firms with wide variations in results. Just because the estimate was computer generated does not mean that the software program gave correct or reasonable results. For most cost estimation tasks discussed in this text, computers are not necessary or not too useful.

4.4 SCOPE AND CONTINGENCY

4.4.1 Scope

The document that defines a project is called the *scope*.The scope is continually referred to by cost control and estimating personnel so that the plant constructed

TABLE 4.21 Code of Accounts

Number	Direct capital cost accounts
01	Equipment items
02	Instrument items
03	Set and test equipment
04	Set and test instrument
05	Piling
06	Excavation
07	Foundations
08	Structural steel
09	Building items
10	Fire protection
11	Piping
12	Ductwork
13	Wiring
14	Land
15	Sewers and drains
16	Underground
17	Yards and roads
18	Railroads
19	Insulation
20	Painting
21	Fence
Contractor's Overhead and Fee	
22	Temporary facilities
80	Indirect charges (engineering)
81	Construction stores
82	Temporary construction equipment
83	Accounts receivable
84	Contractor's fee
85	Premium wages
Owner's Overhead	
90	Indirect charges
91	Temporary construction stores
92	Temporary construction equipment
93	Owner's miscellaneous
94	Relocation and modification expense

Source: Ref. 56.

will correspond to the intent of engineering and management. A scope should answer the following questions clearly:

- What product is being manufactured?
- How much is being produced?
- What is the quality of the product?
- Where is the product to be produced?
- What is the quality of the estimate?
- What is the basis for the estimate?
- What are the "knowns" and "unknowns" with respect to the project?

Changes during the progress of a project are inevitable but a well-defined scope planned in advance can help minimize changes.

A scope is defined by words, drawings, and cost figures. If a scope is properly defined, then the following results may be obtained:

- Clear understanding between those who proposed the scope (engineering) and those who accepted it (management)
- A document that indicates clearly what is to be provided in terms of technology, quality, schedule, and cost
- A basis in enough detail to be used in controlling the project and its costs to permit proper evaluation of any proposed changes
- A device to permit subsequent evaluation of the performance compared to the intended performance
- Development of a detailed estimate from which to control the final design, construction, and start-up

4.4.2 Contingency

The word *contingency* is probably the most misunderstood word associated with cost estimates whether they are fixed capital, working capital, or operating expense estimates. A definition is that "contingency is a provision for unforeseen elements that experience has shown are likely to occur" [57]. There are two types of contingencies: process and project contingency.

4.4.2.1 Process Contingency

Process contingency was recognized in the 1970–1980 period when large-scale pioneer energy projects were considered. It was used to deal with uncertainties in

1. Technical uncertainties in equipment and performance
2. Integration of new and old process steps
3. Scaling up to large scale plant size
4. Accurate definition of certain process parameters, such as

a. Severity of process conditions
b. Number of recycles
c. Process blocks and equipment
d. Multiphase streams
e. Unusual separations

Guidelines for process contingency are poor primarily as a result of the lack of historical data.

4.4.2.2 Project Contingency

No matter how much time and effort are spent preparing an estimate, there is the likelihood of errors occurring due to

1. Engineering errors and omissions
2. Cost and labor rate changes
3. Construction of problems
4. Estimating inaccuracies
5. Miscellaneous “unforeseens”
6. Weather-related problems
7. Strikes by fabricator, transportation, and construction personnel

4.4.2.3 What Contingency Values Should Be Used?

For preliminary estimates a 15–20% project contingency should be applied if the process information is firm. If not, then a process contingency of 15–20% should also be added. As the quality of the estimate moves to definitive and detailed, the contingency value may be lowered to 10–15% and 5–10%, respectively. Experience has shown that the smaller the dollar value of the project, the higher the contingencies should be.

4.5 OFFSITE CAPITAL

The offsite facilities include all structures, equipment, and services that do not directly enter into the manufacture of a product. These costs are estimated separately from the fixed capital investment. They are not easy to estimate. Offsite capital would include the utilities and services of a plant. Among the utilities are:

1. Steam-generating and distribution
2. Electrical-generating and distribution
3. Fuel gas distribution
4. Water-well, city, cooling tower, and pumping stations for water distribution
5. Refrigeration

6. Plant air
7. Environmental control systems

The service facilities might include

1. Auxiliary buildings
2. Railroad spurs
3. Service roads
4. Warehouse facilities
5. Material storage—raw material as well as finished goods
6. Fire protection systems
7. Security systems

For preliminary estimates, it is suggested that offsite investment be a percentage of the processing unit's fixed capital investment. Kharbanda [58] and Jelen [59] suggested ranges of percentage values. Woods [60–63] published a series of articles that may be used to estimate offsite capital. As an approximation, he recommended the following as a percentage of the FOB process equipment costs:

1. Small modification of offsites, 1–5%
2. Restructuring of offsites, 5–15%
3. Major expansion of offsites, 15–45%
4. Grass roots plants, 45–150%

4.6 ALLOCATED CAPITAL

When a company proposes to produce a new product, it is wise to examine various sources of raw materials and their costs. If the company produces the raw material at one of its locations, then almost without exception, it is cheaper to use that raw material rather than buying it on the open market. In such cases, the raw material is referred to as an intermediate. If it represents a potential sales item, then a proportion of the intermediate's fixed capital investment should be allocated to the new product's capital investment. The benefit to the new product department is that the intermediate is charged to the intermediate's manufacturing expense, in addition to a transfer price to deliver it to the new product department. The new department receives a price break for the raw material since it is being bought at below market price, but with every benefit there is a penalty. In this case, the new product department must accept a proportion of the intermediate's fixed capital investment based upon the amount of raw material to the new department and the total capacity of the intermediate total capacity.

On paper, the intermediate's fixed capital investment is reduced by the allocated amount. The theory is that part of the intermediate's production cannot be sold at a profit on the market. Therefore, the intermediate department then earns a return only on that amount of material produced for sales and should not be penalized for acting as a raw material producer. This process of allocating capital is referred to as the *proportionate share of existing facilities*.

In some companies, the same reasoning is used with respect to utilities and services facilities capital. Therefore, a new product project shares on a proportionate-use basis the capital burden of the existing facilities. Sales, administration, research, and engineering capital is proportioned to the various production departments using their services in a similar fashion.

The total allocated capital then may consist of contributions from

1. Intermediate chemicals
2. Utilities
3. Services
4. SARE

The total allocated capital is added to other capital items to form the total capital investment. An illustration of the calculation method is found in Example 4.14.

Example 4.14

Problem Statement:

Ajax Petrochemical is considering the manufacture of 18MM lb/yr of a specialty chlorinated hydrocarbon. In the process some 4MM lb/yr of chlorine is required. Ajax has an older caustic-chlorine facility at the same location that has a rated capacity of 100 tons/day. The book value of the chlorine unit's capital investment is $20MM. Calculate the amount of allocated capital to be charged to the chlorinated hydrocarbon unit if the chlorine is to be transferred from the existing caustic-chlorine-plant. Assume 330 operating days per year for both plants.

Solution:

$$\begin{aligned}\text{Chlorine required} &= 4{,}000{,}000\,\text{lb/yr} \times (1\,\text{ton})/(2000\,\text{lb/yr}) \\ &= 2{,}000\,\text{tons/yr}\end{aligned}$$

$$\begin{aligned}\text{Yearly capacity of the chlorine plant} &= 100\,\text{tons/day} \times 330\,\text{days/yr} \\ &= 33{,}000\,\text{tons/yr}\end{aligned}$$

Therefore, the proportion of the chlorine facility capital allocated to the chlorinated hydrocarbon facility is

$$\frac{33{,}000\,\text{tons/yr}}{2000\,\text{tons/yr}} \times \$20\text{MM} = \$1{,}212{,}000$$

In addition, the chlorinated hydrocarbon plant can now receive the chlorine at manufacturing cost plus a price to transfer the chlorine to the new unit.

As an alternate to this approach, each department must achieve a certain return on the investment as mandated by management. This is referred to as the *profit-center* approach. Departments that have a salable product are required to show a higher return than utilities, services, and SARE facilities.

4.7 WORKING CAPITAL

Working capital are the "working funds" necessary to conduct a day-to-day business of the firm. These funds are necessary to pay wages and salaries, purchase raw materials, supplies, etc. Although the initial input of working capital funds come from the company's financial resources, it is regenerated from the sale of products or services. Working capital is continuously liquidated and regenerated but is generally not available for another purpose, so it is regarded as an investment item.

Working capital is a very important aspect of plant operations, especially for unproven processes and new products. If an adequate amount of working capital is available, management has the necessary flexibility to cover expenses in case of delays, strikes, fires, or recessions. Many small firms fail due to an insufficient amount of working capital to pay the expenses as the new venture begins to become established.

Several methods are available for estimating an adequate amount of working capital for a proposed venture. These methods may be classified into two broad categories:

Percentage methods
Inventory method

4.7.1 Percentage Methods

These methods are adequate for order-of-magnitude, study, and preliminary methods of estimating. The working capital requirements are based upon either annual sales or capital investment.

4.7.1.1 Percentage of Capital Investment Methods

The ratio of working capital to total capital investment varies with different companies and different types of business. If a company manufactures and sells a product at a uniform yearly rate, then 15–25% of the total capital investment is an adequate amount of working capital. Some companies are in a seasonal business, such as agricultural chemicals. If that is the case, then it would be advisable to provide 20–30% of the total capital investment for working capital. The method is shown in Example 4.15.

Example 4.15

Problem Statement:

A company is considering an investment in an aldehyde facility. The engineering department has estimated that the battery-limits fixed capital investment to be \$19MM. Land allocated for the project is \$500,000 and start-up expenses to be capitalized are expected to be \$900,000. The company normally uses 15% of the total capital investment for working capital. Determine the estimated amount of working capital for this project.

Solution:

Land	\$500,000
Fixed capital investment	\$19,000,000
Start-up expenses	\$900,000
Subtotal	\$20,400,000

Since the working capital is 15% of the total capital investment, the subtotal above is 85%, providing no other capital items are added.

Therefore,

$$\text{Total capital investment} = \frac{\$20{,}400{,}000}{0.85} = \$24{,}000{,}000$$

and

$$\text{Working capital} = \$24{,}000{,}000 - \$20{,}400{,}000 = \$3{,}600{,}000$$

Checking then

$$\frac{\text{working capital}}{\text{total capital investment}} = 15\%$$

or

$$\frac{\$3{,}600{,}000}{\$24{,}000{,}000} \times 100 = 15\%$$

4.7.1.2 Percentage of Sales Method

The estimate of an adequate amount of working capital for certain specialty chemicals is frequently based upon a percentage of annual sales. Products that may fall into this category are fragrances, cosmetics, flavors, perfumes, food additives, etc. To illustrate this method, let's consider the manufacture of a perfume. The essences and long-chained alcohols used in the manufacture of a perfume are expensive items. The fixed capital investment to produce these products is rather small compared to the manufacture of a petrochemical. A perfume producer may have considerable money tied up in raw materials and finished goods inventory and only a modest amount in fixed capital. Therefore, it would be reasonable to base the estimate of working capital on a percentage of sales as reported by one manufacturer [64]. Wessel [65] reported that the percentage values vary from 15 to 49% with 30 to 35% being a reasonable value. Annual and 10K reports provide enough information to calculate the percentage for specialty manufacturers. Example 4.16 is an illustration of this method.

Example 4.16

Problem Statement:

A perfume manufacturer is planning to produce a new product. Annual sales are expected to be about \$15,000,000. Estimate the amount of working capital required for this product.

Solution:

Since this is a high-cost product due to the raw materials and the fact that little fixed capital is required, the working capital should be based on a percentage of annual sales. A mean value of 35% of sales will be used.

Annual sales = \$15,000,000
Estimated working capital = (\$15,000,000)(0.35) = \$5,250,000

4.7.1.3 Inventory Method

There are several variations on this method mentioned in the literature, but they all have the common basis of inventory. The reader should note that this method uses the categories in current assets and current liabilities from a balance sheet (see Chap. 3) and is consistent with the accounting definition of working capital, namely, current assets minus current liabilities, see Table 4.22. Example 4.17 demonstrates how this method is applied.

Example 4.17

Problem Statement:

Plastics, Inc. is considering a project to manufacture a specialty product for the polymer industry. The expected sales are 10,000,000 lb/yr at 65 cents/lb. In the manufacture of this product, all raw materials are delivered by pipeline from other operating departments except one, so the only on-site storage is an inorganic compound. It costs 18 cents/lb and is consumed at a rate of 500,000 lb/month. The total manufacturing expense is estimated to be 30 cents/lb of product. Goods-in-process amount to about \$300,000 because of hold tanks in the process. The fixed capital investment for this process is \$8,000,000 and

TABLE 4.22 Working Capital—Inventory Method[a]

Item	Factors
Raw materials	Two weeks supply depending on availability—use purchase price.
Goods in process	Estimate on an average retention time in tanks. Convert back to raw materials and charge at purchase price plus one-half the sum of the direct and indirect conversion costs.
Finished product	Two weeks supply depending on product sales and charge at selling price.
Supplies and stores	10% of the annual maintenance expense.
Cash	One month's manufacturing expense.
Accounts receivable	5% of annual net sales.
Accounts payable	One month's average accounts payable.

Source: Ref. 2.

[a] These are estimating factors for a typical inventory method calculation.

the maintenance is 6% per year of the fixed capital investment. Estimate the amount of working capital required by the inventory method.

Solution:

Raw materials—2 weeks supply of the inorganic compound

$$500{,}000\ \text{lb/month} \times \frac{14\ \text{days}}{30\ \text{days}} = 233{,}000\ \text{lb}$$

$$\text{Inventory} = 233{,}000\ \text{lb} \times \$0.18/\text{lb} = \$42{,}000$$

Goods in process = \$300,000

Finished product—2 weeks supply of product

$$10{,}000{,}000\ \text{lb/yr} \times \frac{2\ \text{weeks}}{52\ \text{weeks}} = 385{,}000\ \text{lb}$$

$$\text{Value of product} = 385{,}000\ \text{lb} \times \$0.65/\text{lb} = \$250{,}000$$

Stores and supplies

$$\text{Annual maintenance cost} = \$8{,}000{,}000 \times 0.06 = \$480{,}000$$

$$10\%\ \text{of the annual maintenance cost} = \$48{,}000$$

Cash—1 month's manufacturing expenses

$$10{,}000{,}000\,\text{lb/yr} \times \frac{1\,\text{month}}{12\,\text{months}} \times (\$0.30/\text{lb}) = \$250{,}000$$

Accounts receivable—5% of annual net sales

$$10{,}000{,}000\,\text{lb/yr} \times 0.65/\text{lb} \times \$0.05 = \$325{,}000$$

Summary:

Items	Working capital
Raw materials	$42,000
Goods in process	300,000
Finished product	250,000
Stores and supplies	48,000
Cash	250,000
Accounts receivable	325,000
Estimated working capital	$1,215,000

Check the result as a percentage of the total capital investment, assuming that the fixed capital investment and the working capital are the only two capital items.

$$\frac{\$1{,}215{,}000}{\$8{,}000{,}000 + \$1{,}215{,}000} \times 100 = 13.2\%$$

This is a reasonable result since other capital like land and start-up expenses have not been included.

Some companies also take into account the accounts payable. These are the bills owed by the company and one month's accounts payable would be an adequate figure to include.

4.8 START-UP EXPENSES

When a process is brought on stream, there are certain one-time expenses related to this activity. From a time standpoint, a variable undefined period exists between the nominal end of construction and the production of quality product in the quantity required. This period is loosely referred to as *start-up*. In this period expenses are incurred for operator and maintenance employee training, temporary construction, auxiliary services, testing and adjustment of equipment, piping, and instruments, etc. In general, a part of these items may be carried as expenses like operating expenses, but the tax laws usually require that a portion be capitalized.

Baasel [40] suggested that start-up expenses vary between 5 and 20% of the fixed capital investment while Peters and Timmerhaus [10] recommend 8–10% of the fixed capital. Most authorities agree that seldom does this cost exceed 15%. One large construction company based start-up cost on 20% of the annual operating expenses. The best source of information is company files as the data are often available but need to be compiled.

In the absence of information, one of the two following methods may be used to estimate start-up expenses.

SINGLE-FACTOR METHOD. For plants with a fixed capital investment of $100MM or greater, 6% of the fixed capital investment is a reasonable figure. For plants in the $10MM to $100MM range, 8% is satisfactory and plants of less than $10MM the factor may be as high as 10% of the fixed capital investment.

MULTIPLE-FACTOR METHOD. This method of estimating start-up expenses consists of three components:

Labor
Commercialization cost
Start-up inefficiency

To calculate the labor component, an assumption used is 2 months training and 3 months start-up for each operator and maintenance person. Commercialization costs may be estimated as a percentage of the battery-limits direct capital cost. Included in this item would be temporary construction, adjustment and testing of equipment and instruments, etc., but not field indirect costs which may be estimated as 5% of the battery-limits direct cost. Start-up inefficiency takes into account those operating runs when production cannot be maintained or false starts. For estimating purposes, 4% of the annual operating expense may be used. When the three components are summed, the result is an estimate of start-up expenses.

4.9 OTHER CAPITAL ITEMS

4.9.1 Paid-up Royalties and Licenses

The purchase of technology through paid-up royalties or licenses is considered to be part of the capital investment. The reasoning is that these are replacements for process research and development. A paid-up royalty is a one-time charge but there is another type called a running royalty. This latter item would appear as an operating expense since it is a recurring charge based upon the amount of product manufactured by the purchased technology.

4.9.2 Initial Catalyst and Chemical Charge

In processes that require a substantial charge of noble metal catalysts, or in electrolytic processes, the initial charge of these materials is a large amount of capital. If these materials have a life of 1 year, then the initial charge is considered part of the total capital investment.

4.9.3 Interest on Borrowed Funds

If funds required for the purchase of a new facility are obtained by borrowing, for example, selling bonds or loans, then the interest on these instruments during the construction period only may be capitalized.

All the items in this section constitute part of the total capital investment.

4.10 SUMMARY

The capital cost estimate is the central core of economic evaluations. The items essential for the preparation of the total capital investment were discussed. For any project, not all the items in the total capital investment may be included. The amount of detail to prepare an estimate of the fixed capital investment depends upon the type estimate required. Methods for preparing such an estimate used by practicing engineers were presented. Working capital, allocated capital, and start-up expenses were estimated by using equations or by assuming a percentage of the fixed or total capital investment. Recommended guidelines were suggested.

Although definitive and detailed estimating methods were presented, the details and examples are beyond the scope of this text. The book is intended to acquaint chemical engineering students with what is involved in preparing from order of magnitude through preliminary estimates; however, the subject of cost estimation would not be complete without mention of definitive and detailed estimating procedures. The chapter concludes with a brief mention of computer use in cost estimation. Most of the calculations in this chapter can be accomplished without the use of computers.

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PROBLEMS

4.1 Using the selling prices listed below, estimate the fixed capital investment using the turnover ratio method for chemical plants manufacturing the following products:

a. Maleic anhydride	\$0.33/lb
b. Acetic acid	\$0.45/lb
c. Methyl isobutyl ketone	\$0.63/lb
d. Styrene	\$0.28/lb
e. Salicylic acid	\$1.00/lb
f. Butadiene	\$0.70/lb

4.2 The following market prices were obtained from a recent issue of *Chemical Market Reporter*:

butyl alcohol, drms., c.l.	\$0.55/lb
butadiene, tanks	\$0.70/lb

Estimate the fixed capital investment using the fixed investment per annual ton of capacity method:

a. A plant to manufacture 100 tons/day of butyl alcohol assuming a 95% stream time.
b. A plant to produce 200,000 tons/yr of butadiene.
c. How do the results compare with those obtained in Problem 4.1. Explain any differences. Which result would you report to management and why?

4.3 You read recently in a trade journal that Cleron, a competitor of your company in the fertilizer business, plans a \$20MM expansion of their existing urea facilities. The article did not mention how much this expansion would increase production. Your supervisor asks you to estimate the increase in annual production assuming that urea is selling for \$0.05/lb.

4.4 The purchased price of glass–lined vessels with agitator, baffle, and thermwell is as follows:

Capacity, gal	Purchased price, FOB factory
500	\$55,300
750	60,400

(*continued*)

Capacity, gal	Purchased price, FOB factory
1000	66,900
1500	76,800
2000	85,300
3000	109,500
4000	123,000

a. Construct a graph of the purchased price as a function of capacity on a logarithmic plot.
b. Determine whether the six-tenths rule applies.
c. Derive an equation of purchased price as a function of vessel size.

4.5 A 100,000 gal carbon steel storage tank was purchased recently for $75,000 FOB, factory.

a. Estimate the purchased price of a 250,000 gal tank.
b. Estimate the purchased price of a 400,000 gal tank

4.6 Determine the cost of a 150 gpm, 100 ft head, cast iron, centrifugal pump with motor, coupling, and baseplate, pump using the algorithms in Appendix C. The CE Index for 1986 is 321 and it presently is 399.

a. What is its installed cost?
b. What is the purchased price of the pump if it were of 316 stainless steel?
c. What is the size exponent in this capacity range?

4.7 A shell-and-tube heat exchanger of 1000 ft^2 surface area fabricated of carbon steel was purchased in 1995 for $30,000.

a. Estimate the purchased price for a 2500 ft^2 exchanger using the six-tenths exponent.
b. You read in the literature that exchangers of this size had a 0.70 cost capacity exponent. What is the difference in price compared to that using an exponent of 0.6?

The 1995 CE Index is 381 and the present one is 399.

4.8 In order to meet an increased demand for high octane gasoline, Peaceful Oil company is considering the installation of an alkylation unit. The following equipment items are required for the project:

Item	Number required	Description
Charge pump	1 + 1 spare	730 gpm, 100 ft head, high-silicon iron
Product pump	1 + 1 spare	300 gpm, 50 ft head, high-silicon iron
Alkylators	5	Use storage tank for reactor, each reactor 12 ft diam. by 103 ft long, carbon steel
Agitators	50	Turbine, dual impeller, carbon steel, 100 rpm, 50 HP each
Settlers	5	Use storage tank, 304 stainless steel, 13 ft diam. by 40 ft long
Compressor	1	20,000 SCFM, 5-stage, axial compressor, carbon steel, 2000 hp

Estimate the fixed capital investment using the following methods:

a. Hand method
b. Brown method
c. Chilton method.

Assume a delivery charge of 7%. The CE Index at present is 399 and that for the algorithms is 318.

d. Compare the results by these methods and comment on the purported accuracy of each method. What figure would you report to management and why?

4.9 A small fluids-processing unit is to be constructed adjacent to a large operating unit in a multiproduct chemical plant. The current purchased equipment costs, FOB the vendor's factory, are:

Number required	Equipment	Total purchased price
1	Tower and internals	$375,000
2	Accumulators	182,000
3	Receivers	450,000
6	Heat exchangers	726,000
5	Pumps and motors	200,000
—	Miscellaneous	160,000

If the delivery charges are 5% of the purchased price, estimate the fixed capital investment, using the Hand and Wroth methods.

4.10 Acme Petrochemicals is considering the manufacture of an aldehyde in the amount of 20MM lb/yr. In the manufacturing process, 4MM lb/yr of chlorine is used, which may be obtained from an onsite plant of 100 tons/day rated capacity. The fixed capital investment of the chlorine plant is \$30MM as carried on the company's books. The engineering department estimated that the fixed capital investment of the proposed aldehyde facility is \$12MM in current dollars. Land for the facility is allocated at \$275,000.

The company uses the proportionate share method for allocated capital. Working capital may be taken as 13% of the total capital investment. The start-up expenses are expected to be 6% of the aldehyde facility fixed capital investment.

Prepare a statement of the total capital investment for the proposed project.

4.11 The corporate planning committee of Luray Chemicals, Inc. met to consider plans again for capital expenditures. It was decided that a total capital investment estimate should be prepared again for the plasticizer, XBC. This project was considered in 1998 but was shelved due to a downturn in the global economy. From the equipment list below, prepare the total capital requirements for a battery-limits plant using both the Chilton and the Peters and Timmerhaus methods now and for 2 years in the future assuming the inflation rates to be 3.2 and 4.5%.

The following guidelines are to be used:

a. The algorithms in Appendix C are on the basis of a CE Index of 318. The present CE Index is 399.
b. As the process is a fluids-processing unit, a considerable amount of piping is required.
c. The company policy is to minimize labor, so extensive instrumentation is to be used.
d. The plant is to be constructed outdoors with only a modest amount of capital for auxiliaries and outside lines.
e. The company has built similar plasticizer plants and the engineering is simple.
f. Working capital is estimated as follows:
   1. Raw materials storage (average)

      Alcohol—10,000 gal at \$1.10/gal

      $POCl_3$—1000 gal at \$0.67/lb

   2. Finished goods storage (average)

      5000 gal at \$3.50/gal

   3. Accounts receivable—\$125,000
   4. Cash—\$500,000
   5. Stores and supplies—1% of the fixed capital investment
g. Land for this project is allocated at \$150,000.
h. Start-up expenses are 8% of the fixed capital investment.

Equipment list

Item no.	Item name	Description
101	Alcohol storage tank	Vertical cylindrical vessel, 15,000 gal, 304 SS
102	Alcohol transfer pump	Horizontal centrifugal pump, 50 gpm, 50 ft head, high-silicon iron, 1.5 hp TEFC motor, 1800 rpm
103	$POCl_3$ head tank	Vertical cylindrical vessel, 1500 gal, 304 SS
104	Reactor	Vertical cylindrical vessel, 2000 gal, 304 SS
105	Agitator	Six-bladed turbine, 304 SS, 20 hp TEFC motor, 1150 rpm
106	Reactor circulating pump	Single-stage horizontal centrifugal pump, 100 gpm, 150 ft head, high-silicon iron, 5 hp TEFC motor, 1800 rpm
107	Reactor cooler	Shell-and-tube heat exchanger, U-tube, 1000 ft^2 304 SS, 100 psig
108	Distillation column	6 ft dia $\times$ 40 ft str. side, 25 sieve trays, 316 SS, 100 psig
109	Reboiler	Kettle reboiler, 304 SS, 1500 ft^2, 100 psig
110	Bottoms pump	2 required each single stage, horizontal, centrifugal pump, 50 gpm, 75 ft head, 304 SS, 3 hp TEFC motor, 1800 rpm
111	Bottoms receiver	Vertical cylindrical tank, 304 SS 1500 gal, 15 psig
112	Condenser	Horizontal shell-and-tube heat exchanger, U tube, 1200 ft^2, 316 SS, 110 psig
113	Accumulator	Horizontal cylindrical tank, 1500 gal, 316 SS
114	Recycle pump	Horizontal centrifugal pump, 2 stage, 300 gpm, 200 ft head, 316 SS, 30 hp TEFC motor
115	Product receiver	Vertical cylindrical tank, 3000 gal, 316 SS, 15 psig

4.12 You are employed as a process engineer for Western Alumina Company in their project evaluation section. One of your company's products, aluminum hydrate, $Al_2O_3(H_2O)_3$, is used as a base for a number of chemicals.

A major manufacturer, and one of our best customers, has projected a need for an additional 30,000 tons/yr of hydrate beginning about mid-2004. You may assume the inflation rate is 3.2% in 2002, 4.0% in 2003, and 4.5% in 2004.

To meet this demand, new equipment will have to installed. You are assigned this project for evaluation and you collect the following information.

The additional hydrate will be available to the new project from an existing hold tank. It is the tank as a 50% water slurry (i.e., 50% free water). The specific gravity of the solids is 2.42. A slurry pump is also available.

The hydrate slurry will be transferred to a dryer feed tank, and then will be pumped to a spray dryer for removal of 100% of the free water. No chemically combined water is removed in the drying operation. The dry hydrate will be removed from the dryer by a pneumatic conveyor to an existing bulk storage tank.

It is proposed to operate the new equipment 24 hr/day but only 5 days/wk. Details of the required equipment items are.

Dryer feed tank—304 SS, agitated to provide a 3-h retention time at the design flow rate,
Dryer feed pump—a diaphragm pump
Spray dryer—304 SS, 18 ft diameter
Pneumatic conveyor—304 SS, 100 ft long

Provide the following information for your supervisor:

1. Flowsheet of the proposed additional equipment
2. Material balance
3. Equipment list
4. Fixed investment cost using the Wroth method for the present and for mid-2004.

Use the rules of thumb in Appendix B and the cost algorithms in Appendix C. State clearly and justify any assumptions you've made in preparing the estimate.

5

Estimation of Operating Expenses

The estimation of capital requirements has received considerable attention in the open literature as evidenced by the vast number of references. On the other hand, operating expenses are estimated from proprietary company files, and hence there is a meager amount of information in the open literature. References 1–4 provide various viewpoints concerning the estimation of operating expenses.

Capital expenditures occur once during the life of a project but operating expenses are recurring expenses and, as such, significantly affect the cash flow and profitability of a venture. Some expenses, such as raw materials and utilities, can be estimated with reasonable accuracies from material and energy balances for a process and from projected price structures. Items such as maintenance and plant indirect expenses are estimated as a percentage of the fixed capital investment. Depreciation is set by the federal government rules. Labor, however, is more difficult to project and this is where practical experience is necessary. Generally, all other items in operating expense estimates are percentages of labor expenses.

Errors in the estimation of operating expenses occur as a result of improper use or misinterpretation of reference data. An inexperienced person should seek advice and guidance from experienced manufacturing personnel when preparing an operating expenses estimate.

5.1 TERMINOLOGY

Operating expenses in this text will consist of the expense of manufacturing a product as well as the packaging and shipping, selling and distribution, and general overhead expenses. The manufacturing expense will be interpreted to mean those expenses required to make a product and to ready it for shipment.

Unit cost is the cost of an item based upon either a mass or volume unit, e.g., dollars per pound, dollars per gallon, dollars per barrel, etc. Raw materials, by-products and utility costs are quoted on these bases.

Direct expenses are those directly associated with the manufacture of a product, e.g., utilities, supplies, and labor. These expenses vary nearly in direct proportion to the production rate. On a unit-cost basis, they tend to remain constant irrespective of the amount of material produced. Raw materials and by-products are often carried on the manufacturing expense sheet as separate items from direct and indirect expenses, although they tend to vary directly with the production rate.

Indirect expenses are those that tend to remain constant with respect to the production rate. Examples are depreciation and plant indirect expenses such as security, fire protection, roads, yards, and docks. On a unit-cost basis, the indirect expenses will tend to decrease with increasing production, since their cost is constant or varies slightly with the production rate.

Another way of classifying expenses is as variable, fixed, and semivariable. Variable expenses vary approximately in direct proportion to the production rate, e.g., utilities, supplies. Like direct expenses, they tend to remain constant on a unit-cost basis as the production rate varies.

Fixed expenses are those that are constant as the production rate changes. Depreciation, ad valorem taxes, insurance, etc., are examples. On a unit-cost basis they tend to decrease as the production rate increases.

Semivariable expenses are expenses that are partially fixed and partially variable with respect to production. They tend to decrease as the production rate increases but they are not zero at zero production level. When the production rate changes, a fraction of a laborer is not possible. Maintenance, supervision, and in some circumstances, utilities may fall into this category.

In the chemical process industries either set of terminology is used depending on how a company sets up their accounting standards.

5.2 MANUFACTURING EXPENSE SHEET

A typical manufacturing expense sheet may be found in Figure 5.1. As we proceed through this chapter, it would be advisable to refer to this figure. The manufacturing expense sheet consists of four distinct parts. At the top is the heading that identifies the name of the product, production capacity, plant location, operating hours per year, the fixed capital investment, etc.

The next section is a listing of the raw materials and by-products. For each, the units (pounds, gallons, etc.), the quantity of material consumed or produced

Date :
By :

MANUFACTURING EXPENSE SHEET

LOCATION: ______ DEPT. NO: ______ PRODUCT ______
Mfg. Capital ______ Design : ______ per yr (______ hr)
Yields : Prod: per yr (hr)

RAW MATERIALS	UNIT	QUANTITY	$/UNIT	$/yr
		GROSS R.M. EXPENSE		

BY-PRODUCT (CREDIT) *

		TOTAL CREDIT		

NET MATERIAL EXPENSE

DIRECT EXPENSE	UNIT	QUANTITY	$ /UNIT	
Steam	MM Btu			
Electricity	KWH			
Water – cooling tower	M Gal			
– city	M Gal			
– sea	M Gal			
Fuel gas	MM Btu			
Compressed air	MCF			
Steam condensate	M Gal			
		TOTAL UTILITIES		
Labor				
Supervision				
Payroll charges				
Repairs – equipment				
– buildings				
Factory supplies				
Laboratory				
Clothing and laundry				
Environmental Control				
Other				
Packaging, loading, and shipping				

TOTAL DIRECT CONVERSION EXPENSE
TOTAL DIRECT MFG. EXPENSE
INDIRECT EXPENSE
Depreciation
Factory indirect expense
TOTAL INDIRECT CONVERSION EXPENSE
TOTAL MANUFACTURING EXPENSE

* Indicates negative quantity, or credit.

FIGURE 5.1 Manufacturing expense sheet.

annually, the unit price of the material, and the total annual expense are given. If the raw materials and by-products are moved within the plant, a handling charge is included. All raw material expenses are summed to yield a gross raw material expense. Similarly, the by-products are summed and a total by-product credit is calculated. If this total is subtracted from the gross raw material expense, the result is the net material expense.

The third section includes variable expenses such as utilities, supplies, and laboratory charges. Some companies include a semivariable expense category which includes labor, supervision, maintenance, and payroll charges. These items vary with the production rate but not directly. The sum of all items in the third section is the total variable expense.

The last section of the manufacturing expense sheet is the fixed expenses that include depreciation and plant fixed (indirect) expenses. The depreciation model used is straight line. Accelerated depreciation models are not used here but are found in cash flow analyses, as shown in Chapter 8. Plant fixed expenses includes expenses for plant security, plant fire protection and safety, cafeteria expenses, roads and docks, etc. The sum of these expenses is the total fixed expenses.

The sum of the net material and variable and fixed expenses is the total manufacturing expense.

These are not all the expenses associated with producing a salable product. A general overhead expense, sometimes referred to as SARE, representing sales, administration, research, and engineering expenses is added to the total manufacturing expenses to yield the total operating expense.

5.3 ESTIMATION OF OPERATING EXPENSE ITEMS

Table 5.1 is a quick reference to the entries in a manufacturing expense sheet together with suggestions of factors for estimation purposes.

5.3.1 Raw Material Expenses

Estimates of the amount of raw materials consumed can be obtained from the process material balance. In the manufacture of organic chemicals, between 50 and 80% of the total manufacturing expense is in raw materials. In inorganic processes, the raw materials account for 30–50% of the bottom line. Since the raw material expense is the largest contributor to the total manufacturing expense, it is essential that the amount of raw materials used and their prices be as accurate as possible.

In some processes, the initial charge of catalysts and certain chemicals is capitalized as part of the total capital investment because, for example, catalysts such as platinum and rhodium are very expensive and represent a large capital outlay. Any makeup for losses of these would appear in the raw material category as an operating expense.

Although some authors recommend using *The Chemical Marketing Reporter* or other open literature sources to obtain chemical prices, they are not the best prices. Companies negotiate contracts to purchase raw materials at

TABLE 5.1 Total Operating Expenses

Raw materials
By-product credits
Net materials
Direct expenses
Utilities
Operating labor
Maintenance
Supervision
Payroll charges
Operating supplies
Laboratory expenses
Clothing and laundry
Technical service
Royalties
Environmental control
Total material and direct expenses
Indirect expenses
Depreciation
Plant indirect expenses
Total indirect expenses
Packaging, loading, and shipping
Total product expenses
General overhead expenses (SARE)
Total operating expenses

a given price for a specified time period. The contract prices are below the prices in the open literature. The prices quoted are on an FOB (free on board) at the supplier's plant or at some basing point in an effort to equalize freight charges. Care must be taken that freight charges are included in the raw material expense. Freight information is obtained from a company's accounting, purchasing, or traffic departments or from rail, barge, or truck companies.

There are instances when a company may have integrated backwards, that is, produce their own raw materials. If that is the case, a transfer price is used which includes the manufacturing expense plus transportation charges to move the raw material to the proposed operating department. If the company operates on a profit-center basis, an additional charge may be assessed. As an alternate, the proportionate-share basis, described in Chapter 4, may be used.

Prices for raw materials vary depending on a number of factors:

- Form of the raw material—powder, flake, crystal, liquid, etc.

- Grade—research, technical, industrial, etc. Frequently, a lower quality material may be used but this must be determined by the research department.
- Quantity discounts or large contract amounts—Potential savings may occur when buying in large quantities but capital must be provided for storage of the material.
- Delivery—tank trucks, rail cars, barges, pipelines, etc.
- Containers—drums, fiberpaks, leverpaks, carboys, or special containers to prevent product deterioration.
- Seasonal products—Some materials like agricultural chemicals are produced at certain times of the year. Again storage must be available and product stability may be a problem.

By-product materials are treated in the same fashion as raw materials and are entered in the manufacturing expense sheet under by-product credit. The prices for these materials may be estimated from market price quotations less purification, packaging, and transportation expenses. If by-products are intermediates for which no market exists, then they are credited to downstream or subsequent operations at a value equivalent to their value as a replacement.

5.3.2 Utilities

The utility requirements for a process are obtained from material and energy balances. The company or plant utility supervisor can provide unit prices for each utility and information concerning rate contracts for the near future. As the demand for a utility increases, its unit cost declines. If large incremental amounts of utilities are required, for example, electricity, it may be necessary to tie the company's utility lines to a local utility as a floating source.

With current energy demands increasing, the costs of all utilities are increasing. Any costs quoted need to be reviewed periodically to determine their effect on plant operations.

In the southwestern United States, typical utility costs as of mid-year 2000 were:

Steam:	
High pressure (~450 psig)	\$6.00–\$9.00/M lb
Medium pressure (~100–150 psig)	\$5.00–\$7.50/M lb
Low pressure (~50–75 psig)	\$4.50–\$7.00/M lb
Electricity: 60 Hz, 440 V	\$0.06–\$0.10/kWh
Natural gas:	\$5.00–\$15.00/SCF
Cooling tower water: (85F, 25 psig)	\$0.10–\$0.15/M gal
City water (75F, 60 psig)	\$2.00–\$10.00/M gal

Refinery fuel costs endured an unsteady course between 1997 and 2001. Fuel costs affect the steam, electricity, and cooling water costs; it is advisable to consult with the plant utilities supervisor. It is difficult to get reliable utility costs from companies since this information is considered to be proprietary.

5.3.3 Labor Expenses and Productivity

Operating labor is usually the second largest direct expense item on the manufacturing expense sheet. The most reliable way to estimate the labor requirements is to prepare a table of shift, weekend, and vacation coverage [5]. If the estimator has not had experience in this task, it would be advisable to seek guidance from experienced plant operating personnel. If we assume 3 shifts per day, and 7 days per week for a continuous operation, 21 shifts must be covered. Next, if an operator works 5 shifts per week, to have complete coverage of the 21 shifts requires 4.2 people. This allows for one operator on a shift. For a batch operation of a noncontinuous process, the preparation of a labor table, listing the tasks and the number of operators required is essential.

In order to obtain labor rates, it is advisable to consult the union contract or the company labor relations supervisor. This person will know of any potential for labor rate increases. Other sources of labor costs may be obtained from the Bureau of Labor Statistics publications. Labor rates have been increasing over the past several years from 5 to 10% per year. One should not forget to include shift differential and overtime charges. A reasonable average operating labor cost in the southwest United States is between \$35,000 and \$40,000 per operator per year. No fringe benefits have been included but will be a separate entry on the manufacturing expense sheet.

A method for estimating labor requirements for various types of chemical processes in the United States was proposed by Wessel [6]. His equation for plants producing product from 2 to 2000 tons/day is as follows:

$$\log_{10} Y = -0.783 \log_{10} X + 1.252B \tag{5.1}$$

where

$Y =$ operating labor in man-hours per ton per processing step
$X =$ plant capacity, tons/day
$B =$ a constant depending upon the type process
$+\,0.132$ (for batch operations that have minimum labor requirements)
$+\,0$ (for operations with average labor requirements)
$-\,0.167$ (for a well-instrumented continuous process)

A processing step is one in which a unit operation occurs; e.g., a filtration step might consist of a feed tank, pump, filter, and receiver. A processing step then may have several items of equipment. With the aid of a flowsheet, the number of processing steps may be counted.

The Wessel equation does not recognize improvement in labor productivity as plant size increases. It does provide a way of extrapolating man-hours to plants of greater or lesser capacity. Although Wessel's equation has been recommended by various authors, this author has found that the equation results in high labor requirements.

The operating expense for labor is found by multiplying the man-hour requirements by the average hourly labor rate for the specific plant location.

Labor productivity is a difficult item to estimate. By definition, it is the physical output of a production unit in pounds, gallons, barrels, tons, etc. divided by the input in man-hours. Labor productivity varies widely with each section of the United States, but even wider variations occur between the United States and foreign countries. Although labor productivity figures are available for the construction industry, no definitive studies are available for chemical plant productivity. Overall productivity in the chemical industry is published as a productivity index in the Economic Indicators section of *Chemical Engineering*. These data are indexed to 1987 = 100. As of December 2000 it is 114.7, meaning there has been a 14.7% increase since 1987. Occasionally, *Chemical Week* and *Chemical and Engineering News* will publish fragmentary data. The only reliable data would be a site-specific study.

5.3.4 Maintenance

There are two components to the maintenance expense, materials and labor. A company's maintenance records are the best source of information. Very little useful information is found in the open literature. Hackney [7] proposed a simple equation for annual maintenance expense for paper and pulp, cement, coke, silicone products refineries, and electrolytic plants. The annual expense was then related to the fixed plant investment and number of years in operation.

For preliminary estimates, a percentage of the fixed capital investment per year is often used. An average of 6–10% of the fixed capital investment is reasonable. For processes having a large amount of rotating equipment such as pumps, compressors, centrifuges, or processes that operate at extremes of temperature and/or pressure, the higher percentage should be used. Processes that have a minimum of rotating equipment or that operate near ambient conditions or a figure near the low end of the range might be used. It should be understood that the percentage includes both labor and materials.

If it necessary to split the maintenance expense into materials and labor, reasonable figures are 60 and 40%, respectively.

For several years *Chemical Week* reported total maintenance expense as a percentage of the fixed capital investment from annual and 10K reports of various chemical and petroleum companies [8].

As plant operating rate increases, maintenance expenses do not vary in direct relation and as a result this item is considered as a semivariable expense.

5.3.5 Supervision

Supervisory personnel are the salaried employees whose responsibility is the unit's operation. They include the department supervisor, foremen and departmental clerks. If the positions and salaries can be identified, then these data should be used with allowances for salary increases. As an alternate, 20–30% of the operating labor expense is reasonable. The lower figure would be for continuous operations while the higher would be more realistic for batch operations.

5.3.6 Payroll Charges

This expense category would include workmen's compensation, social security premiums, unemployment taxes, paid vacations, and holidays as well as life, medical, and dental insurance premiums. In recent years, a company's contribution to pension plans has declined with more of the responsibility placed upon the employee. Up until the 1980s, these expenses amounted to about 45–50% of the labor plus supervision expenses; however, beginning in the late 1990s, this figure began to decline to between 30 and 40%.

5.3.7 Operating Supplies

This expense includes instrument charts, computer paper, filter cloths, brooms, mops. Company records for similar operations are the best source of information. For new operations, a reasonable estimate might be 5–7% of the operating labor.

5.3.8 Laboratory Expenses

With the advent of in-line analyzers and other sophisticated equipment for production-line use, these expenses as a separate item will decline in the future. Many products, however, still must be subjected to various quality-control tests in the laboratory. The charges for these expenses approach \$100–\$150 per laboratory hour. As an alternate, a reasonable estimate for preliminary purposes might be 15–20% of the operating labor.

5.3.9 Clothing and Laundry

In the production of food-grade products, pharmaceuticals, toxic chemicals, high-technology microelectronics, etc. companies provide clothing and laundry service for manufacturing personnel. This expense will vary depending upon the product made and the manufacturing process. Company records are an excellent source of data. If no information is available, then 15–20% of the operating labor expense is reasonable.

5.3.10 Technical Service

In some companies, the maintenance of technical and/or engineering assistance to manufacturing departments from a central pool of technically trained personnel is an operating expense. These people are concerned with process or production improvement in product quality or quantity, and in some cases the addition of new equipment. It is recommended that about 25% of a new engineer's salary be allocated. The 25% figure is based upon the assumption that this engineer might be assigned responsibility for about four such projects.

5.3.11 Royalties

This expense item applies if a firm buys technology. It is a difficult item to estimate since there are a number of ways that a royalty agreement may be drawn. In Chapter 3, there was an entry for royalties, patents, and licenses. These were one-time charges that are regarded as replacement for research and thus are capitalized. In contrast to royalties mentioned in Chapter 3, there is a "running royalty." Under this type of royalty, a fraction of a cent per unit of production is assessed for use of this technology. As an alternate, 0–5% of sales might be used.

5.3.12 Environmental Control Expense

Wastes from manufacturing operations must be disposed of in a safe and in an environmentally acceptable manner. This expense is borne by the manufacturing department. Some companies may have their own facilities for proper disposal or may contract with other firms, but no matter how the wastes are handled, there is a fee. Published data of waste disposal expenses are found in the open literature, some of which are presented in Table 5.2 [9].

5.3.13 Total Direct Expense

The total direct expense is the sum of all expenses beginning with utilities and ending with the environmental control expense.

5.3.14 Total Direct Manufacturing Expense

This item is the sum of the net material expense and the total direct expenses.

TABLE 5.2 Environmental Control Expenses

Type of waste management	Type or form of waste	Expense
Landfill	Drum	\$100–\$150 per 55-gal drum
	Bulk	\$150–\$300/U.S. ton
Land treatment	All	\$0.25–\$0.60/gal
Incineration (where permitted)	Relatively clean fluids, high Btu value	\$0.25–\$1.25/gal
	Liquid	\$0.25–\$2.50/gal
	Solids, highly toxic liquids	\$6.00–\$15.00/gal
Chemical treatment	Acids/alkalies	\$0.40–\$2.00/gal
	Cyanides, heavy metals, and highly toxic wastes	\$2.00–\$20.00/gal
Land farming		\$15.00–\$30.00/yd^3
Composting (sewage sludge)		\$150–\$400/ton dry material
Biological treatment	Land treatment	\$45–\$110/yd^3
	Bioventing	\$65–\$175/yd^3
	Bioreactor	\$175–\$300/yd^3
Transportation		\$0.15–\$0.50/ton-mile

Source: Ref. 9.

5.3.15 Indirect Expenses

5.3.15.1 Depreciation

The Internal Revenue Service allows a deduction for the "exhaustion, wear and tear, and normal obsolescence of a property used in the trade or business." The subject is treated more fully in Chapter 7. With each revision to the tax laws, there are modifications to the rules for depreciating equipment.

For operating expense reports, straight-line depreciation is used, and the MACRS method is used for cash flow analysis. The overall effect of depreciation on cash flow will be discussed later in Chapter 8.

5.3.15.2 Plant Indirect Expense

Plant indirect expense covers a wide range of items such as property insurance; personal and property liability insurance; workmen's compensation; franchise and real estate taxes; fire protection; safety; plant security; maintenance of roads, yards, and docks; plant personnel staff, cafeteria expense. A firm's accounting department usually has developed factors based upon capital investment, operating labor, or a combination of the two for each plant site.

A quick estimate of these expenses is 3–5% of the fixed capital investment. Hackney [7,10] proposed a method based upon a capital investment and a labor component. It is presented in Table 5.3.

5.3.16 Total Indirect Expense

The sum of depreciation and plant indirect expense is the total indirect expense.

TABLE 5.3 Plant Indirect Expense Factors

Plant type	Investment factor, %	Labor factor, %
Heavy chemical (large capacity)	1.5	45
Power	1.8	75
Electrochemical	2.5	45
Cement	3.0	50
Heavy chemical (small capacity)	4.0	45

Source: Ref. 6.

5.3.17 Total Manufacturing Expense

This item is the sum of the total direct and indirect expenses. At this stage the product has been manufactured but now must be made ready for shipment to the customer.

5.3.18 Packaging, Loading, and Shipping Expense

Products may be packaged in a variety of packages or containers, such as fiber drums, leverpaks, barrels, carboys. Some products, however, may be transferred by pipeline, e.g., gases and some liquids.

If the finished product is shipped in containers, a charge must be made for the containers. Associated with the package expense is also the labor to perform this task. There is an expense for moving the product from the manufacturing department to a warehouse or to a transporting conveyance. Under some circumstances, dunnage may be required in trucks or rail cars to protect the container from shifting or being damaged during shipment.

A third expense may be incurred when shipping the product to the customer. It may be absorbed by the manufacturer or it may be charged to the customer. If the manufacturer assumes the shipping expense, it becomes part of the total operating expense.

The best source of these cost data is a firm's records for products of similar characteristics, since companies maintain good cost control records on packaging and in-plant handling and warehouse expenses. Transportation charges may be obtained from a company transportation specialist or from local rail, trucking, or barge companies. Current transportation charges may be found in Table 5.4 [11].

For estimating purposes, 0–7% of sales may be used.

5.3.19 Total Product Expense

The sum of the total manufacturing expense and the packaging, loading, and shipping expense is the total product expense.

TABLE 5.4 Transportation Charges

Transportation means	$/ton-mile
Pipeline	$0.003–$0.007
Barge and tanker	0.005–0.012
Railroad	0.03–0.07
Truck	0.05–0.18

Source: Ref. 9.

5.3.20 General Overhead Expense

The general overhead expense includes the expense of maintaining sales offices throughout the country, staff engineering departments, research laboratories, and administrative offices. All products are expected to share in these expenses so an appropriate charge is made for each product. The charge will vary between 6 and 15% of the annual sales revenue. The wide range in this charge will vary as some products may require more customer service due to the nature of the product.

5.3.21 Total Operating Expense

The sum of the general overhead expense and the total operating expense is the total operating expense.

There are occasions when an order-of-magnitude operating expense would suffice. The total manufacturing expense may be estimated for the following processes:

Organic chemical processes: 50–70% of the total manufacturing expense is in raw materials.
Inorganic chemical processes: 30–50% of the total manufacturing expense is in raw materials.

Example 5.1

This example will illustrate the preparation of an estimate of the total operating expense for a product. It should be understood that material and energy balances must be available to prepare this estimate.

Problem Statement:

Altos Chemical Company is a producer of specialty chemicals. A market survey indicates that a solid specialty chemical additive, XQ, is expected to be in demand in the near future. A preliminary fixed capital investment estimate of \$18MM will be required to produce 25 MM lb/yr of XQ. The selling price of the product is estimated to be 80 cents per pound. The raw materials needed are:

Material	Annual requirements	Cost
A	17 MM lb	22 cents/lb
B	22 MM lb	15 cents/lb

The process is semicontinuous and is assumed to operate at 90% stream time. Two operators per shift around the clock will be required. Other costs and operating requirements are:

Utilities:

	Usage/lb product	Cost
Steam	4.0 lb	\$4.25/M lb
Electricity	0.25 kWh	6.2 cents/kWh
Cooling water	6.0 gal	5.0 cents/M gal
City water	2.0 gal	\$0.40/M gal

Maintenance: 5.4%/yr of the fixed capital investment
Average operating labor expense: \$40,000/yr/operator
Supervision: \$3500/month
Payroll charges: 38% of operating labor plus supervision/yr
Supplies: \$300/month
Clothing and laundry: \$350/month
Laboratory charges: 40 hr/month at \$150/laboratory hour
Packaging, loading, and shipping charges: 1.0 cents/lb product
Waste disposal expense: \$1000/month
Other direct expenses: \$300/month
Depreciation: straight line for 5 years
Plant indirect expense: 2.5% of the fixed capital investment/yr
General overhead expense (SARE): 6% of the net annual sales

a. Prepare an annual manufacturing expense estimate based on full production for year 1.
b. Calculate the total operating expense at full production for year 1.

Solution:

Basis: 1 year of operation
Annual sales:

$$25,000,000\,\mathrm{lb/yr} \times \$0.80 = \$20,000,000$$

Manufacturing expense sheet

Net material expenses:

$$\text{Raw material } A: \quad 17,000,000\,\mathrm{lb/yr} \times \$0.22/\mathrm{lb} = \$3,740,000$$
$$\text{Raw material } B: \quad 22,000,000\,\mathrm{lb/yr} \times \$0.15/\mathrm{lb} = \$3,300,000$$
$$\text{Net material expense} = \$7,040,000$$

Direct expenses:
Utilities:
Stream:

$$25,000,000\,\text{lb/yr} \times 4\,\text{lb steam/lb product} \times \$4.25/1000\,\text{lb steam}$$

$$= \$425,000$$

Electricity:

$$25,000,000\,\text{lb/yr} \times 0.25\,\text{kWh/lb product} \times \$0.062/\text{kWh}$$

$$= \$387,500$$

Water:

$$\text{Cooling tower}: \quad 25,000,000\,\text{lb/yr} \times 6.0\,\text{gal/lb product} \times \$0.05/1000\,\text{gal} = \$7500$$

$$\text{City water}: \quad 25,000,000\,\text{lb/yr} \times 2.0\,\text{gal/lb product} \times \$0.40/1000\,\text{gal} = \$20,000$$

$$\text{Total utilities} = \$840,000$$

Labor: 2 operators/shift × 4.2 shifts × \$40,000/yr = \$336,000
Maintenance: 0.054/yr × \$18,000,000 = \$972,000
Supervision: \$3500/month × 12 months/yr = \$42,000
Payroll charges: 0.38(\$336,000 + 42,000) = \$143,640
Supplies: \$300/month × 12 months/yr = \$3600
Clothing and laundry: \$350/month × 12 months/yr = \$4200
Laboratory charges: 40 hr/month × \$150/hr × 12 months/yr = \$72,000
Environmental control: \$1000/month × 12 months/yr = \$12,000
Other direct expenses: \$300/month × 12 months/yr = \$3600
Packaging, loading, and shipping: 25,000,000 lb/yr × \$0.01/lb = \$250,000
Total direct expense: \$2,679,040
Total direct manufacturing expense: \$9,719,040
Indirect Expense:
Depreciation: \$18,000,000/5 yr = \$3,600,000
Factory indirect expense: 0.025 × \$18,000,000 = \$450,000
Total indirect expense: \$4,050,000
Total manufacturing expense: \$13,769,040
SARE (general overhead expense): 0.06 × \$25,000,000 = \$1,500,000
Total operating expense: \$15,269,040 (say \$15,300,000)

Figure 5.2 is the manufacturing expense sheet for the example.

Date : 06 / 06 / 01
By : JRC

MANUFACTURING EXPENSE SHEET

LOCATION: Anywhere, U.S.A. DEPT. NO: 59 PRODUCT: XQ
Mfg. Capital $ 18,000,000 Design : 25,000,000 1b per yr (7:884 hr)
Yields : Prod: per (hr)

RAW MATERIALS	UNIT	QUANTITY	$/UNIT	M$/yr
A	1b	17,000,000	$ 0.22	3,740
B	1b	22,000,000	0.15	3,300
		GROSS R.M. EXPENSE		7,040
BY - PRODUCT (CREDIT) *				
		TOTAL CREDIT		
NET MATERIAL EXPENSE				7,040
DIRECT EXPENSE	UNIT	QUANTITY	$/UNIT	
Steam	MM 1 b	100 MM 1b	$4.25	425
Electricity	KWH	6625 MMKWH	0.062	388
Water – cooling tower	M Gal	150 MM gal	0.05	7
– city	M Gal	50 MM gal	0.40	30
– sea	M Gal			
Fuel gas	MM Btu			
Compressed air	MCF			
Steam condensate	M Gal			
		TOTAL UTILITIES		840
Labor				336
Supercision				42
Payroll charges				144
Repairs – equipment				972
– buildings				
Factory supplies				4
Laboratory				72
Clothing and laundry				4
Environmental Control				12
Other				3
Packaging, loading, and shipping				250
TOTAL DIRECT CONVERSION EXPENSE				2,679
TOTAL DIRECT MFG. EXPENSE				9,719
INDIRECT EXPENSE				
Depreciation				3,600
Factory indirect expense				450
TOTAL INDIRECT CONVERSION EXPENSE				4,050
TOTAL MANUFACTURING EXPENSE				13,769

* Indicates negative quantity, or credit.
Calculated values have been rounded before entering in this sheet.

FIGURE 5.2 Manufacturing expense sheet.

Table 5.5 Operating Expense Estimating Factors

Material expense	
Raw materials	Material balance
By-products	Material balance
Direct expenses	
Utilities	Energy balance
Labor	Itemize
Maintenance	6–10% fixed capital investment
Supervision	20–30% of labor
Payroll charges	30–40% of labor plus supervision
Operating supplies	5–7% of labor
Laboratory expense	\$100–\$150 per laboratory hour or 15–20% of labor
Clothing and laundry	15–20% of labor
Technical service	25% of a new engineer's salary
Royalties	0–5% of sales
Environmental control	See Table 5.2
TOTAL MATERIAL AND DIRECT EXPENSES	
Indirect Expenses	
Depreciation	Straight-line method (see Chap. 7)
Plant indirect expenses	3–5% fixed capital investment
TOTAL INDIRECT EXPENSE	
Packaging, loading, and shipping	0–7% of sales
TOTAL PRODUCT EXPENSE	Sum of above items
General overhead expenses (SARE)	6–15% of sales
TOTAL OPERATING EXPENSE	Sum of last two items

Source: Ref. 2.

Typical estimating factors for operating expense may be found in Table 5.5.

5.4 COMPANY EXPENSE REPORTS AND EXPENSE STANDARDS

Once an operating department commences producing product, it receives monthly expense reports from the accounting department. This report lists the amount of each expense item used and the expenditure for that month under the appropriate category on the manufacturing expense sheet. In addition, as time progresses, year-to-date and previous year usages and expenses are listed for comparison purposes.

In some companies, expenses standards are developed for each product. The standards are the goals that the department supervisor sets in conjunction with his or her immediate supervisor. Often the expense standards for several operating levels are prepared. These levels might be for zero production, one or more intermediate levels, say 60 or 75% of full operating capacity and full capacity. The zero production level indicates what expenses are incurred when no product is made. Line-by-line comparison of the current expense report with the expense standard is reviewed with the immediate supervisor. Goals are set for the next review period. After repeated reviews, it may become obvious that certain expense items are increasing. For example, if maintenance is increasing markedly, that may be an indication that some existing equipment may need to be replaced with more efficient, lower maintenance equipment. Such reviews pinpoint areas that need attention to reduce operating expenses. Perhaps consideration may need to be given to a new process to replace the old one.

5.5 OPERATING EXPENSE SCALE-UP

The total manufacturing expense of a product presented in the foregoing sections consists of the following major items: raw materials and direct and indirect expenses. The latter two expenses are estimated by relating the individual items roughly to the fixed capital investment, labor, and utilities. For example, maintenance, depreciation, and plant indirect expenses are often expressed as percentages of the fixed capital investment, whereas supervision, supplies, payroll charges, etc. are labor related.

Holland et al. [12] developed an expression for the estimation of the annual conversion expense at a given production rate based upon investment costs, labor, and utility expenses. The equation is

$$A_1 = mC_{\mathrm{fci}} + nc_L N_1 + pU_1 \tag{5.2}$$

where

C_{fci} = fixed capital investment
C_L = cost of labor, \$/operator/shift
N_1 = annual labor requirements, operators/shift/year at rate 1
U_1 = utility expenses at production rate 1
A_1 = annual conversion expense at production rate 1
m, n, p = constants

Equation (5.2) may be modified to include a raw material term qM_1 so that

A_1 would be the total manufacturing expense.

$$A_1 = mC_{\mathrm{fci}} + nc_L N_1 + pU_1 + qM_1 \tag{5.3}$$

If one wants to estimate the annual manufacturing expense at another production rate, Eq. (5.2) may be further modified as follows:

$$A_2 = mC_{\mathrm{fci}}\left(\frac{R_2}{R_1}\right)^{0.7} + nc_L N_1\left(\frac{R_2}{R_1}\right)^{0.25} + pU_1\left(\frac{R_2}{R_1}\right) + qM\left(\frac{R_2}{R_1}\right) \tag{5.4}$$

where

A_2 = annual manufacturing expense at production rate 2
R_1 = production rate 1
R_2 = production rate 2

All other terms are the same as in Eqs. (5.2) and (5.3).

The exponents in Eqs. (5.3) and (5.4) are appropriate. The first term in Eq. (5.4) reflects the increase in the capital investment using the 0.7 power for increased production rates, as shown in Chapter 4. Labor varies as the 0.25 power for continuous operations based again upon experience. Utilities and raw materials are essentially in direct proportion to the amount of product manufactured, so the exponent on the rate terms is unity.

A plot of the annual conversion expense A as a function of production rate on log–log coordinates is a straight line, as shown in Figure 5.3. This type of plot may be used for estimating the conversion expense at interpolated rates. Extrapolation beyond the production rates for which the plot was prepared is not advisable because significant errors may be encountered. Occasionally, management requests a break-even plot as part of a preliminary evaluation or an

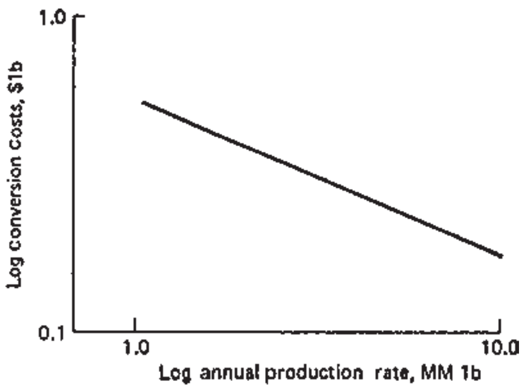

FIGURE 5.3 Annual conversion expense as a function production rate.

appropriation request. The above procedure may be helpful in obtaining operating expenses at intermediate production values.

Other items in the total operating expenses, such as packaging, loading, and shipping, as well as general overhead expenses, have not been included and must be determined separately if they are to be considered.

The modified Holland method is satisfactory for preliminary estimates but for more accurate estimates item-by-item consideration of each expense component must be undertaken. This latter procedure eliminates the possibility of overlooking an expense item that might have significant bearing on the total operating expenses.

5.6 OPERATING EXPENSE INDEX

Attempts have been made in the past to develop operating expense indices to update these expenses, similar to those used to update equipment costs. The one surviving index is known as the Nelson–Farrar Refinery Operating Expense Index published in the first issue each month of the *Oil and Gas Journal* [13].

The Nelson Refinery Operating Index began in 1956 with an index = 100 for an average U.S. refinery and there have been numerous revisions to accommodate different "weighting" techniques for the items constituting the index. This index was designed to be a "true" index corrected for the following items:

- Productivity of labor
- Changes in the amount and kinds of fuels used
- Productivity in the design and construction of refineries
- Amounts and kinds of chemicals and catalysts used

TABLE 5.6 Nelson–Farrar Operating Expense Index (1956 Basis = 100)

Item	1962	1980	1997	1998	Nov. 2000
Fuel cost	100.9	810.5	529.3	411.8	886.9
Labor cost	93.9	200.5	241.9	241.0	246.2
Wages	123.9	439.9	929.6	978.3	1,120.3
Productivity	131.8	226.3	385.2	406.3	455.0
Investments, maintenance, etc.	121.7	324.8	575.1	579.5	593.7
Chemical costs	96.7	229.2	255.2	239.1	224.6
Operating indices					
Refinery	103.7	312.7	415.6	405.1	454.7
Process units	103.6	457.5	459.1	419.2	591.7

Source: Ref. 13.

A major revision was reported on page 145 of the December 30, 1985 issue of the journal. Table 5.6 is an example of the Refinery Operating Expense Index.

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PROBLEMS

5.1 A custom manufacturer has been contacted by a pharmaceutical company about producing 15 MM/lb/yr of an intermediate chemical. L. Jones & Co. has a proprietary catalyst that the custom manufacturer needs to produce the intermediate. The charge for this “running” royalty will be \$200,000 per year. Other pertinent expenses are expected to be:

Fixed capital investment	\$6,800,000
Natural gas	\$100,000/yr
Raw materials	\$250,000/yr
Steam	\$563,000/yr
Solvent inventory	\$53,000/yr
Cooling water	\$85,000/yr
Solvent makeup	\$54,000/yr
Electricity	\$18,000/yr
Labor	\$200,000/yr
General overhead	\$269,000/yr

Supplies inventory	$25,000/yr
Depreciation	5-year straight-line
Cash	$600,000
Real estate	$50,000
Interest on loan	$260,000/yr
Local taxes and insurance	$134,000/yr

From the information above only, prepare

A statement of the total capital requirements
An estimate of the total operating expenses

5.2 A company is considering the possibility of producing a rubber-additive chemical used in the manufacture of automobile tires. The total fixed capital investment estimated by the company's engineering department is $7.5MM. This plant will produce 12 MM lb/yr of the chemical. The land on which the facility is to be located cost $100,000 and the working capital necessary for this venture is $200,000. The specialty chemical sells for 65 cents/lb. The plant requires 3 operators/shift around the clock and operates at 95% stream time. The total raw material costs 20 cents/lb of product other usages and costs are:

Utility	Usage/lb product	Cost
Steam	5.0 lb	$5.25/M lb
Electricity	0.25 kWh	$0.06/kWh
Cooling tower water	6.0 gal	$0.05/M gal
City water	10 gal	$0.40/M gal

Maintenance: 6% FCI/yr
Depreciation: 5 yr straight-line
Average labor rate: $40,000/yr/operator
Supervision: $4,000
Payroll charges: 40% of labor plus supervision
Supplies: $150/month
Clothing and laundry: $400/month
Laboratory charges: 50 hr/month at $120/hr
Plant indirect expenses: 2.5% FCI/yr

Calculate:

a. Total product expense
b. The total operating expenses if the general overhead expenses are 10% of the annual sales

5.3 The fixed capital investment for a plant to manufacture of a food additive is expected to be \$5,000,000. It is proposed to manufacture 8 MM lb/yr. The working capital may be assumed to be 15% of the total capital investment. Start-up expenses are estimated at 6% of the fixed capital investment. According to the marketing department, the additive is expected to sell for 80 cents/lb of product. Manufacturing expenses per pound of product are:

Raw materials and catalyst	\$0.070/lb
Utilities	\$0.040/lb
Labor	\$0.62/lb
Supervision	20% of labor
Payroll charges	35% labor plus supervision
Maintenance	5.4% fixed capital investment/yr
All other direct expenses	\$0.030/lb
Depreciation	5-yr straight-line
Packaging and shipping	\$0.006/lb
Other indirect expenses	307% fixed capital investment/yr

a. Estimate the total product expense per pound of product
b. Determine the net profit after taxes per pound of product using 36% federal income tax rate

(*Note*: Use only the information given in the problem statement.)

5.4 A company built a plant to produce 10 MM lb/yr of dichloroethane in 1995 for \$5.0 MM fixed capital investment. The plant is operating at full capacity and cannot meet expected sales demand. Management has decided to build a second plant by essentially the same process and bring it on stream with a target date of January 2003. The second plant is to have a capacity of 15 MM lb/yr.

Dichloroethane is to be produced by the gas-phase reaction of ethylene and chlorine:

$$C_2H_4 + Cl_2 = C_2H_4Cl_2$$

The reaction is 100% complete with respect to chlorine but only 90% with respect to ethylene. The excess ethylene is sent to the boiler house to be used as fuel. The cost of chlorine is \$6.00/1000 SCF and ethylene costs \$0.50/1000 SCF. The value of ethylene in the fuel gas is \$0.30/1000 SCF and by-product credit may be taken for this excess ethylene.

Other operating expenses per 1000 lb product are:

Utilities	$10.00
Labor	$20.00
Maintenance	$8.00
All other direct expenses	$20.00
Depreciation	5-yr straight-line
All other indirect expenses	$5.00

The general overhead expenses may be taken as 8% of sales and the estimated sales price is $0.50/lb.

Provide a total operating expense in dollars per year for the new plant in January 2003. Assume inflation rates of 4.0% in 2001 and 5.1% in 2002.

5.5 Excalibar Plastics, Inc., is currently producing a resin for the toy market centered in the New York–New Jersey area. The present batch reactors are old. New reactors must be purchased in the near future to replace the old equipment. In order to meet market demands, 100,000 lb/day must be produced. Batch reactors similar to the ones currently in use are estimated to have an installed cost of $150,000 each. A typical batch reactor is stainless steel, jacketed, agitated with a temperature recorder, pressure recorder, and control valves. A heating medium used is chlorinated biphenyl vapor to achieve the desired temperature. One batch kettle has a capacity of 10,000 lb resin per 10 hr polymerization cycle but it takes another 2 hr between batches for discharging, cleanup, and recharging the reactor for the next cycle. Depreciation may be taken as 5 years straight-line. The labor cost is estimated to be 50 cents/lb resin produced. Raw material and other direct expenses are estimated to be $1.20/lb resin. Fixed costs per batch are $25.00 per batch reactor per day, assuming 340 operating days per year.

The Gelt Company of Hottentot, New Jersey offers for sale a continuous reactor package with automatic controls at an installed cost of $500,000 each. This reactor is stainless steel and is capable of producing 25,000 lb resin per day. The labor expenses are expected to be 25 cents/lb resin produced. Raw material and other variable expenses are expected to be $1.20/lb resin. Note that this is the same as for the batch reactors. The other fixed costs on each continuous reactor are expected to be $35/day operation.

Interest on capital borrowed for the reactors must be considered as an expense in the initial selection of the new production equipment. Invested money is worth 10%/yr to the company.

Summarize the solution based on 1-day operation:

Daily production	Continuous	Batch
Raw material and other expenses		
Variable expenses		
Labor expenses		
Depreciation		
Fixed expenses		
Interest on capital		
Total operating expenses		
Expense per pound of resin		
Total investment required		
Number of reactors required		

a. Which reactor should be purchased?
b. What will be the total annual savings based on a 340-day operation?
c. There are 10 batch reactors in the plant that were installed 1 year ago. They can be sold to a foreign subsidiary at $20,000 each in place when a replacement is available. Should these batch reactors be replaced by the continuous reactors now? Justify your answer with figures and reasons.

5.6 A company is considering the manufacture of a specialty chemical for use the synthetic fiber industry. An outside consulting firm has estimated that a fixed capital investment of $15MM will be required to manufacture 18 MM lb of product annually. The marketing department believes that a selling price of 70 cents/lb would be competitive with similar products in the market place. You may assume that all product made is sold.

The following information is available:

Raw material costs: 8.9 cents/lb
Utilities: 5.6 cents/lb
Labor: 4 operators per shift around the clock
Supervision: 10% of labor
Fringe benefits: 40% of labor plus supervision
Laboratory charges: 15% of labor
Maintenance: 6% FCI/yr
Waste disposal charges: 4.0 cents/lb
All other direct expenses may be assumed to be average

Depreciation: 5 yr straight-line
Plant indirect expenses: 2% FCI/yr
Packaging and shipping expenses: 0.4 cents/lb
General overhead expenses: 8% of annual sales
Working capital: 15% TCI
Neglect start-up expenses

Prepare:

a. Total operating expense report
b. Estimate of capital requirements
c. Net profit after taxes
d. Based upon your calculations, what recommendations could you make to management concerning this proposed venture? Be sure to substantiate your answer(s) with numbers.

5.7 Acme Petrochemicals, Inc. manufactures ethylene and chlorine at its Hopeless Springs facility. The company is considering building a vinyl chloride monomer plant at that facility to produce 200 MM lb/yr from excess chlorine and ethylene. The engineering department has supplied the following information for a VCM plant at a rated capacity of 200 MM/yr:

Fixed capital investment (current figure) $325MM
Annual consumption is:

Ethylene	96 MM lb
Chlorine	134 MM lb
Catalyst and chemicals	Negligible
Steam	306 MM lb
Cooling water	6170 MM gal
Electricity	21.4 MM kWh
Fuel	350,000 MM Btu
Labor	5 operators/shift
Supervision	$55,000
Maintenance	6% FCI
Payroll charges	35% of labor plus supervision
Other direct expenses	1% FCI/yr
Depreciation	5 yr straight line
All other indirect expenses	3% FCI/yr
General overhead expenses	7% annual sales
Selling price	$0.18/lb

Pertinent costs are:

Chlorine	Use current cost
Ethylene	Use current cost
Steam	\$5.50/M lb
Cooling water	\$0.17/M gal
Electricity	\$0.07/kWh
Fuel	\$5.00/MM Btu
Labor	\$38,000/operator/yr

a. Prepare a total operating expense sheet for the production of 200 MM lb/yr of VCM.
b. Estimate the total operating expenses for 60 and 85% of rated capacity.

6

Time Value of Money

When a person loans money, a charge is made for the use of these borrowed funds. The lender perhaps could have invested the funds somewhere else and made a profit; therefore, the interest is the compensation for the foregone profit. The borrower may look upon this interest as the cost of renting money. The amount charged depends on the scarcity of money, the size of the loan, the length of the loan, the risk the lender feels that the loan may not be paid back, and the prevailing economic conditions. Because engineers may be involved in the presentation and/or the evaluation of an investment of money in a venture, it is important that they understand the time value of money and how it is applied in the evaluation of projects. Later we shall see that in modern times, the term "return on investment" is used for the classical term "interest." It is the charge paid for borrowed money.

6.1 INTEREST RATE

The interest rate is the ratio of the interest charged at the end of a period (usually 1 year) to the amount of money owed at the beginning of the period expressed as a percentage. For example, if \$10 of interest is payable at the end of a year on a loan of \$100, the interest rate is \$10/\$100 or 0.10 or 10% interest. When an interest rate is quoted, it is usually expressed on an annual basis unless otherwise quoted. The nominal interest is 10% without any consideration of the effect of compounding during the year. Interest may be compounded on bases other than annual and this topic will be considered later in this chapter [1].

6.2 INTEREST NOMENCLATURE

The nomenclature used in interest calculations may be found in Table 6.1. The terminology presented in the table is to acquaint the reader with the numerous meanings for the same symbols and will be used throughout the text.

6.3 SIMPLE INTEREST

If P is the principal, the loan amount or the original capital, n is the number of interest periods, and i is then interest rate for the period, the amount of simple interest I earned for n periods is

$$I = Pin \tag{6.1}$$

Ultimately, the principal must be paid plus the simple interest for n periods at a future time, F; therefore,

$$F = P + I = P + Pin = P(1 + in) \tag{6.2}$$

The interest is charged on the original loan and not on the unpaid balance. Simple interest is paid at the end of each time interval. Although the simple interest concept still exists, it is seldom used [1].

Example 6.1

If \$1000 has been borrowed at 10% simple interest for 4 years, develop a table of values for the interest owed each year and the total amount owed.

Table 6.2 is the solution of the simple interest calculation in Example 6.1.

TABLE 6.1 Interest Nomenclature

Symbol	Definition
F	Future sum Future value Future worth Future amount
P	Principal Present worth Present value Present amount
A	End of period payment in a uniform series

TABLE 6.2 10% Simple Interest on \$1000

End of year	Interest owed at end of each year	Total amount owed
0	—	\$1000
1	\$100	1100
2	100	1200
3	100	1300
4	100	1400

6.4 COMPOUND INTEREST

Since interest has a time value, often the lender will invest this interest and earn more additional interest [1]. It is assumed that the interest is not withdrawn but is added to the principal and then in the next period interest is calculated based upon the principal plus the interest in the preceding period. This is called compound interest. In equation format, the future amount for each year is

$$\text{Year } 1\text{: } P + Pi = P(1+i) = F_1$$

$$\text{Year } 2\text{: } P + Pi(1+i) = P(1+i)^2 = F_2$$

$$\text{Year } n\text{: } P(1+i)^n = F_n$$

So, the principal plus interest after n years is

$$F = P(1+i)^n \tag{6.3}$$

An interest rate is quoted on an annual basis and is referred to as nominal interest. However, interest may be payable on a semiannual, quarterly, monthly, or daily basis. In order to determine the amount compounded, the following equation applies:

$$F = P\left[1 + \left(\frac{i}{m}\right)\right]^{(m)(n)} \tag{6.4}$$

where

$m =$ the number of interest periods per year
$n =$ the number of years
$i =$ the nominal interest

Example 6.2

If \$2500 were invested for 5 years at 10% nominal interest compounded quarterly, what would be the future amount?

$$F = P\left[1 + \left(\frac{i}{m}\right)\right]^{(m)(n)} = (\$2500)\left[\left(1 + \frac{0.10}{4}\right)^{(5)(4)}\right]$$

$$F = (\$2500)(1.025)^{20} = (\$2500)(1.638616) = \$4096.54$$

In this example, if the interest were compounded monthly, the future amount would be

$$F = P\left[1 + \left(\frac{0.1}{12}\right)\right]^{(12)(5)} = (\$2500)(1.00833)^{(60)}$$

$$F = (\$2500)(1.645276) = \$4113.19$$

If the interest had been compounded on a daily basis, then

$$F = P\left[1 + \left(\frac{0.10}{365}\right)\right]^{(365)(5)} = (\$2500)(1.000274)^{(1825)}$$

$$F = (\$2500)(1.648690) = \$4121.73$$

(*Note*: It is necessary to carry the number of digits to six places to reflect the difference in the future amounts. See also Sec. 6.8).

If companies immediately invest receipts from sales and/or services, the interest on this cash is compounded and the process is called continuous compounding. This will be discussed later in this chapter.

6.5 COMPOUND INTEREST FACTORS

6.5.1 Compounding–Discounting

The process of moving money forward in time is referred to as *compounding*. Moving money backward in time is called *discounting*. These processes are shown in Figure 6.1.

The calculations associated with these processes are not difficult but as the number of compounding or discounting periods increases, the calculations may be time consuming. The periods are in years and the interest is normally on an annual basis; however, shorter compounding periods may be used as mentioned previously [1]. Only end-of-year cash flows will be considered, a widely used convention.

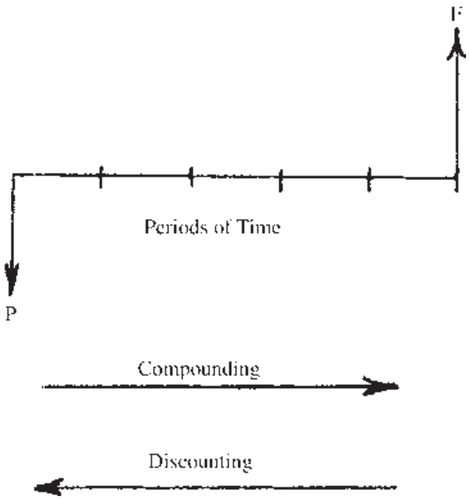

FIGURE 6.1 Compounding–discounting diagram.

6.5.2 Compound Interest Factors

6.5.2.1 Single-Payment Compound Amount Factor

Let's assume that $1000 is borrowed at 10% interest compounded annually for 5 years. Table 6.3 is a summary of the results.

An equation for this process may be written as follows:

$$F = P(1+i)^n \tag{6.5}$$

where

F = a future sum of money
P = a present sum of money
i = interest rate per period expressed as a decimal
n = number of interest periods

At the end of 5 years the future amount is

$$F = (\$1000)(1+0.10)^5 = (\$1000)(1.61051) = \$1610.51$$

The term $(1+i)^n$ is known as the single-payment compound amount factor [1]. A short-hand designation for the equation is $(F/P\ i,n) = (1+i)^n$. Tables of these values may be found in economic texts; however, it is a simple matter to determine the factor without extensive tables by using hand-held calculators or by computers. Therefore, such tables will not be included in this text.

TABLE 6.3 10% Compound Interest on $1000

Year	Amount owed at beginning of year, $	Interest accrued during year, $	Amount owed at end of year, $
1	1000.00	100.00	$1000 \times 1.10 = 1100.00$
2	1100.00	110.00	$1000 \times (1.10)^2 = 1210.00$
3	1210.00	121.00	$1000 \times (1.10)^3 = 1331.00$
4	1331.00	133.10	$1000 \times (1.10)^4 = 1464.10$
5	1464.10	146.41	$1000 \times (1.10)^5 = 1610.51$

Example 6.3

If $2500 were invested at 5% interest compounded annually, what would be the balance in the account after 5 years?

This is a simple problem but as with all these problems, as they become more complex, it is advisable to analyze the information for use in Eq. (6.3). For example,

$$F = ?$$

$$P = \$2500$$

$$i = 0.05$$

$$n = 5$$

A device useful in understanding these problems is the "time" or "dollar–time" diagram. In Figure 6.2, an arrow in the downward direction represents money invested at the present time, and an arrow in the upward direction is the balance at the end of the period including principal plus interest.

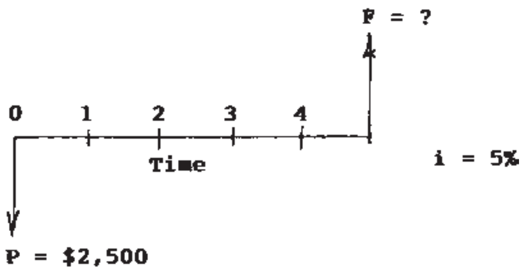

FIGURE 6.2 Dollar–time diagram for Example 6.3.

6.5.2.2 Single-Payment Present Worth Factor

This factor is the reciprocal of the single-payment compound amount factor [1]. Equation (6.3) is solved for P, the present amount instead of F.

$$P = \frac{F}{(1 + \mathrm{i})^n} \tag{6.6}$$

Example 6.4

IF \$5000 were needed 5 years from now to meet a certain obligation, how much would have to be deposited at 4% interest compounded annually to have \$5000 in 5 years?

Analyzing the problem,

$F = \$5000$

$P = ?$

$I = 0.04$

$n = 5$

$$P = \frac{\$5000}{(1.04)^5} = \frac{\$5000}{(1.2167)} = \$3946.33$$

The dollar–time diagram for Example 6.4 is found in Figure 6.3.

6.5.2.3 Uniform Series Compound Amount Factor

In economic analysis of alternative investments, a series of equal receipts or payments occurs at the end of a successive series of periods [1]. The equation is

$$F = A\left[\frac{(1 + i)^n - 1}{(i)}\right] \tag{6.7}$$

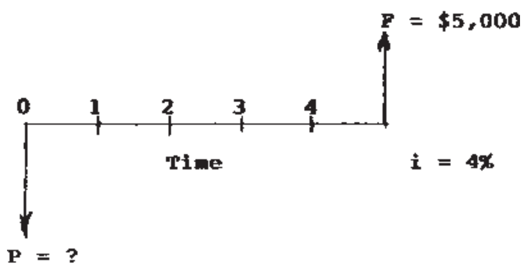

FIGURE 6.3 Dollar–time diagram for Example 6.4.

The bracketed term is the uniform series compound amount factor. Using the shorthand format,

$$F = A(F/A\ i,n)$$

Example 6.5 and the dollar–time diagram, Figure 6.4, may illustrate this process.

Example 6.5

If \$100 were deposited at the end of every year for 5 years in an account earning 6% interest compounded annually, how much will be in the account at the end of 5 years?

In the solution, F is the quantity required, $A = \$100$, $i = 0.06$, and $n = 5$.

$$F = (\$100)\left[\frac{1.06^5 - 1}{(0.06)}\right] = (\$100)\left[\frac{1.33822 - 1}{(0.06)}\right] = \left[\frac{(\$100)(0.33822)}{(0.06)}\right]$$

$$= \$563.70$$

The $(F/A\ i,n)$ factor is 5.6370.

The model assumes that we are waiting 1 year to start the annual deposits, it may not seem logical but you may recall that this is the assumption behind all these equations, namely the end-of-year convention. The assumption is that the money is accumulated during the year and moved to the end of the period. However, it may be desirable to start the payments at time 0, and this can be done by applying the single-payment compound amount factor to the calculation, moving all payments up 1 year. The result is

$$F = (\$100)(1.06)^1(5.6370) = \$597.52$$

This is an example of using the product of two factors to change the time base. Note that more money accumulates when the money is put to work earlier.

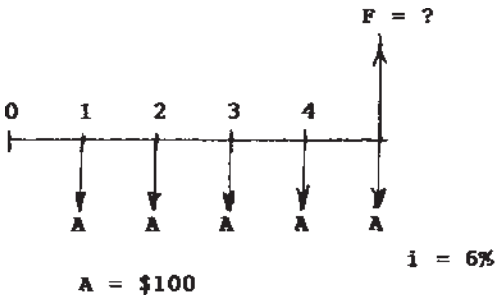

FIGURE 6.4 Dollar–time diagram for Example 6.5.

6.5.2.4 Uniform Series Sinking Fund Factor

If a uniform amount of money is placed in a fund, a sinking fund, at a certain interest rate for a number of years, a certain amount will be achieved in the future [1,2]. Equation (6.7) is solved for A instead of F as follows:

$$A = F\left[\frac{(i)}{(1+i)^n - 1}\right] \tag{6.8}$$

Example 6.6

Assuming there is a need for $5000 in 5 years as in Example 6.4, it was decided to deposit a certain amount of money at the end of every year for 5 years at 4% interest instead of a single sum at time 0. What would the annual amount to be deposited be?

An analysis of the problem is that $F = \$5000$, $n = 5$ years, $i = 0.04$, and $A = ?$

$$A = F\{(i)[(1+i)^n - 1]\} = (\$5000)\left[\frac{(0.04)}{(1.04)^5 - 1}\right] = \frac{(\$5000)(0.04)}{(1.21665) - 1}$$

$$= \$923.15$$

Therefore, we have found that a present sum of $3946.33 (Example 6.4), a uniform series of $923.15, and a future sum of $5000 are equivalent as long as $n = 5$ periods and the interest is 4% per period.

The dollar–time diagram is shown in Figure 6.5 for this model.

6.5.2.5 Uniform Series Present Worth Factor

This factor is the product of two factors that were presented previously, the uniform series compound amount factor and the single-payment present worth

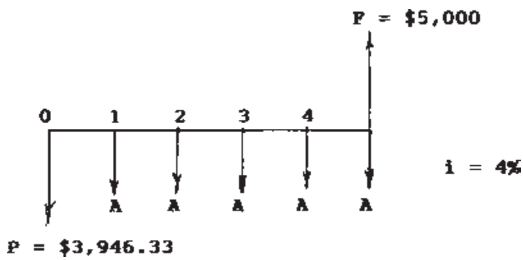

FIGURE 6.5 Dollar–time diagram for Example 6.6.

factor, $(F/A\ i,n)(P/F\ i,n)$ respectively [1].

$$P = A(P/A\, i,n) = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{6.9}$$

Example 6.7 is an illustration of how this factor is used and Figure 6.6 is the dollar–time diagram for this model.

Example 6.7

A person wants to borrow as much money as possible today with an annual payment of \$1000 at the end of each year for 5 years. If he is charged 7% interest compounded annually, how much could he borrow?

In this problem $A = \$1000$, $i = 0.07$, $n = 5$, and $P = ?$

$$P = A\left[\frac{(1+i)^n - 1}{(i)(1+i)^n}\right] = (\$1000)\left[\frac{(1.07)^5 - 1}{(0.07)(1.07)^5}\right] = (\$1000)\left[\frac{(0.40255)}{(0.09818)}\right]$$

$$= \$4130.25$$

6.5.2.6 Uniform Series Capital Recovery Factor

This factor is used by a lender to determine the annual payments to be made by a borrower in order to recover the capital plus interest [1].

$$A = P\left[\frac{(i)(1+i)^n}{(1+i)^n - 1}\right] \tag{6.10}$$

The shorthand expression is

$$A = P(A/P\, i,n)$$

The following example illustrates how Eq. (6.8) is used.

Example 6.8

A person desires to borrow \$18,500 now to be paid back in 10 years at 8.5% compounded annually. How much is this person required to pay annually?

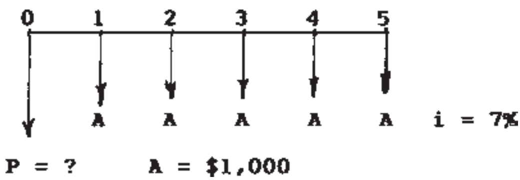

FIGURE 6.6 Dollar–time diagram for Example 6.7.

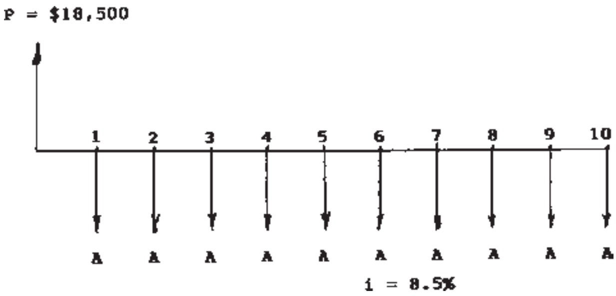

FIGURE 6.7 Dollar–time diagram for Example 6.8.

In this problem, $P = \$18{,}500$, $i = 0.085$, $n = 10$ years, and $A = ?$

$$A = P\left[\frac{(i)(1+i)^n}{(1+i)^n - 1}\right] = (\$18{,}500)\left[\frac{(0.085)(1.085)^{10}}{(1.085)^{10} - 1}\right]$$

$$= (\$18{,}500)\left[\frac{(0.085)(2.26098)}{2.26098 - 1}\right] = \$2819.50$$

This is annual amount required to retire the loan. The dollar–time diagram is Figure 6.7.

Table 6.4 is a detailed illustration of Example 6.8 showing that paying \$2819.55 annually will retire the loan in 10 years. Note that the amount of interest paid is slowly reduced as the outstanding principal is reduced. Over the 10-year period, \$9695.99 interest was paid on the \$18,500 loan.

Industrial loans may be compounded monthly, quarterly, semiannually, or annually. Personal loans, however, on home mortgages and automobile loans are compounded monthly. Example 6.9 demonstrates the effect of monthly compounding on Example 6.8.

Example 6.9

Suppose a person wants to obtain a home equity loan of \$18,500 for remodeling. The interest rate is 8.5% compounded monthly and it is agreed to retire the loan in 5 years. How much will the monthly payments be?

$$A = P\left[\frac{(i)(1+i)^n}{(1+(i)^n) - 1}\right] = (\$18{,}500)\left[\frac{(0.085/12)(1+(0.085))^{60}}{(1+(0.085))^{60} - 1}\right]$$

$$= (\$18{,}500)\left[\frac{(0.00708)(1.00708)^{60}}{(1.00708)^{60} - 1}\right] = (\$18{,}500)\left[\frac{(0.00708)(1.5270)}{(0.5270)}\right]$$

$$= \$379.52$$

TABLE 6.4 Detailed Illustration of Example 6.8

Year	Amount owed at beginning of period	Interest due for period at 8.5%	Amount paid on principal	Balance of principal owed after payment
0				$18,500.00
1	$18,500.00	$1,572.50	$1,247.05	17,252.95
2	17,252.95	1,466.50	1,353.05	15,899.50
3	15,899.50	1,351.49	1,468.06	14,431.44
4	14,431.44	1,226.67	1,592.86	12,838.56
5	12,838.56	1,091.28	1,728.27	11,110.29
6	11,110.29	944.37	1,857.18	9,235.11
7	9,235.11	784.98	2,034.57	7,200.54
8	7,200.54	612.05	2,207.50	4,993.04
9	4,993.04	424.41	2,395.14	2,597.90
10	2,597.90	221.74	2,597.90	0
Total		9,695.90	18,500.00	

34.4% of the total payment was interest.

Note that the monthly interest rate, 8.5%, is divided by 12 months and that in turn is raised to the 60th power to account for the 60 months to retire the loan. Therefore, the person must pay \$379.52 every month for 5 years. The total payment is \$22,771.20 over the 5-year period and \$4,271.20 is the interest.

6.6 EFFECTIVE INTEREST RATES

Nominal interest rates as noted previously are on an annual basis but effective interest rates may be for any period. When one borrows or invests money, although a nominal interest is stated, an effective rate must be given according to government regulations. The term APY is the effective rate for money loaned and yield is the corresponding effective term for money invested [1].

The effective interest rate is calculated from the following expression

$$i_{\text{eff}} = \left[1 + \left(\frac{i}{m}\right)\right]^{(m)(1)} - 1 \tag{6.11}$$

Note that the time period for calculating the effective interest rate is 1 year.

Example 6.10

A person is quoted an 8.33% interest rate on a 4-year loan and the interest is compounded monthly. What is the effective interest rate on this purchase?

$$i_{\text{eff}} = \left[1 + \left(\frac{0.0833}{12}\right)\right]^{(12)(1)} - 1 = (1.006941)^{(12)} - 1 = 1.0865 - 1$$

$$= 0.0865, \text{ or } 8.65\%$$

6.7 CHANGING INTEREST RATES

Thus far in this chapter, it was assumed that the interest rates were constant over the period. Interest rates may change appreciably over time depending on economic conditions [1]. To illustrate how the changes are handled, let's consider that a sum of \$5000 was placed in a certificate of deposit for three 3-year periods with the corresponding interest rates of 5.5, 4.7, and 4.0%, respectively.

If we let C_1 be the balance at the end of the first 3-year period at 5.5%, then

$$C_1 = (\$5000)(F/P\ 5.5\%,3) = (\$5000)(1 + 0.0550)^3 = (\$5000)(1.1742)$$

$$= \$5871.00$$

For the second period, C_1 is the amount invested or P. C_2, the balance at the end of the second 3-year period at 4.7% interest, becomes

$$C_2 = (\$5871.00)(F/P\ 4.7\%,3) = (\$5871.00)(1 + 0.0470)^3$$

$$= (\$5871.00)(1.1477) = \$6738.33$$

C_2 becomes the P for the third 3-year period; therefore, the balance at the end of the third 3-year period becomes

$$C_3 = (\$6738.33)(F/P\ 4.0\%,3) = (\$6738.33)(1 + 0.040)^3$$

$$= (\$6738.33)(1.1249) = \$7579.95$$

The \$5000 deposited in the CD grew to \$7579.95 over the 9 years at the specified interest rates.

6.8 SUMMARY OF COMPOUND INTEREST FACTORS

Table 6.5 is a summary of the discrete compound interest factors developed in the previous sections. The equations for each factor and the short-hand destinations are given. It is useful to have these equations summarized in one place for use in subsequent chapters.

TABLE 6.5 Summary of Discrete Compound Interest Factors

			Discrete payments	
Factor	Find	Given	Discrete compounding	
Single payment				
Compound amount	F	P	$F = P(1+i)^n$	$P(F/P\ i,n)$
Present worth	P	F	$P = F\frac{1}{(1+i)^n}$	$F(P/F\ i,n)$
Uniform series				
Compound amount	F	A	$F = A\left[\frac{(1+i)^n-1}{i}\right]$	$A(F/A\ i,n)$
Sinking fund	A	F	$A = F\left[\frac{i}{(1+i)^n-1}\right]$	$F(A/F\ i,n)$
Present worth	P	A	$P = A\left[\frac{(1+i)^n-1}{i(1+i)^n}\right]$	$A(F/A\ i,n)$
Capital recovery	A	P	$A = P\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$	$P(A/P\ i,n)$

Source: Ref. 1.

6.9 CONTINUOUS INTEREST

In some organizations, namely, petroleum and chemical companies, transactions occur hourly or daily and the receipts from sales and/or services are invested immediately. The interest on this cash flow is continuously compounded [1]. These same companies use continuous compounding when evaluating investments in proposed ventures, since the assumption is that cash flows continuously [2].

In continuous compounding, the year is divided into an infinite number of periods [2]. The limit of the interest term is

$$\lim\left(1+\frac{r}{m}\right)^{mn} \text{ as } n \text{ approaches infinity is } e^{rn}$$

where

n = number of years
m = number of interest periods per year
r = nominal annual interest rate
e = base for the Naperian logarithms

In Example 6.2, as the compounding period decreases, the compounding factor increases.

$$F = P[e^{rn}] = (\$2500)[e^{(0.10)(5)}] = (\$2500)(1.648721) = \$4121.80$$

Table 6.6 illustrates the effect of increasing the number of compounding periods and, although the difference in the compounding factor is small, the ultimate is continuous compounding.

6.9.1 Continuous Interest Factors

6.9.1.1 Single-Payment Compound Amount Factor

Under continuous compounding, Eq. (6.5) becomes

$$F = Pe^{rn} \tag{6.12}$$

TABLE 6.6 Effect of Increasing the Number of Compounding Periods

Interest type	Period	Relationship	If $i = 15\%$	Factor
Simple	Annually	$(1 + in)$	(1.15)	1.150000
Compound	Annually	$(1 + i)^1$	(1.15)	1.150000
	Semiannually	$(1 + i/2)^2$	$(1.075)^2$	1.155625
	Quarterly	$(1 + i/4)^4$	$(1.0375)^4$	1.158650
	Monthly	$(1 + i/12)^{12}$	$(1.0125)^{12}$	1.160755
	Daily	$(1 + i/365)^{365}$	$(1.000410958)^{365}$	1.161798
Continuous	—	e^i	$e^{0.15}$	1.161834

In shorthand format

$$F = P(F/P\ r,n)^{\infty}$$

The superscript ∞ denotes that continuous compounding is being used. Example 6.11 illustrates how this equation is used [1].

Example 6.11

If \$10,000 is deposited in a savings account at 5% interest compounded continuously, what is the amount at the end of 7 years?

$$F = P(F/P\ r,n)^{\infty} = Pe^{rn} = (\$10{,}000)e^{(0.05)(7)} = (\$10{,}000)(1.419067)$$
$$= \$14{,}190.67$$

6.9.1.2 Single-Payment Present Worth Factor

This factor is the inverse of the single-payment compound amount factor, or

$$P = F\left(\frac{1}{e^{rn}}\right) \tag{6.13}$$

The shorthand form is

$$P = F(P/F\ r,n)^{\infty} = F\left(\frac{1}{e^{rn}}\right) \tag{6.14}$$

6.9.1.3 Uniform Series Compound Amount Factor

When a single payment in a uniform series is considered individually, the future amount is

$$F = A[1 + e^{r} + e^{2r} + \cdots + e^{r(n-1)}] \tag{6.15}$$

The geometric progression with the common ratio e^{r} reduces to the sum of n terms as

$$\frac{e^{rn} - 1}{e^{r} - 1} \tag{6.16}$$

Therefore,

$$F = A\left[\frac{e^{rn} - 1}{e^{r} - 1}\right] = A(F/A\ r,n)^{\infty} \tag{6.17}$$

The term in brackets is the series compound amount factor [1]. Example 6.12 illustrates how this equation is used.

Example 6.12

If \$1000 is deposited every year at the end of the year in an account earning 4.5% interest compounded continuously, how much will be in the account at the end of 5 years?

$$F = A(F/A\ r,n)^{\infty} = A\left[\frac{e^{rn} - 1}{e^{r} - 1}\right] = (\$1000)\left[\frac{e^{(0.045)(5)} - 1}{e^{(0.045)} - 1}\right]$$

$$= (\$1000)\left[\frac{1.252323 - 1}{1.046027 - 1}\right] = (\$1000)(5.48206) = \$5482.06$$

If an amount is deposited quarterly, the method of calculating the amount at the end of a period is shown in Example 6.13.

Example 6.13

Suppose that in Example 6.12, \$1000 is deposited in an account quarterly at 4.5% interest compounded continuously. What is the amount in the account at the end of 5 years?

$$F = A(F/A\ r,n)^{\infty} = (\$1000)[F/A(4.5/4); (5)(4)]^{\infty} = A\left[\frac{e^{rn} - 1}{e^{r} - 1}\right]$$

$$= (\$1000)\left[\frac{e^{(0.045/4)(5)(4)} - 1}{e^{(0.045/4)} - 1}\right] = (\$1000)\left[\frac{1.252323 - 1}{1.011314 - 1}\right]$$

$$= (\$1000)(22.3018) = \$22{,}301.80$$

6.9.1.4 Uniform Series Sinking Fund Factor

As in the case of the discrete interest equations, this factor is the inverse of the uniform series compound amount factor, or

$$A = F\left[\frac{e^{r} - 1}{e^{rn} - 1}\right] = F(A/F\ r,n)^{\infty} \tag{6.18}$$

6.9.1.5 Uniform Series Present Worth Factor

A combination of the single-payment compound present worth factor, $(P/A\ r,n)^{\infty}$, and the uniform series compound amount factor, $(F/A\ r,n)^{\infty}$, will result in

$$(P/A\ r,n)^{\infty} = \frac{e^{rn} - 1}{(e^{rn})(e^{r} - 1)} \tag{6.19}$$

or

$$P = A(P/Ar,n)^{\infty} = A\left[\frac{e^{rn} - 1}{(e^{rn})(e^{r} - 1)}\right] \tag{6.20}$$

6.9.1.6 Uniform Series Capital Recovery Factor

This is the inverse of the uniform series present worth factor.

$$(A/P\,r,n)^{\infty} = \frac{(e^{rn})(e^{r} - 1)}{e^{rn} - 1} \tag{6.21}$$

and

$$A = P(A/P\,r,n)^{\infty} = P\frac{(e^{rn})(e^{r} - 1)}{e^{rn} - 1} \tag{6.22}$$

Example 6.14 illustrates the use of Eq. (6.22) [1].

Example 6.14

If \$1000 was deposited in an account now at 4% interest compounded continuously and it is desired to withdraw 5 equal payments so that the fund will be depleted in 5 years, what would be the amount of each equal withdrawal?

$$A = P(A/P\,r,n)^{\infty} = P\left[\frac{(e^{rn})(e^{r} - 1)}{e^{rn} - 1}\right] = (\$1000)\left[\frac{e^{(0.04)(5)}(e^{0.04} - 1)}{e^{(0.04)(5)} - 1}\right]$$

$$= (\$1000)\left[\frac{(e^{(0.2)})(e^{0.04} - 1)}{e^{(0.2)} - 1}\right] = (\$1000)\left[\frac{(1.221403)(1.040811 - 1)}{1.221403 - 1}\right]$$

$$= (\$1000)\left[\frac{0.049847}{0.221403}\right] = (\$1000)(0.225141) = \$225.14$$

6.10 EFFECTIVE INTEREST WITH CONTINUOUS COMPOUNDING

The effective interest rate using continuous computing is

$$i_{\text{eff}} = e^{r} - 1 = (F/P\,r,1)^{\infty} - 1 \tag{6.23}$$

In this case, e^{r} replaces the $(1 + r/m)^{m}$ in the discrete interest case [1,2]. A 15% nominal interest rate compounded continuously is 16.1834% compared with 16.1798% for daily compounding. Note that each result has been carried out to the same number of significant figures.

6.11 COMPARISON OF ALTERNATIVES

In an economic evaluation, the cash flow of alternative ventures involves the comparison of the income and disbursement of funds. These funds will be different between alternatives for each period considered. So, too, the initial capital investment for each alternative will probably be different. It is therefore necessary to compare and evaluate these alternatives on a common basis, e.g., the present time [1,2]. The may be done in the following ways:

1. By discounting all cash flows back to their present value and comparing the present values of the alternatives.
2. By compounding all cash flows forward in time to their future value and again comparing the future values of the alternatives.
3. By converting all cash flows into equivalent uniform annual costs and annual worths and comparing the equivalent for each alternative.
4. By determining the rate of return or economic value added for each alternative and comparing the alternatives. The techniques for doing this will be considered at length in the chapters on Profitability and Choice Between Alternatives.

6.12 CAPITALIZED COST

The capitalized cost method is a present analysis in which the economic life of an asset or venture is considered indefinitely long [1–3]. Dams, canals, railroad beds, tunnels, etc., are all installations that could be considered to have indefinitely long lives. The continuous compound interest factors in Table 6.7

TABLE 6.7 Summary of Continuous Compound Interest Factors

Factor	Find	Given	Continuous compounding	
Single payment				
Compound amount	F	P	$F = P(e^{rn})$	$P(F/P\ r,n)^{\infty}$
Present worth	P	F	$P = F(e^{-rn})$	$F(P/F\ r,n)^{\infty}$
Uniform series				
Compound amount	F	A	$F = A\left[\frac{e^{rn}-1}{e^{r}-1}\right]$	$F(F/A\ r,n)^{\infty}$
Sinking fund	A	F	$A = F\left[\frac{e^{r}-1}{e^{rn}-1}\right]$	$F(A/F\ r,n)_{\infty}$
Present worth	P	A	$P = A\left[\frac{e^{rn}-1}{e^{rn}(e^{r}-1)}\right]$	$A(P/A\ r,n)^{\infty}$
Capital recovery	A	P	$A = P\left[\frac{e^{rn}(e^{r}-1)}{e^{rn}-1}\right]$	$A(P/A\ r,n)^{\infty}$

Source: Ref. 1.

may be used, since n is considered to be infinity. In the chemical process industries, this method is not used.

REFERENCES

1. JR Couper, WH Rader. Applied Finance and Economic Analysis for Scientists and Engineers. New York: Van Nostrand Reinhold, 1986.
2. EL Grant, WG Ireson, RS Leavenworth. Principles of Engineering Economy. 6th ed. New York: Wiley, 1976.
3. KK Humphreys, ed. Jelen's Cost and Optimization Engineering. 3rd ed. New York: McGraw-Hill, 1991.

PROBLEMS

6.1 If Ted invests \$6000 at 10% interest compounded annually, how much will the investment be worth in 10 years? What total interest will be earned?

6.2 If a person borrows \$6000 at 10% interest compounded annually and pays it back with equal annual payments in 10 years, how much will each payment be? How much interest will be paid in the 10-year period?

6.3 Joan borrows \$6000 at 8% interest compounded monthly and pays it back in equal monthly payments in 10 years. How much will each payment be? How much interest will she have paid in the 10-year period?

6.4 If Joe wanted to have \$10,000 in the bank in 7 years and certificates of deposit were paying 5% interest compounded monthly, how much should be invested in the CD?

6.5 If \$150 per month were put into a credit union that paid 4.5% interest, how much would be in the account at the end of 12 years?

6.6 What is the effective interest rate in Problem 6.3?

6.7 What is the effective interest rate in Problem 6.4?

6.8 A couple takes out a \$75,000 mortgage on a house at 8% interest compounded monthly and agrees to pay it off in 20 years with monthly payments. How much are the monthly payments? How much will be left to pay off after the 100th payment?

6.9 If \$1616.50 is paid back at the end of 6 years for \$1000 borrowed 6 years ago, what interest compounded annually was paid?

6.10 A person is considering depositing an amount in a "savings" account. Various interest rates are listed below. Which is the best for the depositor?

a. 5% compounded annually
b. 4.5% compounded semiannually
c. 4.2% compounded quarterly
d. 4.4% compounded continuously

6.11 How many years will it take to double a sum of money at 5% interest compounded annually?

6.12 Skinflint Loan Company offers the following personal loan plan called the "1% plan." For a 10-month repayment period, this operates as follows: The company adds 10% (i.e., 1% for each month) to the amount borrowed; the borrower pays back one-tenth of this total at the end of each month for 10 months. Thus, for each $100 borrowed, the monthly payment is $11. Find the nominal and effective interest rates per annum.

6.13 A revolving charge account is opened at a local department store that charges 1.5% on the unpaid balance. What is the effective annual interest rate if charges are monthly?

6.14 What is the uniform annual amount that is equivalent to the following series of cash flows at the end of each year if the interest rate is

a. 7% compounded annually
b. 7% compounded continuously

End of year	Amount
0	$5000
1	1000
2	1200
3	1400
4	1600
5	1800
6	2000
7	2200
8	2400

6.15 A man places $5000 in a CD account for 3 years paying 4.5% compounded monthly. At the end of 3 years he withdraws one-third of the money and leaves the remainder in a 3-year CD at 5%. How much is in the CD account at the end of the sixth year?

6.16 If $15,000 were borrowed at 8% interest compounded continuously for 7 years, what would the quarterly payments be?

6.17 Dorothy invests \$3000 in a money market account at 4.75% interest compounded monthly. At the end of the twelfth month she deposits \$100 into the account and continues to do so every month for 3 years, making 37 such monthly deposits. At the end of 5 years from time 0, assuming a constant interest rate, how much money is in the account?

6.18 A father wishes to establish a fund for his son's college education. He wishes the fund to provide \$15,000 on the son's eighteenth, nineteenth, twentieth, and twenty-first birthdays. He will make the first deposit when the son is 6 months old and will make semiannual deposits thereafter until the boy is 17 years and 6 months. If 5% compounded semiannually can be earned on the fund, what should the semiannual deposit be? *Note*: there are 35 deposits and realize that the problem has two parts. (Adapted from Ref. 2.)

6.19 A debt of unknown amount is entered into at time 0. The debtor has agreed to pay \$5000 at the end of year 1, \$4000 at the end of year 2, \$3000 at the end of year 3, \$2000 at the end of year 4, and \$1000 at the end of year 5. The debt will be fully settled at that time. At 8% interest compounded annually, how much was borrowed at time 0?

6.20 Find the present worth of a uniform cash flow of \$150,000 per year over a 5-year period at 15% continuous interest.

6.21 What is the present worth of a cash flow that occurs during the fifth year (4 to 5) of a project? The normal discounting rate of interest is 12% compounded continuously.

6.22 What is the present worth at start-up time (time 0) for \$100M of land purchased or allocated to a project 3 years before the plant start-up assuming 16% continuous interest?

6.23 The present worth is desired for construction costs of \$10MM occurring uniformly over 2 years prior to start-up (year − 2) to start-up (year 0). Interest is compounded continuously at 13%.

6.24 Determine the present worth of maintenance charges that increase continuously from 0 to \$100,000 per year over a 10-year period. The interest rate is 15% compounded continuously.

7

Depreciation, Depletion, Amortization, and Taxes

Everyone is aware of the fact that as equipment is used wear and tear results in the decline in value of the equipment. Most engineers and scientists accept the concept of *obsolescence*, for they are cognizant of the effect of obsolescence on equipment, processes, and techniques due to technological advancements. *Depreciation* is a more elusive concept but it is an important consideration in operating expenses and cash flow analysis. To understand a company's strategy when funding projects, engineers need to be conversant with the depreciation concept.

7.1 DEPRECIATION

"Depreciation is a decrease in value of a property over a period of time. Events that can cause a property to depreciate include wear and tear, age, deterioration, and normal obsolescence," according to the Internal Revenue Service [1]. The intent of depreciation is to allow a business to recover the cost of an asset over a period of time. In this chapter a very important aspect of accounting, namely, accounting for depreciable fixed assets like machinery, equipment, buildings, and structures, will be considered.

Depreciation begins when a property is placed in service in a business or trade for the production of income. It ends when the cost of the asset has been fully recovered or when the asset is retired from service, whichever occurs first.

As suggested by the IRS definition, obsolescence plays a major part in determining the useful life of an asset [2]. The causes of obsolescence may be categorized as follows:

- *Product obsolescence*. This is caused by the development and marketing of either cheaper or better substitutes. An example might be milk containers: Glass was used for many years and was followed by waxed paper cartons until polyethylene was introduced.
- *Equipment obsolescence*. Equipment designs are radically improved. Consider the replacement of shell-and-tube heat exchangers by plate-type units in certain applications.
- *Process obsolescence*. For many years phenol was made by a benzenesulfonic acid or chlorobenzene route. These processes involved large, expensive equipment subject to severe corrosion and erosion problems. The newer cumene–phenol process is less costly from a capital investment and operating expense standpoint for the same production rate. This is an example of technological improvement.
- *Capacity obsolescence*. Batch processes are replaced by continuous processes for increased production, and for reducing overall operating expenses.

In order for a property to be depreciated, it must meet the following requirements:

- It must be used in a business or held to produce income.
- It must be expected to have a useful life of more than 1 year.
- It must be something that wears out, decays, gets used up, becomes obsolete, and loses its value from natural causes.

The type of property may be tangible or intangible. A tangible property is one that one can touch or see, whereas an intangible property is one that has value but cannot be touched or seen, e.g., copyrights, patents, trademarks, franchises, trade names, and software. Land, inventory including containers, goodwill, leased property, and equipment to build capital improvements cannot be depreciated [1].

7.2 TERMINOLOGY

There are certain terms used in depreciation accounting that need to be defined:

Depreciation reserve is the accumulated depreciation at a specific time.

Book value is the original asset investment minus the accumulated depreciation.

Service life is the time period during which an equipment item or asset is in service and is economically feasible.

Economic or useful life as used in this text is synonymous with *service life*.

Salvage value is the net amount of money obtained from the sale of a used property over and above any charges involved in the removal and sale of the property. The term implies that the asset can give some type of service. Salvage value was regarded as a nondepreciable part of the first cost that is frozen in a project and then removed at the end of the useful life. Depending upon tax law revisions, salvage value has been allowed and then disallowed.

Scrap value implies that the asset has no further useful life and is sold for the value of scrap material in it.

7.3 HISTORY OF DEPRECIATION METHODS

A review of the policies of the Internal Revenue Service over time since 1934 affords a valuable background for understanding the historical events that have occurred in the tax laws. Six major publications in the past 65 years have provided guidelines for depreciation allowances. Each succeeding publication has superceded but not necessarily excluded previous publications. Table 7.1 is a tabulation of the bulletins or laws and each will be discussed more fully.

TABLE 7.1 Depreciation History

IRS bulletin or law	Issued	Average write-off	Comments
Bulletin F	1934 Rev. 1942	19 yr	500 separate categories
Treasury Decision 6182	1954	15 yr	Interim policy and introduced use of accelerated methods
Depreciation Guidelines and Rules	1962 Rev. 1964	13 yr	Outlined 75 broad business categories
Class Life Asset Depreciation Range System	1971	± 20 yr	Increased to 143 asset categories
Congressional Act 1980	1981	5 yr	Simplified previous system to 4 categories and eliminated salvage value
MACRS	1986	Varies	Lengthened recovery period and established 6 recovery periods

Sources: Refs. 1–7.

In 1934, following the Great Depression, Bulletin F was published [2]. It classified 5000 different equipment or machinery items with an average write-off of 19 years. This document was revised in 1942 to accommodate the need for a fast write-off of plants that were critical to the war effort in World War II. A Certificate of Necessity could be obtained for plants that manufactured essential materials. A 100% write-off was permitted for these facilities so that these assets could be written off in 1 year.

In 1954, Treasury Decision 6182 was issued as an interim policy that permitted taxable businesses to enter into agreements with the IRS regarding useful life and depreciation rate on any property based upon pertinent experience information [3]. At this time, accelerated depreciation rates, e.g., declining balance and sum-of-the-digits methods, were introduced. This occurred during the 1950s recession to stimulate the economy. It allowed for greater write-offs in the early years of an asset when markets for a product were not fully developed and manufacturing expenses were high due to bringing a new facility on stream. It encouraged plant investment as well as investment in research and development facilities. In some instances, the stimulation was successful but not in a number of instances. The average write-off was 15 years.

In 1962, a major revision in depreciation policy occurred with the issuance of Depreciation Guidelines and Rules, Publication 456 by the IRS [4]. The objective, in part, was to simplify procedures for maintaining depreciation accounts. The adoption of these rules by industry was not mandatory if a company and the Treasury Department were mutually satisfied with current practices. A key feature of these guidelines was that asset classes had lives that were shorter than previously allowed. The average write-off was 13 years for 75 broad business categories. These guidelines were revised in 1964 with minor modifications.

In 1971, the Class Life Asset Depreciation Range (ADR) System was developed by the IRS and it could be elected by the taxpayer [5]. The basis for this system is found in the asset lives set forth in the 1962 Guidelines. The ADR System permitted the selection of a useful life from a designated range of years that were $\pm 20\%$ of the years in the 1962 Guidelines. The range was designed to minimize disputes between the taxpayer and the IRS. The asset categories were expanded to 143. A partial listing of selected classes and their tax lives is found in Table 7.2. An additional feature of the ADR System was the annual asset repair allowance that is also found in Table 7.2. This allowance permitted a credit for maintenance.

The ADR System was replaced by the Congressional Act of 1981 and was known as the Accelerated Cost Recovery System (ACRS) [6]. This act simplified the many diverse categories of depreciable assets into four broad recovery periods, namely, 3, 5, 10, or 15 years, for tax purposes. Another

TABLE 7.2 Class Life ADR Table (Partial Listing)

Asset class	Description	Asset depreciation range, yr: Lower limit	Guideline period	Upper limit	Repair allowance, %
13.3	Petroleum refining	13	16	19	7.0
20.4	Food, other than sugar, grain	9.5	12	14.5	5.5
22.2	Manufacture of yarn	9	11	13	16.0
26.1	Manufacture of pulp from wood	13	16	19	4.5
26.2	Manufacture of paper	9.5	12	14.5	5.5
28.0	Manufacture of chemicals including petrochemicals	9	11	13	5.5
30.1	Manufacture of rubber products	11	14	17	5.0
30.2	Manufacture of finished plastics	9	11	13	5.5
32.1	Manufacture of glass products	11	14	17	12.0
32.2	Manufacture of cement	16	20	24	3.0
33.1	Primary ferrous metal	14.5	18	21.5	8.0
33.2	Primary nonferrous metal	11	14	17	4.5
49.12	Electric utilities, nuclear plant	16	20	24	3.0
49.5	Industrial steam and electric generation	22.5	28	33.5	2.5
65.11	Factory building	—	45	—	—
65.41	Office building	—	45	—	—
70.11	Office furniture	8	10	12	2.0

Source: Ref. 5.

feature of the act was to eliminate salvage value from depreciation calculations. Most process equipment and machinery was in the 5-year category.

In 1986, Congress passed a new tax law that was a modification of the 1981 Act [7,8]. It was called the Modified Accelerated Cost Recovery System (MACRS) and became effective in 1987. The net effect was to lengthen the period for the depreciation of business assets. Property was classified into 3-, 5-, 7-, 10-, 15-, and 20-year groups. Research and development equipment was classified as a 5-year property instead of a 3-year property under the ACRS System. Manufacturing machinery life varied from 3 to 20 years but most chemical processing equipment fell in the 5-year category. Table 7.3 contains the depreciation class lives and the MACRS recovery periods. A 200% declining balance method is applied to class lives of less than 10 years and 150%

TABLE 7.3 Depreciation Class Lives and MACRS Recovery Periods

Asset class	Description of asset	Class life, yr	MACRS recovery period, yr
00.12	Information systems	6	5
00.4	Industrial steam and electric generation and/or distribution systems	22	15
13.3	Petroleum refining	16	10
20.3	Manufacture of vegetable oils and vegetable oil products	18	10
20.5	Manufacture of food and beverages	4	3
22.4	Manufacture of textile yarns	8	5
22.5	Manufacture of nonwoven fabrics	10	7
26.1	Manufacture of pulp and paper	13	7
28.0	Manufacture of chemicals and allied products	9.5	5
30.1	Manufacture of rubber products	14	7
30.2	Manufacture of finished plastic products	11	7
32.1	Manufacture of glass products	14	7
32.2	Manufacture of cement	20	15
32.3	Manufacture of other stone and clay products	15	7
33.2	Manufacture of primary nonferrous metals	14	7
32.4	Manufacture of primary steel mill products	15	7
49.223	Substitute natural gas-coal gasification	18	10
49.25	Liquefied natural gas plant	22	15

Source: Ref. 1.

is applied to 15- and 20-year class lives. This method will be discussed more fully later in this chapter. As an alternate to the MACRS, straight-line depreciation may be used. No salvage value may be claimed under MACRS. This is a simple, brief description of the depreciation guidelines currently in effect. For more details, see the IRS Bulletin Form 4562, Publications 946 and 534 [1,8,9].

Depreciation begins when an asset is placed in service in a business or for the production of income. It ends when the cost has been fully recovered or when the asset is retired, whichever happens first.

7.4 DEPRECIATION EQUATIONS

In this section, the current methods for determining annual depreciation charges are presented. The following methods will be discussed:

Straight line
Declining balance
Unit of production
Modified Accelerated Cost Recovery System (MACRS)

7.4.1 Straight-Line Method

In this method the cost of an asset is distributed uniformly over its expected useful life. If I is the cost of the asset, n is the expected service life, then the annual depreciation charge is I/n. If salvage value is estimated, then the annual depreciation is

$$D = \frac{I - S}{n} \tag{7.1}$$

If salvage value is not taken, than $S = 0$ and the depreciation charge is

$$D = \frac{I}{n} \tag{7.2}$$

The book value at the n of any given year is

$$I - \left(\frac{I}{n}\right) r = \mathrm{BV}_r \tag{7.3}$$

where r is a certain year in the life of an asset.

The IRS has adopted for either the straight-line or MACRS methods a half-year convention. Table 7.4 has the factors for this method based on the half-year convention. Under this convention, a property is considered placed in service (or disposed of) in the middle of the first year. A half-year of depreciation is allowed for the year the property is placed in service. This applies regardless of when during the year the property is placed in service.

Table 7.4 Straight-Line Method
Half-Year Convention 3, 5, 7, 10, 15, 20 Years

	Recovery period, yr					
Year	3	5	7	10	15	20
1	16.67%	10.00%	7.14%	5.0%	3.33%	2.5%
2	33.33	20.00	14.29	10.0	6.67	5.0
3	33.33	20.00	14.29	10.0	6.67	5.0
4	16.67	20.00	14.28	10.0	6.67	5.0
5		20.00	14.29	10.0	6.67	5.0
6		10.00	14.28	10.0	6.67	5.0
7			14.29	10.0	6.67	5.0
8			7.14	10.0	6.66	5.0
9				10.0	6.67	5.0
10				10.0	6.66	5.0
11				5.0	6.67	5.0
12					6.66	5.0
13					6.67	5.0
14					6.66	5.0
15					6.67	5.0
16					3.33	5.0
17						5.0
18						5.0
19						5.0
20						5.0
21						2.5

Source: Ref. 1.

If the property is disposed of before the end of the recovery period, a half-year of depreciation is allowed in the year of disposition. Again, this applies regardless of when during the year the company disposes of the property. This half-year convention does not apply to nonresidential real and residential rental property [10].

Straight-line depreciation is used for financial reporting such as annual reports.

7.4.2 Declining-Balance Method

The declining-balance method is also called the fixed-percentage method. It is the basis for the Modified Accelerated Cost Recovery System (MACRS) that will be presented in a later section.

The declining-balance equation is

$$V_e = V_i(1 - f) \tag{7.4}$$

where

V_i = value of the asset at the beginning of a year
V_e = value of the asset at the end of the year
f = the declining-balance factor applied to each year and is constant from year to year

The declining-balance factor f is defined as rate/n, where the rate is either 150 or 200%. If the latter figure is used, the method is known as the double declining-balance method and $f = 2$. In like manner for the 150% rate, $f = 1.5$. The factor is applied to the previous year's remaining balance to determine the amount depreciated. For example, the amount depreciated in any given year, using the 200% rate, is

$$D = \left(\frac{2}{n}\right)(I)\left[1 - \left(\frac{2}{n}\right)\right]^{(r-1)} \tag{7.5}$$

where

I = asset cost
n = asset life in years
r = year for which the depreciation is calculated

The book value at the end of a given year is

$$\mathrm{BV}_r = I\left[1 - \left(\frac{2}{n}\right)\right]^{r} \tag{7.6}$$

Upon inspection of the depreciation equation, it is evident that the declining-balance method will not recover the cost of the asset. Since the IRS permits a company to recover the full cost of the asset, a combination of the declining balance method and the straight line method is used. The switch to straight line takes place at about two-thirds of the asset life. For example, for an asset life of 5 years, the switch occurs in the fourth year and for a 7-year life, it occurs in the fifth year. The declining-balance method is not used but its variation, MACRS, is permitted under current law.

7.4.3 Unit-of-Production Method

This is a method for calculating the depreciation of certain properties usually used in the manufacture of tools, equipment, and objects. The depreciation is determined by estimating the number of units that can be produced by a property before it is worn out. For example, if it is estimated that a machine will produce 10,000 units before its useful life ends and that 1000 units are produced each year, the percentage to calculate depreciation is 10% of the machine cost less salvage value, if permitted. This percentage is applied to the cost of the asset as yearly depreciation.

7.4.4 Modified Accelerated Cost Recovery System (MACRS)

The MACRS went into effect on January 1, 1987 [8]. There are six asset recovery periods under this system: 3, 5, 7, 10, 15, and 20 years. The class lives for selected industries is found in Table 7.3. Most chemical processing equipment falls into the 5-year category. Table 7.5 is the MACRS deduction rates for the six periods based upon 200% declining-balance method. This rate applies to class lives of 10 years or less and 150% applies to the 15- and 20-year lives. In Table 7.5, there is a switch to the straight-line method in the later years of the asset life to recover fully the asset cost. The half-year convention is built in the table so that for a 5-year life recovers the rest of the depreciation in the sixth year.

Under MACRS two systems determine how property is depreciated. The main system is called the general depreciation system (GDS) and the other system is the alternative depreciation system (ADS). The latter system provides longer recovery periods and uses the straight-line depreciation method. Unless a company is required by law to use the ADS or it is elected, the GDS is used (see Ref. 1 for details). In this book, only the GDS MACRS will be considered. Accelerated depreciation (MACRS) is used for tax purposes whereas straight-line depreciation is used for financial reporting.

The factors for MACRS will be determined using the following example:

Example 7.1

A $75,000 drier used in a chemical plant is to be depreciated over a 5-year period using the GDS MACRS. Table 7.5 has the factors for a 5-year class using the 200% declining-balance factor. The 200% factor is based on 2 times the straight-line rate that occurs in the first year when the value V is $75,000 and the depreciation is $75,000/5 = $15,000. Thus, the 200% declining-balance factor is $(2)(\$15,000)/(\$75,000) = 0.40$ for the first full year. However, for the first year, the *half-year* convention is applied, meaning that the investment is made at the midpoint of the year or that the full benefit of the asset was not realized in the first year. Therefore, the f that applies to the first year is one-half the f value in the succeeding years or 0.20. This is the first value in Table 7.5.

Book value at midpoint of the year 1 = $75,000
Book value at end of year 1 = ($75,000)(1 − 0.2) = $60,000
Factor for year 1 = {[($75,000) − ($60,000)]/($75,000)}(100) = 0.20

TABLE 7.5 MACRS Deduction Rates
General Depreciation System
Applicable Depreciation Method: 200 or 150%
Declining Balance Switching to Straight Line
Applicable Recovery Periods: 3, 5, 7, 10, 15, 20 Years
Applicable Convention: Half-Year

	Depreciation rate for recovery period, yr					
Year	3	5	7	10	15	20
1	33.33%	20.00%	14.29%	10.00%	5.00%	3.750%
2	44.45	32.00	24.49	18.00	9.50	7.219
3	14.81	19.20	17.49	14.40	8.55	6.677
4	7.41	11.52	12.49	11.52	7.70	6.177
5		11.52	8.93	9.22	6.93	5.713
6		5.76	8.92	7.37	6.23	5.285
7			8.93	6.55	5.90	4.888
8			4.46	6.55	5.90	4.522
9				6.56	5.91	4.462
10				6.55	5.90	4.461
11				3.28	5.91	4.462
12					5.90	4.461
13					5.91	4.462
14					5.90	4.461
15					5.91	4.462
16					2.95	4.461
17						4.462
18						4.461
19						4.462
20						4.461
21						2.231

Source: Ref. 1.
Note: 200% declining balance applies to class lives of 10 years or less. 150% applies to 15- and 20-year class lives.

Book value at end of year 2 = (60,000)(1 − 0.4) = \$36,000
Factor for year 2 = {[(\$60,000) − (\$36,000)]/(\$75,000)}(100) = 0.32

Book value at end of year 3 = (\$36,000)(1 − 0.40) = \$21,600
Factor for year 3 = {[(\$36,000) − (\$21,600)]/(\$75,000)}(100) = 0.192

Book value at end of year 4 = ($21,600)(1 − 0.4) = $12,960
Factor for year 4 = {[($21,600) − ($12,960)]/($75,000)}(100) = 0.1152

For years 4 and 5 there is a switch to straight line, therefore the same factor applies to year 5, namely, 0.1152. At the end of year 3, the value was $21,600 which is to be distributed by the straight-line method over 2.5 years or $\$21,600/2.5 = \$8640$ in year 4 and $8640 in year 5 leaving a residual amount to be depreciated in year 6. Therefore, $\$21,600 - (2)(\$8640) = \$4320$. The factor then for the rest of the half-year convention in year 6 is $[(\$4320)/(\$75,000)](100) = 0.0576$. In summary, the factors are as follows:

These factors are consistent with those in Table 7.4 for a 5-year class life.

In order to organize depreciation calculations, it is recommended that a

Year	Factor
1	0.200
2	0.320
3	0.192
4	0.1152
5	0.1152
6	0.0576

tabular format be used similar to Table 7.6. Such a table permits the scanning of the values generated for potential errors.

7.4.5 Other Depreciation Methods

The following methods were at one time widely used for economic studies but have fallen into disuse.

TABLE 7.6 Depreciation Calculation Form

Year	Annual depreciation	Depreciation reserve	Book value

7.4.5.1 Sum-of-the-Years Digits Method

This is one of the two accelerated depreciation methods, the other being the MACRS. The sum-of-the-years digits (SOYD) provided higher than average depreciation amounts in the early years of an asset's life and less than average in the latter years.

The name comes from the fact that SOYD is

$$1 + 2 + \cdots + (N - 1) + N = \frac{N(N + 1)}{2} = \text{SOYD}_n \tag{7.7}$$

where

$n =$ number of years

and is used in calculating yearly depreciation. The allowance for depreciation for any year t is given by

$$D_{\text{t}} = \left[\frac{N - (t - 1)}{\text{SOYD}_n}\right](P - S) \tag{7.8}$$

The book value at the end of year t is given by

$$B_{\text{t}} = P - \left[\frac{P - S}{\text{SOYD}_n}\right]\left\{\text{SOYD}_n - \left[\frac{(N - t)(N - t + 1)}{2}\right]\right\} \tag{7.9}$$

7.4.5.2 Sinking-Fund Depreciation

This method was used in economic studies for governmental agencies and regulated public utilities. It was calculated by determining from interest tables how much annual payment would be required to accumulate at a given interest rate I for a period of N years, an amount of money equal to the difference between the first cost of an asset P and its salvage value S, or $(P - S)(A/F\ \ I, \text{N})$ [2]. That is the amount of money, the depreciation D for the first year. For the second year, the depreciation would be $D_1\ (1 + I)^1$, for the third year $D_1\ (1 + I)^2$, and so forth. Therefore, assets depreciate at an increasing rate. If the MACRS method is considered accelerated depreciation, the sinking-fund method must be considered decelerated depreciation.

As mentioned earlier, this method was used by governmental agencies because of little concern for the cost of money expressed as an interest rate, for they paid no interest on money. It was considered "free" because it came from taxes. With more scrutiny of governmental expenditures and broader realization that an alternative to governmental expenditures is debt reduction and thus may be considered an opportunity cost.

7.5 DEPLETION

Depletion is the "removal or reduction of natural resources by mining, quarrying, drilling, or felling" [10]. From the standpoint of the recovery of an asset, depletion is related to depreciation. The depletion deduction allows an owner or operator to account for the reduction of a materials reserves.

There are two ways to calculate depletion:

Cost depletion
Percentage depletion

7.5.1 Cost Depletion

To calculate the cost depletion, the following information must be determined:

- The property's basis for depletion that is often the total cost of the property, C
- The total recoverable units of material in the property's natural deposit, U_T
- The number of units of material sold during the year, U_t

The depletion allowance D_p is then

$$D_p = \frac{C \times U_t}{U_T} \tag{7.10}$$

This figure is subtracted from the before-tax cash flow, just like depreciation, to calculate taxable income.

TABLE 7.7 Percentage Depletion Rates

Material deposits	Percent
Sulfur, uranium; and if deposits in the United States, asbestos, lead ore, zinc ore, and mica	22
Gold, silver, copper, iron ore, and certain oil shale, if from deposits in the United States	15
Geothermal deposits	15
Borax, granite, limestone, marble, mollusk shells, potash, slate, soapstone, and carbon dioxide from a well	14
Coal, lignite, and sodium chloride	10
Clay and shale used or sold for use in making sewer pipe or bricks or used or sintered or burned for lightweight aggregate	7.5
Clay used or sold for use in making drainage or roofing tile, flower pots, kindred products, gravel, sand, and stone (other than stone used or sold for use by a mine owner or operator as dimension or ornamental stone)	5
Natural gas sold under a fixed contract	22
Small producers and royalty owners for any oil or gas well	15

Source: Ref. 10.

7.5.2 Percentage Depletion

The yearly gross income produced by a property is multiplied by a certain percentage for each mineral. The percentages are assigned in the appropriate tax law and relate to the material being depleted, as shown in Table 7.7.

Refiners cannot claim percentage depletion if the refined crude oil is more than 50,000 barrels in any day during the tax year. Since the depletion allowance rules for oil and gas often change, it is wise to review the IRS Publication 535, Business Expenses.

The percentage depletion cannot be more than 50% (100% for oil and gas property) of the taxable income from the property calculated without the depletion deduction [10].

7.6 AMORTIZATION

Amortization is a ratable deduction for the cost of intangible property over its useful life over a 15-year period [8,10]. It is similar to straight-line depreciation. Using amortization, the cost of a certain property may be recovered over a specific number of years or months. Examples of what can be amortized are:

- Goodwill
- Going concern value
- Patents, copyright, formula, process, design, pattern, know-how
- Franchise, trademarks or trade name
- License, permit or other right granted by a government unit or agency
- A covenant not to compete entered into in connection with the acquisition of an interest in a trade or business
- Customer-based and supplier-based intangibles
- Bond premiums
- Cost of getting a lease
- Costs of research and experimentation

7.7 TAXES

7.7.1 Income Taxes

Corporate income tax is an extremely complex subject. Only a cursory treatment will be presented because the interpretation and consideration of the continually changing tax regulations require the attention of specialists. Income taxes are beyond the control of a company insofar as negotiation and litigation with the Internal Revenue Service and state tax departments are concerned. Income taxes, however, are important because of their affect on a firm’s cash flow. Therefore,

TABLE 7.8 Corporate Federal Income Tax Rates (2000)

Taxable income	Tax rate
Annual gross earnings less than \$50,000	15%
Annual gross earnings greater than \$50,000 not over \$75,000	25%
Annual gross earnings greater than \$75,000 plus 5% of gross earnings over \$100,000 or \$11,750 whichever is greater	34%
Corporations with at least \$335,000 pay a flat rate of 34%	

Source: From Ref. 12.

income taxes must be properly treated in economic evaluations of projects [2]. Current federal income taxes on corporations are shown in Table 7.8.

Most major corporations pay a federal tax rate of 34% on their annual gross earnings above \$75,000. In addition, many states have a corporate income tax that is stepwise. State income tax is deductible as an expense before calculating the federal income tax. If T_s is the incremental state tax and if T_f represents the incremental federal tax rate, both expressed as decimals, the combined incremental tax rate T_c is

$$T_c = T_s + (1 - T_s)T_f \tag{7.11}$$

For example, if the incremental federal rate is 34% and the incremental state rate is 7% the combined rate is

$$T_c = 0.07 + (1 - 0.07)(0.34) = 0.39 \tag{7.12}$$

Therefore, the combined rate is 39%, but for most economic evaluations a combined rate of 35% is used. In many states, concessions are made with respect to lowering state taxes to induce a company to locate in the state.

7.7.2 Capital Gains Tax

A capital gains tax is levied on the profit from the sale of assets like buildings, equipment, and land. The amount of time an asset has been held as a long-term capital gain (or loss) must be more than 1 year under current law. For an asset to qualify it must meet two requirements—the nature of the asset and the time held—to qualify for a reduced tax. Short-term capital gain (or loss) occurs if the time held is less than for a long-term capital gain.

The net capital gain (or loss) is the sum of the long-term and short-term capital gains and is generally taxed for corporations at the same rate as ordinary income in the year the gain occurs. In 2000, this rate was 34%. Since the regulations change frequently for corporate capital gains, it is advisable to consult the latest IRS publications or a tax consultant. In most economic evaluations, capital gains (or losses) are not considered [2,11,12].

7.8 TAX CREDITS

7.8.1 Investment Tax Credit

Technological progress is a contributing factor to high living standards. To advance technology, an investment of capital is required but high tax rates are deterrents to capital investment. High tax rates plus long depreciation periods are still greater deterrents. In 1962, the government initiated tax reform permitting an investment tax credit but there have been periods when this credit has been discontinued. At present (2003), a company cannot claim this credit. Tax credits are enacted at times when there is a perceived need to stimulate the economy.

7.8.2 Research and Development Tax Credit

This tax credit has been an "off-on" reform on equipment used for research and development purposes. The amount credited has ranged from full investment credit to one-half the investment. Congress extends the credit for short time periods so it is best to consult someone familiar with the current status of this credit. In 2001, it was extended through mid-2004.

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PROBLEMS

7.1 Often it is said, "depreciation and taxes are irrevocably tied to each other." Explain what is meant by this.

7.2 A chemical company that manufactures specialty chemicals is considering building a multipurpose production facility. The design of the unit has been outsourced to a consulting firm. This company has estimated that the fixed capital investment is $27MM. The plant is expected to have a useful life of 15 years. Compare the depreciation schedules for this facility using both the straight-line and MACRS methods with the half-year convention.

7.3 A refinery is planning the addition of a small dewaxing unit. It is estimated that the fixed capital investment is $63MM. Prepare a depreciation schedule using the MACRS method with half-year convention. What is the book value at the end of the fourth year?

7.4 An automobile manufacturer purchases primary nonferrous metals from Apex, Inc. There is an indication that Apex will need to increase capacity to meet the automobile company demands. The proposed facility will be located next to their existing plant on a site that will cost $500,000. The plant is estimated to have a $15MM capital investment. Determine the depreciation in the fifth year using the MACRS method with the half-year convention.

7.5 A firm has annual gross earnings in 2002 of $1,200,000. It is located in a state that has an incremental state tax rate of 6.5%. What is the combined federal and state tax rate?

7.6 Knox Cement Company owns a property from which it mines a part of the limestone used in the manufacture of Portland cement. The total cost of the property was $100MM and the recoverable units of material are expected to be 1000 kilotons. This property produces an annual gross income $21MM and the estimated expenses excluding depletion are $14MM annually. The taxable income before depletion is $7MM. Calculate the annual depletion by both the cost and percentage depletion methods.

8

Cash Flow Concept

The term *cash flow* is in common use today in the news media and in company financial statements. Much confusion has arisen over the definition and use of cash flow. Cash flow may be expressed on the basis of before taxes or after taxes but the basis must be stated. The after-tax cash flow is defined as net income (profit) after taxes plus depreciation and depletion. Accountants use the concept of *funds* or *money flow* that includes cash flow and other *noncash items*. Cash flow is important to people preparing financial and engineering cost analyses.

For an engineer to be able to prepare economic evaluations of ventures or projects, it is necessary to identify the sources of cash flow and the disposition of monies. Simple diagrams analogous to the flow of materials through a process may be used to illustrate the cash flow concept. The diagrams and discussion leading to the *cash flow model* may be found in Figures 8.1 to 8.3.

8.1 CASH FLOW MODEL

A cash flow model can be developed similar to the process flow model in Figure 8.1 [1]. In this figure, raw materials are charged into a process and finished goods exit. So, too, revenue from sales and intellectual property is fed into the operation and, if cash operating expenses are deducted, operating income results. Figure 8.2 illustrates this process [1,2].

In any industrial process, it is essential to have a supply of funds available to meet the demands of current expenses. These funds, called *working capital*, are used to purchase raw materials, pay wages and salaries as well as other operating expenses. In this model, Figure 8.3, although working capital is charged into an

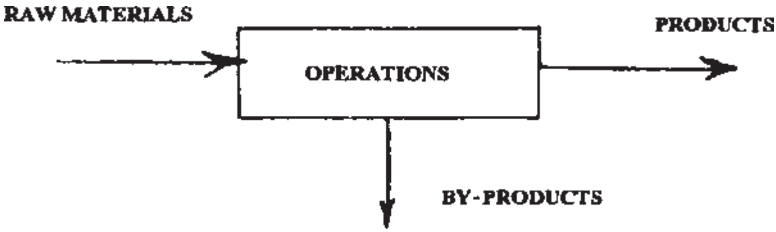

FIGURE 8.1 Process flow diagram.

operation at start-up, it is replenished from revenue or sales. Over a period of time, a dynamic equilibrium is established and the net flow of working capital into and out of an operation is zero, with none of it going into net annual operating expenses or operating income.

If the above concept is expanded to include a company's entire operation, a *money flow diagram* can be developed to demonstrate the sources and movement of cash flow. One should recognize that the money flow diagram in Figure 8.4 has been idealized [3,4]. Let's examine this diagram more closely.

If the *cash operating expenses* are subtracted from the *sales or revenue*, the result is the *operating income*. If depreciation and depletion are then subtracted from then operating income, the *gross profit* is the result. Since depreciation is an allowance, it is handled as an annual operating expense by tax laws and appears as an expense item on annual operating expense reports. Depreciation then is considered as an internal expense and it is retained in the company. When income taxes are subtracted from gross profit *net income after* taxes results. If depreciation and depletion are added to the net income after taxes, *after-tax cash flow* occurs. It is customary to separate depreciation from net income after taxes because a part of the net income may leave the company.

The terminology in Figure 8.4 is consistent with that found in most company income statements in annual reports [2]. Note that the cash operating expenses do not include depreciation and depletion. In Chapter 5, depreciation

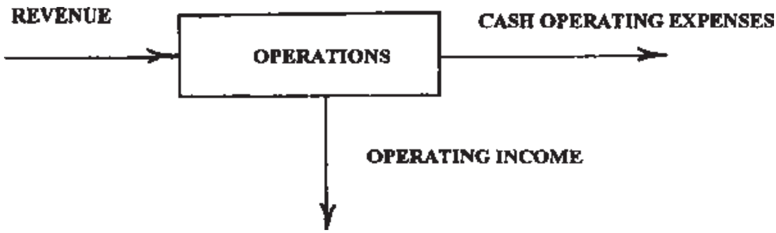

FIGURE 8.2 Flow of money.

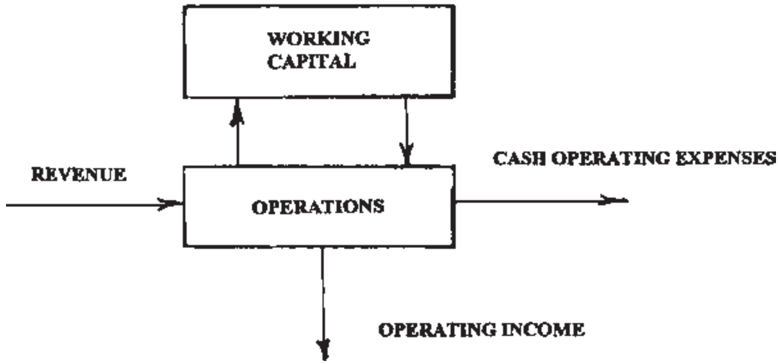

FIGURE 8.3 Money flow diagram with working capital.

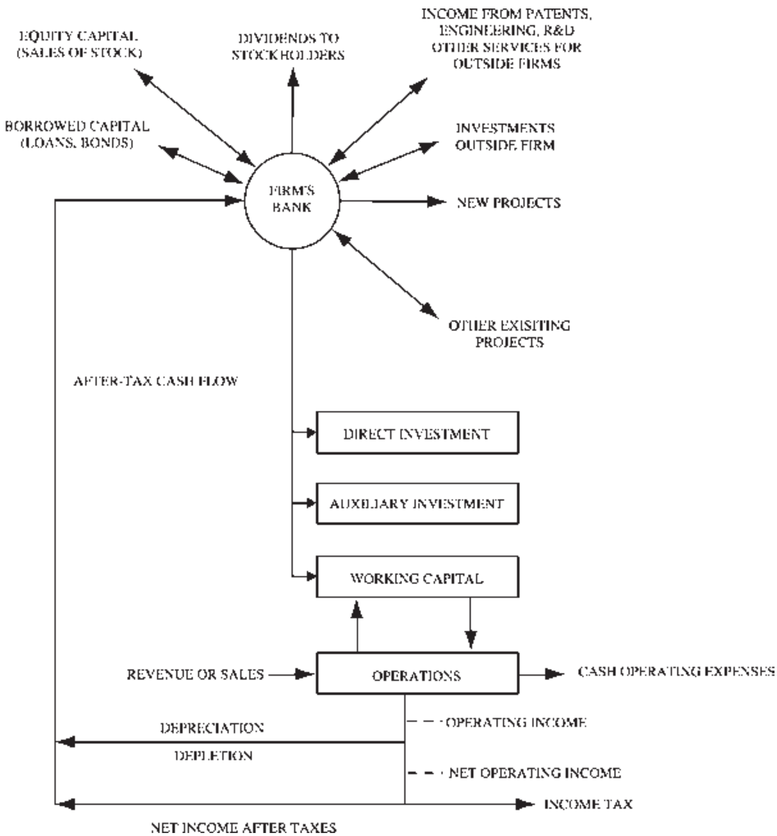

FIGURE 8.4 Money flow diagram for a company.

was entered in the manufacturing expense sheet as an operating expense. Depreciation is then considered as an internal expense or an allowance for tax purposes and is retained within the company.

The after-tax cash flow is available to the company for funding numerous items such as new projects, research, and development. At the top of the figure, there is an item *firm's bank* but it is fictitious. Capital may be borrowed through bonds or loans. The double-headed arrow indicates that money may come to the company in this manner or in turn it may be loaned to subsidiary operations. Equity stock may be bought back from stockholders or sold by the company to increase money flow; hence, the double-headed arrow. Dividends are paid to stockholders representing a flow of money leaving the company. Income may be derived from patents, licenses, engineering, selling technology and services to outside firms. Also, a company may purchase any of these items. Investment in outside firms may require an outflow of money and income may be derived from these sources. New projects require an expenditure of funds so there is an outflow of money. Lastly, existing projects may require funds for expansion or retrofitting but these projects will also return money to the firm. The firm's bank may be regarded as a part of the money flow diagram that decides how to invest, expand operations using the source of funds. In this respect, it is similar to a commercial bank.

The lower section of Figure 8.4 contains the definition of the after-tax cash flow. This lower section is an isolated part of the money flow diagram as seen in Figure 8.5. Cash operating expenses C are subtracted from the revenue R; then the operating income is $R - C$. Depreciation and depletion D, is then subtracted from the operating income to yield the gross profit, $R - C - D$. Next, an income tax rate t, is applied to the gross profit, and the income taxes become $t(R - C - D)$. The net income (profit) after taxes becomes $(1 - t)(R - C - D)$. After-tax cash flow, by definition, is the net income after taxes plus depreciation and depletion, or

$$\text{Cash flow} = \text{CF} = D + (1 - t)(R - C - D) \tag{8.1}$$

This equation may be rearranged algebraically:

$$\text{CF} = t(D) + (1 - t)R - (1 - t)(C) \tag{8.2}$$

The term tD is the contribution to cash flow from depreciation and $(1 - t)R$ and $(1 - t)C$ are contributions to cash flow from the revenues and the cash operating expenses, respectively.

When two cash flow cases are compared, Eq. (8.2) may be modified as follows:

$$\Delta\text{CF} = t(\Delta D) + (1 - t)(\Delta R) - (1 - t)(\Delta C) \tag{8.3}$$

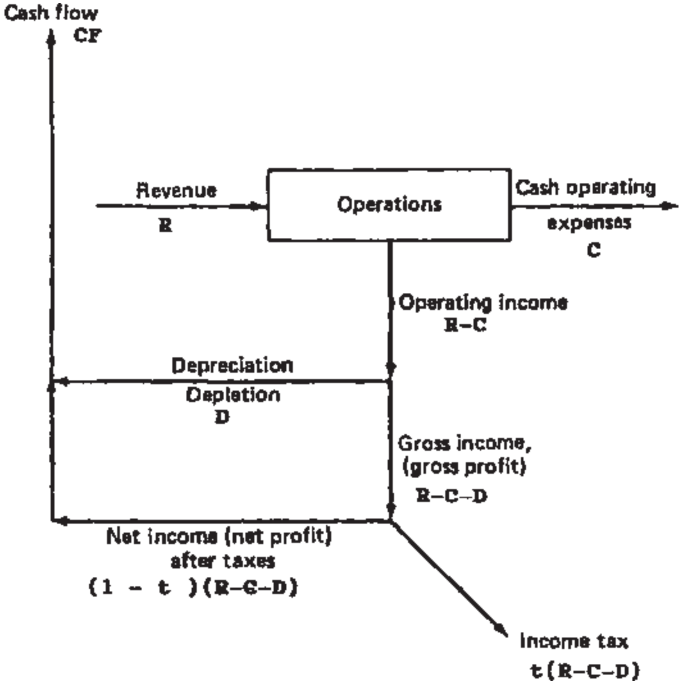

FIGURE 8.5 Cash flow diagram.

where

ΔCF = difference in cash flow \$
ΔD = difference in depreciation and depletion \$
ΔR = difference in revenue \$
ΔC = difference in cash operating expenses \$

There are some cases when revenue is not affected by a process; then $\Delta R = 0$. An example would be comparing the cash flow for two processes making the same product. Since the amount of product manufactured would be the same, $\Delta R = 0$.

In Example 8.1, the use of the cash flow model is demonstrated. It is advisable to first draw the cash flow model, label all streams, and then proceed with the problem solution using a tabular format.

Example 8.1

Problem Statement:

A company is considering the manufacture of a new specialty chemical for a limited market. To build the new plant, land must be acquired that is estimated to be \$350,000. A design–construction firm estimated the fixed capital investment for the project to be \$12,000,000. Approximately \$1,500,000 working capital will be required initially. The 1986 MACRS depreciation rules apply and the company will elect to use the half-year convention. The federal income tax rate is 35%. The product is estimated to have an 11-year life and the projected sales data are as follows:

Year	Annual sales (MM lb)	Selling price (\$/lb)	Total operating expenses (\$/lb)
1	20.0	0.480	0.310
2	22.0	0.480	0.320
3	25.0	0.500	0.306
4	27.0	0.510	0.293
5	30.0	0.510	0.279
6	35.0	0.490	0.276
7	35.0	0.490	0.286
8	34.0	0.480	0.292
9	32.0	0.470	0.310
10	30.0	0.460	0.320
11	27.0	0.450	0.340

Calculate the summary of capital requirements and the yearly cash flow of the venture using the cash flow model.

Solution:

Summary of Capital Requirements	
Land	\$350,000
Fixed capital requirements	\$12,000,000
Working capital	\$1,500,000
Total capital requirements	\$13,850,000

For the yearly cash flow, see Table 8.1. According to Table 7.3, the recovery period is 5 years and the class life is 9.5 years for the equipment to manufacture this product. Note that the decrease in cash flow is significant beginning in year 6, and thereafter depreciation is not applicable in years 7–11. The cash flow diagram, Figure 8.6, is helpful for envisioning how cash flows in a project during the first year of operation only. For subsequent years, a similar diagram may be developed.

Table 8.1 Cash Flow Table for Example 8.1

Year	Sales, MM lb/yr	Selling price, $/lb	Annual sales, $MM	Total operating expense, $MM	Depreciation, $MM	Cash operating expenses, $MM	Operating income, $MM	Depreciation, $MM	Gross profit, $MM	35% fit, $MM	Net income after taxes, $MM	Depreciation, $MM	After-tax cash flow, $MM
1	20	0.48	9.60	6.20	1.20	5.00	4.60	1.20	3.40	1.19	2.21	1.20	3.41
2	22	0.48	10.56	7.04	2.40	4.64	5.92	2.40	3.52	1.23	2.29	2.40	4.69
3	25	0.50	12.50	7.65	2.40	5.25	7.25	2.40	4.85	1.70	3.15	2.40	5.55
4	27	0.51	13.77	7.91	2.40	5.51	8.26	2.40	5.86	2.05	3.81	2.40	6.21
5	30	0.51	15.30	8.37	2.40	5.97	9.33	2.40	6.93	2.43	4.50	2.40	6.90
6	35	0.49	17.19	9.66	1.20	8.46	8.73	1.20	7.53	2.64	4.89	2.40	6.09
7	35	0.49	17.19	10.01		10.01	7.18		7.18	2.51	4.67	1.20	4.67
8	34	0.48	16.32	9.93		9.93	6.39		6.39	2.24	4.15		4.15
9	32	0.47	15.04	9.92		9.92	5.12		5.12	1.79	3.33		3.33
10	30	0.46	13.80	9.60		9.60	4.20		4.20	1.47	2.73		2.73
11	27	0.45	12.15	9.18		9.18	2.97		2.97	1.04	1.93		1.93

	Summary of capital requirements, $
Land	350,000
Fixed capital investment	12,000,000
Working capital	1,500,000
Total capital investment	13,850,000

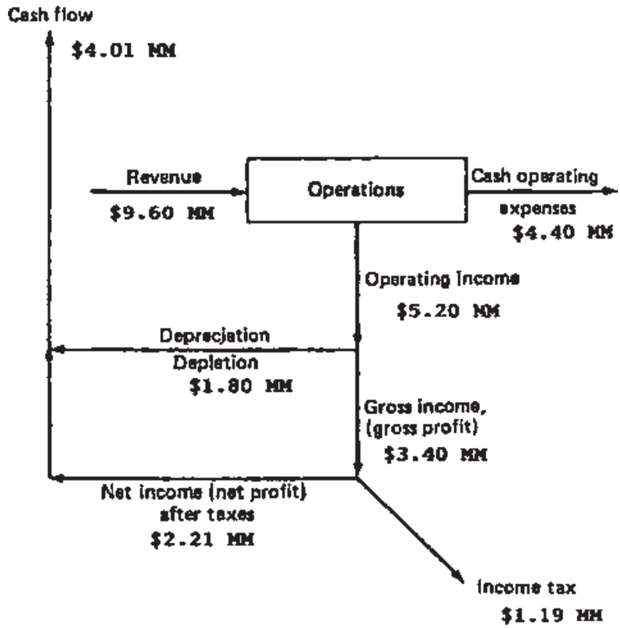

FIGURE 8.6 Cash flow diagram for Example 8.1 (first year of operation).

8.2 COMPARISON OF ALTERNATIVES

The cash flow model is particularly useful when comparing alternative proposals. This methodology was developed by Uhl and Hawkins [1]. Example 8.2 is an illustration of the utility of the cash flow diagram.

Example 8.2

Problem Statement:

A chemical manufacturer of a specialty product finds that to debottleneck the operation, a new clarifying filter will be required. Two vendors presented bids for the equipment. The cost estimates for the installation and operating expenses were prepared by the firm's engineering department. The data are as follows:

	Vendor *A*	Vendor *B*
Cost of installed equipment	$98,500	$110,000
Annual cash operating expenses	10,950	9,850

Assume a 5-year straight-line depreciation, ignoring the half-year convention. The federal income tax rate is 35%.

Based upon cash flow only, which vendor's equipment should be purchased?

Solution:

One cannot tell which vendor's equipment to select based upon visual inspection. A numerical comparison must be made. Figure 8.7 is the cash flow analysis for vendor *A*'s equipment. The cash flow analysis for vendor *B*'s equipment is shown in Figure 8.8.

A basic assumption in the analysis of this problem is that either vendor's equipment will provide the same service. From the problem statement, if vendor *A*'s equipment is installed, it would cost the firm $98,500 more money than "at present." "At present" assumes nothing is to be done—the status quo is maintained. Vendor *A*'s equipment will cost $10,950 more cash operating expenses, resulting in $10,950 less operating income. The depreciation on this equipment is $19,700 more. The gross profit is found by subtracting the depreciation from the operating income, and the result is $30,650 less. The income taxes is 35% of the gross profit, or $10,728. When the income tax is subtracted from the gross profit, the net profit after taxes results, namely, $19,922. By definition, after-tax cash flow is the sum of the depreciation and the net profit after taxes, or $19,700 more and $19,922 less. Therefore, the after-tax cash flow for this case is $222 less than doing nothing. (*Note*: The rules of algebra apply in this analysis, namely, when a value is subtracted from another quantity the sign

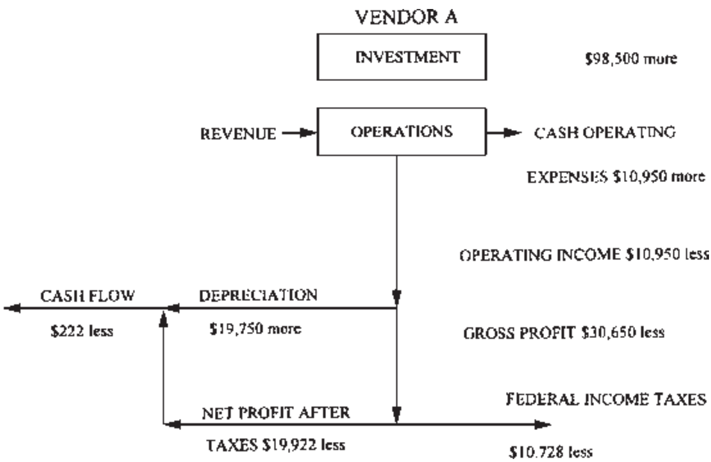

FIGURE 8.7 Cash flow diagram for Example 8.2, vendor *A*.

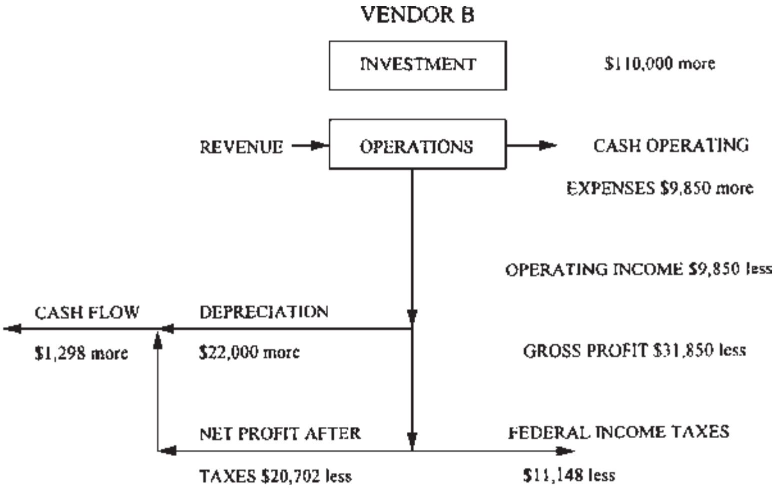

FIGURE 8.8 Cash flow diagram for Example 8.2, vendor *B*.

is changed and the quantities are summed. All “more” quantities have a + sign and all “less” quantities have a − sign.)

In similar fashion, the case for vendor *B*’s equipment may be determined and it resulted in $1298 more cash flow than doing nothing. Therefore, vendor *B*’s equipment should be selected based on the fact that it generates more cash flow than vendor *A*’s. There may be other considerations in the selection of either equipment but the analysis above is strictly based on cash flow.

This problem may be solved using differences in cash flows of the two cases. The larger investment should be compared to the lesser one because the resulting numbers are positive, case *B* versus case *A*. The cash flow comparison of vendor *B*’s equipment with vendor *A*’s equipment is shown in Figure 8.9.

The $1520 more cash flow checks with the cash flows for the individual, vendor *A*’s and vendor *B*’s equipment, namely, $1298 more minus $222 less = $1520 more cash flow in favor of vendor’s *B* equipment.

This “more–less” or “difference” analysis is particularly useful for small plant investment problems involving additions or replacing equipment. We shall again use this technique in Chapter 12.

8.3 CUMULATIVE CASH POSITION PLOT

Frequently, we are interested in the flow of funds for a single project and not the entire company. The cash flows may be shown over a project’s life on a *cumulative cash position plot*. To develop this plot, an arbitrary time frame is

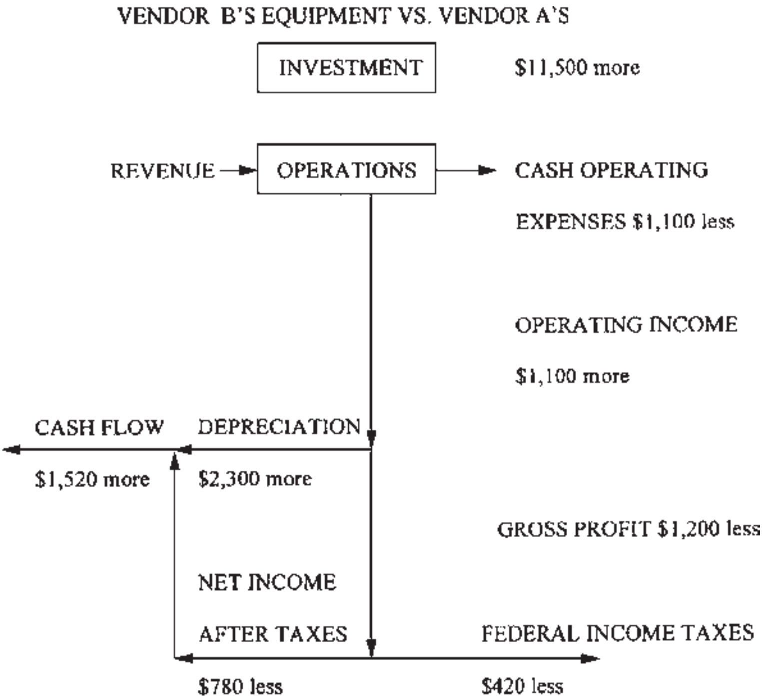

FIGURE 8.9 Cash flow diagram for Example 8.2 using difference method.

selected. There are normally two choices—time zero being when the plant starts up and produces a salable product or when the first expenditure is made.

In Figure 8.10, time zero is selected as start-up. Expenditures for land and equipment in this case are made prior to time zero and represent a negative cash flow. At time zero, working capital is charged to the project, representing a further negative cash flow. As the plant begins to operate, revenues are generated from the sale of product and positive cash flows occur. Figure 8.10 represents a historical flow of cash and the cumulative effect of cash flow for the project, hence the name *cumulative cash position plot*. When the project terminates, the land and working capital are recovered by the company. For this case, these capital items may be regarded as interest-free loans to the project.

In the previous paragraph, time zero was selected as start-up. As an alternative, it may be more convenient to select time zero when the first funds are spent. The former approach is useful for cases when a new project is being considered. The latter approach is frequently more convenient for cases when equipment is being added to or an expansion of an already existing plant is to be

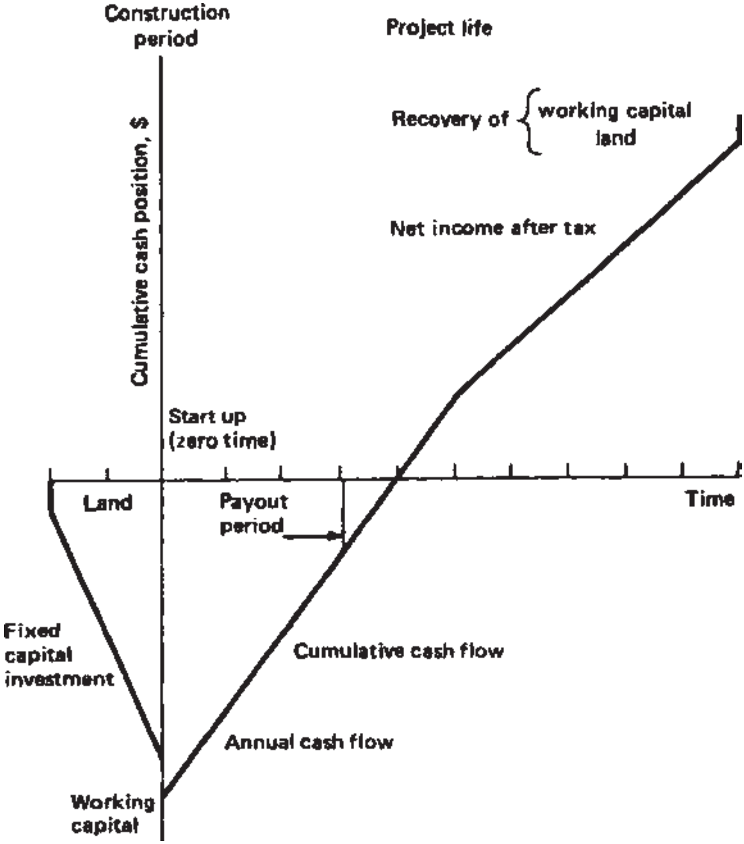

FIGURE 8.10 A typical cumulative cash position plot.

made. The selection of either time base is satisfactory for economic analysis as long as consistency is maintained. The resulting decision based upon either time base will be the same but the numbers may be different.

In order to illustrate the development of the cumulative cash position plot, a modification of Example 8.1 will be used.

Example 8.3

Problem Statement:

Read again Example 8.1. The fixed capital investment is to be purchased and installed over a 2-year period prior to start-up. Land will be available 2 years prior to time zero, and working capital will be charged to the project at time zero.

Both will be recovered at the end of the project. Using this information and the data from Example 8.1, prepare a cumulative cash position table and plot.

Solution:

The cumulative cash position data are found in Table 8.2, and a cumulative cash position plot for Example 8.3 is presented in Figure 8.11. If it assumed that time zero for this analysis is start-up, the land is charged to the project instantaneously 2 years prior to start-up. The firm may have already owned the land or it may have been purchased at that time. In either case, the price of the land is transferred to the project by the company's accountants. This outflow of cash is depicted in Figure 8.11 as a negative cash flow 2 years before start-up. Equipment is purchased and installed over a 2-year period. In Figure 8.11, this expenditure is shown as a uniform cash outflow over that period. The actual project expenditure for the purchase and installation of equipment is a skewed bell-shaped curve with the peak occurring about 60% between minus 2 years and zero (see Fig. 8.12). From an economic standpoint, the simplification of uniform cash flow does not normally affect the ultimate decision although the absolute value of the cash flow will vary whether it is uniformly or nonuniformly dispensed.

TABLE 8.2 Cumulative Cash Position Table for Example 8.3 with No Interest

	Cash flows, $M		
Time period	Investment	After-tax cash flow	Cumulative cash position
2 yr prior to start	−$350		−350
2 yr during	−12,000		−12,350
1 yr prior to start			
1 yr during			
At start	−1,500		−13,850
1		3,410	−10,440
2		4,690	−5,570
3		5,550	−200
4		6,210	6,010
5		6,900	12,910
6		6,090	19,000
7		4,670	23,670
8		4,150	27,820
9		3,330	31,150
10		2,730	33,880
11		1,930	35,810
End 11	2,500		38,310

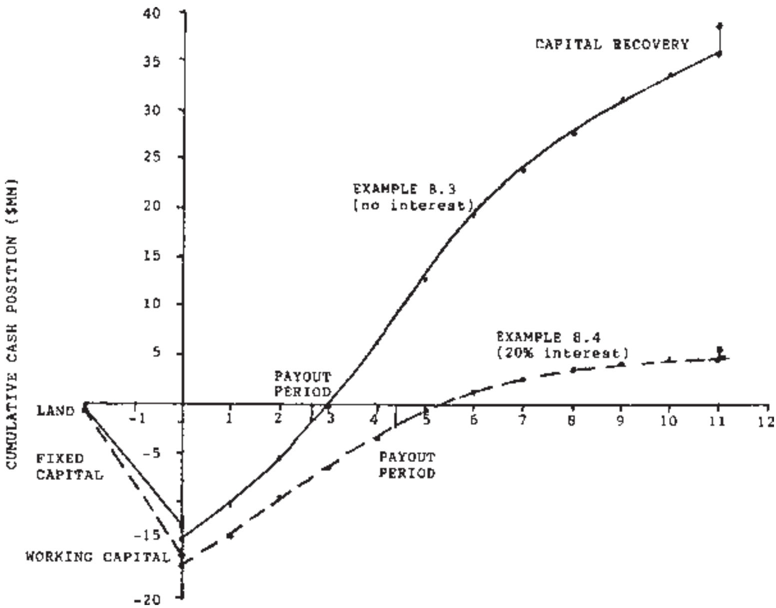

FIGURE 8.11 Cumulative cash position plot for Example 8.3.

At start-up, working capital is charged to the project. Therefore, at this point in time, there have been only expenditures and no positive cash flow has occurred since no product has been produced or sold. After time zero, product is made and the income from sales after taxes plus depreciation begins to reduce the negative cumulative cash position, as noted in Table 8.2. The yearly cash flows are summed and a cumulative total is calculated for each year of the project. The sixth year is the last year depreciation is considered, since the fixed capital investment has been recovered. Thereafter, net profit after taxes is the only component of cash flow. At the end of the eleventh year, the land and working capital are recovered instantaneously and is shown in the investment column as positive cash flow.

Payout period, a measure of profitability, may be determined using the cumulative cash position plot. The basic definition of the payout period is the fixed capital investment divided by the after-tax cash flow. One might think that the payout time occurs where the cumulative cash position line crosses the x axis in Figure 8.11, but that is incorrect because land and working capital have been included. To find the correct payout period, the sum of the ordinate for the land and working capital must be subtracted. The correct payout time lies to the left of the cumulative cash position line and the x axis, as shown in Figure 8.11. The solution to Example 8.4 is shown in Figure 8.11.

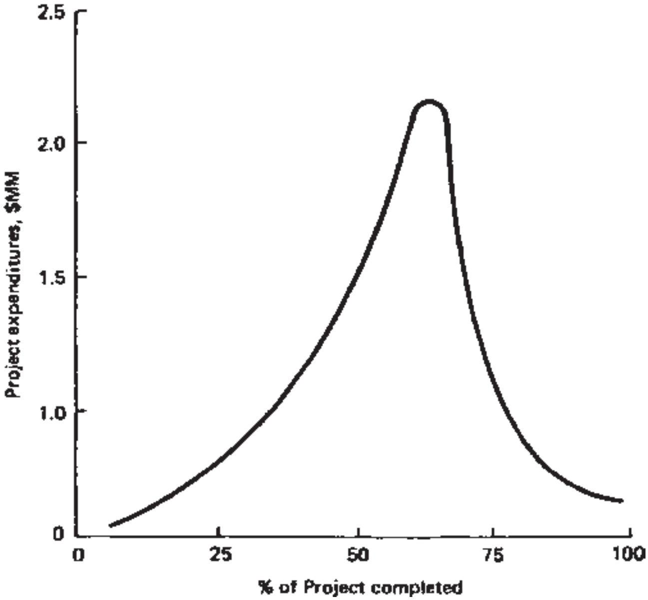

FIGURE 8.12 Typical cash flow of fixed capital.

Up to this point in the discussion, the cash flow patterns have been idealized to illustrate the mechanics of calculating and displaying cash flow. In reality, project expenditures as a function of project completion follow a skewed bell-shaped curve, as displayed in Figure 8.12. Expenditures are stepwise additions to the capital but in this plot have been smoothed. At about 60% project completion, the maximum expenditures are made for a typical project. It should be realized that in any given project, expenditure curves vary but will show a similar pattern to Figure 8.12.

8.4 EFFECT OF THE TIME VALUE OF MONEY ON THE CASH POSITION PLOT

Thus far, the time value of money has not been considered in Example 8.3. To be realistic, it must be included in the calculations, therefore, let's determine how the effect of interest changes the cash position plot in Example 8.3.

Example 8.4

Problem Statement:

Reread Example 8.3. The firm uses 20% continuous interest for its present worth calculations. Discrete end-of-year or midyear convention may be used instead of continuous interest. The methodology is the same regardless of the interest model used. Prepare a cumulative cash position table and plot using 20% continuous interest.

Table 8.3 is the cumulative cash position table for 20% continuous interest. Figure 8.11 is a plot of the cumulative cash position for Examples 8.3 and 8.4. The net effect of including interest in cash flow calculations is that the payout period is increased and the terminal cash position is less. The positive value of the terminal present worth indicates that the project will earn more than 20% interest after taxes and, conversely, a negative value indicates that the project will earn less than 20% after taxes. In Chapter 9, the case where the terminal cash position is zero will be discussed.

Electronic spreadsheets like LOTUS, EXCEL, and QUATTRO PRO are ideal for preparing cash flow analyses and they permit the study of various cases using "what if" analysis. The spreadsheet selected will depend on the user's personal preference.

The EXCEL spread sheet is illustrated in the cash flow analysis in Example 8.5.

TABLE 8.3 Cumulative Cash Position Table for Example 8.4 with 20% Interest

	Cash flows, $M				
Time period	Investment	After-tax cash flow	Interest factor	Present worth	Cumulative cash position
2 yr prior to start	−350		1.492	−522	−522
2 yr during	−12,000		1.230	−14,760	−15,282
1 yr prior to start					
1 yr during					
At start	−1,500		1.000	−1,500	−16,782
1		3,410	0.906	3,089	−13,693
2		4,690	0.742	3,780	−9,913
3		5,550	0.608	3,374	−6,534
4		6,210	0.497	3,086	−3,453
5		6,900	0.407	2,808	−645
6		6,090	0.333	2,028	1,383
7		4,670	0.273	1,275	2,658
8		4,150	0.224	930	3,588
9		3,330	0.183	609	4,197
10		2,730	0.150	410	4,607
11		1,930	0.140	270	4,877
End 11	2,500		0.135	338	5,215

Example 8.5

Problem Statement:

Small plastics, Inc. is considering the manufacture of novelty items for a given market. Land may be purchased adjacent to their existing operation for \$425,000. An estimate of the fixed capital investment for the proposed operation is \$3,600,000. At start-up, \$550,000 will be required as working capital. It will take 2 years to prepare the land site, purchase and install the necessary equipment. At the end of project, the land and working capital are recovered. For this 11-year project, the following income and cash operating expenses have been estimated:

Year	Income, \$M	Cash operating expenses, \$M
1	\$3,700	\$2,950
2	4,280	3,400
3	4,750	3,600
4	5,400	3,850
5	6,200	4,400
6	6,500	4,750
7	6,300	4,800
8	6,200	4,900
9	5,800	4,600
10	5,100	4,200
11	4,500	3,900

The 5-year MACRS depreciation with half-year convention will be used and the federal income tax rate is 35%. Develop a cash flow summary table and a cash position plot for this project using an electronic spreadsheet.

Solution:

Table 8.4 contains the major elements of a cash flow analysis. Across the top of the table are the project years starting with -2 years and ending with the eleventh year when the capital is recovered. In the left-hand column are the items that contribute to the cash flow so that they may be considered properly at the proposed time. Beneath the total capital investment are the individual entries constituting the profit–loss statement. At the bottom left are the items after-tax cash flow, capital recovery, and cumulative cash flow.

This template is constructed so that systematically various entries from Example 8.5 are entered in the appropriate places. This template may be thought to lie behind Table 8.4 and may be used for subsequent cases. The cumulative

TABLE 8.4 Cash Flow Table for Example 8.5

Year-item investment	Cash flow, $M														
	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11	End 11
Land	−425														
Fixed capital investment	−1,000	−2,600													
Working capital			−550												
Total capital investment	−1,425	−2,600	−550												
Profit−loss statement															
Income				3,700	4,280	4,750	5,400	6,200	6,500	6,300	6,200	5,800	5,100	4,500	
Expenses															
Cash operating expenses				2,950	3,400	3,600	3,850	4,400	4,750	4,800	4,900	4,600	4,200	3,900	
Depreciation				360	720	720	720	720	360						
Total operating expenses				3,310	4,120	4,320	4,570	5,120	5,110	4,800	4,900	4,600	4,200	3,900	
Operating income				750	880	1,150	1,550	1,800	1,750	1,500	1,300	1,200	900	600	
Net income before taxes				390	160	430	830	1,080	1,390	1,500	1,300	1,200	900	600	
Federal income taxes				137	56	151	291	378	487	525	455	420	315	210	
Net income after taxes				253	104	279	539	702	903	975	845	780	585	390	
After-tax cash flow				613	824	999	1,259	1,422	1,263	975	845	780	585	390	
Capital recovery															975
Cumulative cash flow	−1,425	−4,025	−4,575	−3,962	−3,138	−2,139	−880	542	1,805	2,780	3,625	4,405	4,990	5,380	6,355

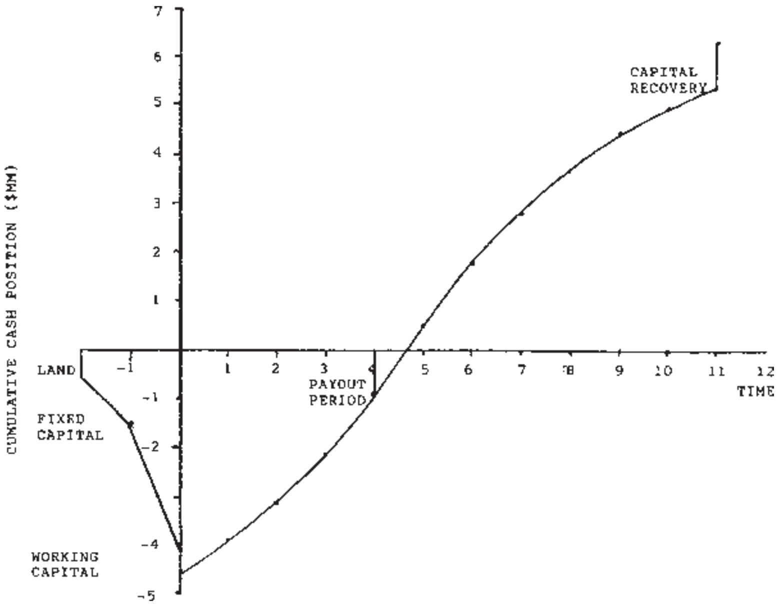

FIGURE 8.13 Cumulative cash position plot for Example 8.5.

cash position plot, Figure 8.13, may be generated from data in Example 8.5 by using appropriate commands in the electronic spreadsheet.

Once the base case has been established, "what if" analysis can be conducted altering various entries that will result in different cash flow patterns.

8.5 EFFECT OF CASH FLOW ON COMPANY OPERATIONS

In this chapter, cash flow movement and timing has been presented with respect to a project. Humphrey [5] discusses the subject of cash flow and its effect on project investments, citing examples.

It is essential to have adequate cash flow in the early years of a new venture to prevent it from floundering. In these years, markets have not been fully developed for the product, product may not have manufactured in the quantity and quality as projected, and manufacturing expenses may be more than estimated. A sufficient amount of funds are essential to keep the venture going while the above problems are overcome.

One of the major elements of cash flow is depreciation. Accelerated methods were devised to allow the company management to recover the fixed capital investment early while affording management the flexibility to meet price competition, stabilize production and reduce operating expenses.

Cash flow is not a measure of profitability but is a component in evaluating profitability of a venture. In Chapter 9, the subject will be more fully addressed.

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PROBLEMS

8.1 To remedy a dust problem in the bulk packaging area of a fertilizer plant, two wet-scrubbing systems have been proposed. The data are as follows:

	A	*B*
Installed equipment cost	$157,000	$230,000
Annual cash operating expenses	32,000	28,000

Depreciation of the equipment may be taken as 5 years with a 6-year class life. The federal income tax rate is 35%.

Compare the cash flows for each proposal. On the basis of cash flow only, which alternative is preferred? What conclusions can you draw from this analysis? Use cash flow diagrams in your analysis.

8.2 A small manufacturing company is considering the expansion of its plastics operation. To meet sales demand, a new molding machine must be installed. An economic analysis based upon cash flow will have to be made using the following data:

	Machine *A*	Machine *B*
Installed fixed investment	$285,000	$197,000
Annual cash operating expenses	42,000	38,000

Depreciation may be taken as 5 years by the straight-line method. The federal income tax rate is 35%.

Determine:

a. Cash flow analysis for installing machine *A*.
b. Cash flow analysis for installing machine *B*.
c. Using the difference method, compare Machine A with Machine B.
d. On the basis of cash flow, which machine is to be preferred?

Use cash flow diagrams for this analysis.

8.3 Star Chemical Company manufactures a line of specialty products. The land for a proposed venture may be considered negligible for this analysis. The fixed capital investment is estimated to be $6,000,000. An adequate amount of working capital is believed to be $1,000,000. The equipment is to be purchased and installed over an 18-month period prior to start-up. The project is estimated to have a 10-year life. For this investment, a 5-year MACRS depreciation with the half-year convention is used. The projected sales, selling price, and cash operating expenses are tabulated below.

If the federal income tax rate is 35%, provide the following for management's consideration:

	Projected sales	
Year	Sales, lb/yr	Selling price, $/lb
1	15MM	$0.28
2	17MM	0.28
3	19MM	0.26
4	20MM	0.27
5	20MM	0.28
6	20MM	0.29
7	18MM	0.30
8	17MM	0.30
9	15MM	0.28
10	13MM	0.28

	Cash operating expenses
Year	Expenses, $/lb
1	0.16
2	0.15
3	0.15
4	0.15
5	0.16
6	0.17
7,8	0.17
9,10	0.18

a. A tabulated cash flow summary
b. A cumulative cash position plot labeling all lines on the chart
c. The cumulative cash position at the end of the project

How would the above change had time zero been selected at the beginning of construction? Compare the numerical results of both cases.

8.4 A small electronics firm needs an inert gas generator to provide an inert gas atmosphere for part of its silicon manufacturing process. The generator can be purchased outright for $2.5MM as a packaged unit or leased for $300,000 per year. The company estimates that $600,000 annual cash operating expenses for the purchased unit but if it decides to lease the equipment, a lease charge is considered to be an operating expense. The company uses the 5-year MACRS method of depreciation (ignore the half-year convention), and the equipment under current tax laws has a 6-year class life. The federal income tax rate is 35%. Develop a cash flow analysis for both cases and discuss the advantages of either leasing or purchasing the equipment, presenting both sets of figures to justify your analysis.

8.5 M and J Enterprises, Inc., a small "Mom and Pop" company, must purchase a new item of equipment costing $500,000 installed to stay in full production. The equipment will generate after-tax cash flows as follows:

Year	After-tax cash flow
1	$75,000
2	80,000
3	90,000
4	100,000
5	82,000
6	76,000
7	74,000
8	70,000
9	68,000
10	65,000

At the end of the third year, new bearings must be installed for $30,000 and again at the end of the sixth year for $40,000. Using the cumulative cash flow diagram, assuming a 10-year project life and time zero occurs when the initial equipment is purchased, show how the cash flows into and out of this venture are effected if these bearings are considered as

a. Capital investment
b. Operating expense in the appropriate years

This venture qualifies for a 7-year straight-line depreciation rate and is subject to a federal income tax rate of 35%.

8.6 Farout Ventures is considering the manufacture of a machine part. The fixed capital investment for the plant if estimated to be \$8,000,000 and the construction period is expected to be 2 years. A market survey for the proposed plant resulted in the following information:

Year	Sales volume, MM units per year	Selling price, \$/unit
1	4.0	\$0.68
2	5.0	0.66
3	7.0	0.65
4	8.0	0.64
5	8.5	0.64
6	8.7	0.63
7	9.0	0.62
8	8.5	0.64
9	8.2	0.65
10	7.8	0.70

Annual cash operating expenses are estimated to be:

Year	Cash operating expenses
1	\$2.0MM
2	2.5MM
3	2.7MM
4	2.8MM
5	3.0MM
6	3.1MM
7	3.3MM
8	3.4MM
9	3.4MM
10	3.5MM

Depreciation is by 7-year MACRS, half-year convention. During the first year of construction, \$3MM of the fixed capital investment is uniformly expended over that year and the remainder uniformly expended in year 2 of the construction period. At start-up, \$1MM working capital is allocated to the project. If the federal income tax rate is 35%, prepare a cash flow analysis and a cumulative cash position diagram for the proposed project. From your analysis, what is your opinion of the proposed venture, justifying all statement with figures?

8.7 Rover Products, Inc. manufactures an intermediate that will be sold to large pharmaceutical companies for processing into vitamin supplements. Land for the project is $300,000 and start-up expenses are estimated to be $500,000. The fixed capital investment for the project is $10MM and a working capital of $2MM is required. The company qualifies for a 5-year MACRS depreciation schedule and is subject to a 35% federal income tax rate. Construction is expected to take 2 years. Your may assume that 50% of the start-up expenses occur in the first year of operation which are expensed and the remainder must be capitalized at the end of year 1. The economic forecasting group has proved the following information:

	Projected sales	
Year	Sales, M$/year	Selling price, $/lb
1	6.0	0.86
2	6.5	0.87
3	7.0	0.87
4	8.0	0.88
5	10.0	0.88
6	10.0	0.88
7	10.0	0.88
8	9.0	0.90
9	7.0	0.87
10	6.0	0.85

Cash operating expenses

Year	Cash operating expenses, $/lb
1	0.30
2	0.31
3	0.31
4	0.33
5	0.34
6	0.35
7	0.35
8	0.36
9	0.36
10	0.37

Management requires the following information to make a preliminary decision:

a. A cash flow summary at 0 and 15% continuous interest.
b. A cumulative cash position plot showing the effect of 0 and 15% continuous interest. Label all segments of this chart.

9

Estimate of Profitability

In a free enterprise system, companies are in business to make a profit. If profits aren't maintained, a company's growth is stifled because retained earnings are derived from profits. A part or all these earnings may be used for new investments to enhance a company's growth. A company is continually confronted with investment decisions. Management has the responsibility of investing in ventures that are financially attractive by increasing the earnings, providing attractive rates of return, and increasing economic value added. Every viable business has limitations on the capital available for investment purposes; therefore, it will invest in the most economically attractive ventures.

The objectives and goals of a company are primary in considering what projects are to be funded. Corporate objectives change as the economy changes. A company that retains static objectives in this rapidly changing world will surely reach economic stagnation. The goal of a company may not be to maximize profit alone, because, if that were the case, then large capital investments might be undertaken that could easily yield a low return on capital. Also, the goal may not be to maximize the return on investment only without considering profit. If this were the case, then only the case that provided the highest return would be selected.

In order to determine the worthiness of a venture, certain quantitative and qualitative measures of profitability are used. Although the term *profitability* is loosely used to measure a project's value, it may not be a good measure. Peter Drucker [1] has said that "profitability is not a perfect measurement; no one has been able to define it, and yet it is a measurement, despite all its imperfections."

It used to be that only quantitative measures were of paramount importance but industry has taken a more responsible posture as a corporate citizen and qualitative factors have become equally important in the decision-making process. Both these measures will be considered in this chapter.

9.1 CORPORATE OBJECTIVES

Corporate objectives might include one or several of the following:

- Maximize the return on investment.
- Maximize the return on stockholder's equity.
- Maximize aggregate earnings.
- Maximize common stock prices.
- Find outlets for a maximum of additional investment at returns greater than the minimum acceptable rate of return.
- Increase market share.
- Increase the economic value added.
- Increase earnings per share of stock.
- Increase the market value added.

These objectives may not be the only ones but they are those that are most frequently listed by executives.

9.2 PROJECT CLASSIFICATION

Any healthy, growing company has more requests for funding projects than funds available. In order to consider the requests for funds, a company will establish a priority or classification system. For example, projects may be classified as follows:

- Necessity projects
- Product improvement projects
- Process improvement projects
- Expansion projects
- New ventures

Examples of typical necessity projects might be those to meet environmental, health and safety regulations, legal requirements or possibly to accomplish intangible but essential needs. Usually these projects do not require the calculation of a return, but an important economic consideration is the change in the cash flow that will occur when the project becomes operational. If this type of project is not funded, operations may be terminated.

Product improvement projects are those that require capital to improve the quality of a product, like clarity, stability, odor, or purity to meet customer needs. A small product improvement often yields positive returns and has small risk.

Process improvement projects are concerned with the reduction of operating expenses, for example, improvement in reaction yields, reduction of utilities, and labor expenses. The risk associated with these ventures is greater than product improvement projects but still is relatively low.

Expansion projects often occur to meet increased sales demand for a product. These projects may require the retrofitting of an existing facility with associated high expenses and/or the building of a new facility. The risk for this type project is higher than the previous projects as the sales may not develop as projected.

New ventures require capital expenditures to introduce new products to the market. These might also involve joint ventures or alliances with another company or companies and are the riskiest projects. Problems such as the market may not have been fully developed, or the share of the market a company can garner may be questionable. When joint ventures are involved, there may be differences in philosophies or operational modes among the companies involved that can cause delays in start-ups and a host of other problems. Therefore, these projects require a high rate of return initially to consider funding.

In the list above, the least risky projects are listed first, and the required return when considering funding increases from necessity projects to new ventures.

A classification system such as the one just described permits management to consider funding projects according to the purpose of a project and the relative degree of risk. Projects from various divisions of a company then can be considered on a similar basis and measured by the same standard of profitability. Management's objective is to allocate capital funds for the greatest benefit to the company. Whatever classification system is used, it should not be so rigid as to restrict management's capital budgeting process and decision making.

9.3 MINIMUM ACCEPTABLE RATE OF RETURN

A number of factors affect the minimum acceptable rate of return, *barrier or hurdle* return, established by management for a venture to be funded. These factors are listed in Table 9.1. Proposals of similar risk levels are classified in each category. Management may increase the rate required for funding a risky project or if funds are limited, and management establishes a minimum rate for a project in each of the above categories to be considered for funding.

An important consideration is the cost of capital. It is what it costs a company to borrow money from all sources, loans, bonds, common and preferred stock. A company must make a return greater than the cost of capital to pay its debts and be profitable. In recent years, some firms through creative accounting have ignored the cost of capital in order to increase the dividends to stockholders. This means that management is not meeting its obligations to pay off outstanding

TABLE 9.1 Factors Affecting Minimum Acceptable Rate of Return

Cost of capital
Availability of capital
Competing investments
Difference in risks of investment
Difference in time to recover capital

debts. A sample calculation of the cost of capital is found in Table 9.2. The information for this calculation may be found in annual, 10-K, or 10-Q reports.

Another factor affecting the acceptable return is the availability of capital. This depends on the health of the economy. In times when capital is in short supply, higher interest rates are charged and capital investment decisions may be delayed.

Competing investments also affect the minimum rate. Management may adjust this rate to screen from the immediate investment considerations those ventures that are less attractive.

TABLE 9.2 Cost of Capital

Balance sheet 12/31/XX	Debt, $MM	After-tax yield to maturity, %	After-tax weighted average cost, %
Long-term debt			
Revolving account	5.0	4.5	0.02
$4\frac{3}{8}$% debentures	12.0	4.0	0.05
$6\frac{1}{2}$% debentures	3.4	4.7	0.02
$6\frac{3}{4}$% debentures	9.4	4.2	0.04
$7\frac{1}{2}$% debentures	74.5	4.2	0.30
$9\frac{3}{8}$% loan	125.0	4.4	0.53
Other	23.2	4.4	0.10
Total long-term debt	252.5		1.06%
Deferred taxes	67.7	0.0	0
Reserves	16.1	0.0	0
Preferred stock	50.0	8.6	0.42
Shareholder's equity	653.9	15.6	9.80
Total debt	1,040.2		11.28%

Each debt item in $M divided by the total debt times the after-tax yield to maturity equals the after-tax weighted average cost contributing to the cost of capital.

The difference in investment risks is also a factor in the planning for capital investment. The greater the risk, the higher the required return. Lastly, the length of time to recover the investment in a venture is important. Management's objective is to recover the investment as quickly as possible because the economy is difficult to predict the longer the time frame.

In today's economy, industry will require a 25–35% return after taxes for low-risk ventures at the early stages of consideration. As a secondary guide, a payout period of up to 3 years is considered reasonable.

As a project is evaluated further, refining sales forecasts, capital investment figures, and operating expenses, the return will usually decline; therefore, acceptable rates of return at preliminary stages are set at a high value to allow for return erosion.

9.4 PROFITABILITY MEASURES

9.4.1 Quantitative Measures

There are a number of methods for measuring venture profitability listed in the literature [2–4], but the most commonly used will be discussed in this section.

9.4.1.1 Return on Investment

The introduction of the return on investment (ROI) was attributed to Du Pont [5]. From a calculation standpoint, it is the simplest and is used frequently for quick answers. These results obtained may be related back by the user to historical decisions, giving the user a sense of confidence in the results. The equation is

$$\text{RO(O)I} = \frac{\text{annual net profit (earnings) after taxes}}{\text{total capital investment}} \times 100 \tag{9.1}$$

There are several variations of this method; for example, the numerator might be net earnings before taxes and the denominator could be fixed capital investment or fixed and working capital. Although this method is simple to use and relates to accepted accounting methods, it has some serious disadvantages:

- The time value of money is ignored.
- A basic assumption in this method is that all projects are similar in nature to each other.
- The project will last the estimated life and this is often not true.
- Equal weight is given all income for all years and that is not always true. The averaging of profits permits laxity in forecasting.

- It does not consider timing of cash flows.
- It does not consider capital recovery.

9.4.1.2 Return on Average Investment

These are methods for measuring the profitability of investments utilizing accounting data and are based on averaging methods. Racklin [6] presents details for several averaging methods but only one method also attributed to Du Pont will be presented.

$$\mathrm{ROAI} = \frac{\text{annual net profit (earnings) after taxes}}{\text{land} + \text{working capital} + \mathrm{FCI}/2} \times 100 \tag{9.2}$$

where FCI is the fixed capital investment.

The fixed capital investment is divided by 2, so that over the life of the investment, the return is earned against the average investment. The justification for this is that at the beginning of a project the return is earned against the full investment, and at the end of a project the investment has been fully depreciated and the capital has been recovered. Therefore, on the average over the life of the investment, half the fixed capital is involved. This method has all the inherent disadvantages of the previous method.

9.4.1.3 Payout Period (POP)

The objective of this method is to calculate the amount of time that will be required to recover the depreciable fixed capital investment from the accrued cash flow of a project.

Payout period is often used in conjunction with other measures of profitability. It is defined as

$$\text{Payout period (POP)} = \frac{\text{depreciable fixed capital investment}}{\text{after-tax cash flow}} \tag{9.3}$$

The denominator may be the averaged annual cash flows or the individual yearly cash flows. Consistency in the use of this measure must be maintained to compare projects against one another.

The method is simple to use and has served as a historical measure of profitability, comparing POP of proposed projects with those in the past. There are some disadvantages to using the method, since no consideration is given to cash flows that occur after the capital is recovered; therefore, this method cannot be considered as a true measure of profitability. The method makes no provision for including land or working capital. As presented in Eq. (9.3), the time value of money is ignored; however, there are provisions for modifying the method to include discounted cash flows. This will be discussed in the next section.

9.4.1.4 Payout Period with Interest (POPI)

The payout period with interest takes into account the time value of money. The net effect of the interest calculation is to increase the payout time, therefore reflecting the advantages for projects that earn most of their profits in the early years. In equation form,

$$\begin{aligned} \text{Payout period with interest} &= (\text{POP})_i \\ &= \frac{(\text{after-tax cash flows})_i}{(\text{fixed capital investment})_I} \end{aligned} \tag{9.4}$$

where

$$\begin{aligned} (\text{After} - \text{tax cash flows})_i &= \text{cash flows discounted to time zero at} \\ &\quad\ \text{interest rate } i \\ (\text{Fixed capital investment})_i &= \text{fixed capital investment compounded to} \\ &\quad\ \text{time zero at an interest rate } i \end{aligned}$$

If a cumulative cash position plot is prepared from the discounted and compounded values, the POP_i may be obtained graphically. Since in the definition of the payout period, land and working capital are excluded; therefore, the sum of these values may be subtracted from the cumulative cash position. Where that intersection of the summed values of land and working capital with the cumulative cash position line occurs is the POP with interest (see Fig. 9.1).

This method has some disadvantages:

- It does not take into account the project's later years.
- It does not consider capital recovery.

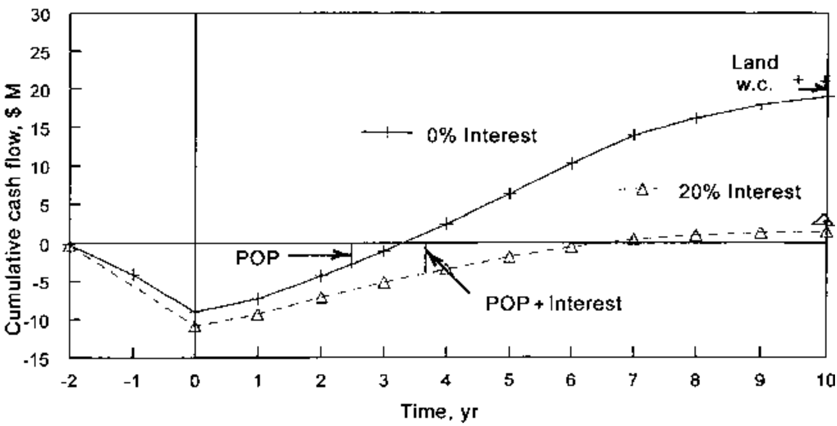

FIGURE 9.1 Cumulative cash position plot for Example 9.1.

9.4.1.5 Net Present Worth (NPW)

As was stated earlier in this chapter, there is no one method for determining profitability satisfactorily; however, the net present worth (NPW) is the one most companies use since it has none of the disadvantages of other methods and treats the time value of money and its effect on project profitability properly. The net present worth is the algebraic sum of the discounted values of the cash flows each year during the life of a project [7].

In the net present worth method, an arbitrary time frame, i.e., time zero, is selected as the basis of calculation. Time zero, the present time, may occur when the first funds are spent on the project or alternatively when project start-up commences. If all projects are considered using the same basis, it makes no difference which time zero is used since the ultimate decision will be the same; only the dollar values will be different. Since consistency in the use of this method must be maintained, all projects must be considered on the same basis.

Figure 9.2, a time-net present worth diagram, may be used to discuss the steps in preparing the net present worth calculations. Lets assume that time zero is arbitrarily selected at start-up. Prior to time zero, expenditures are made for land, fixed capital investment, and working capital. Land is allocated instantaneously to a project sometime before purchase and construction of the plant equipment.

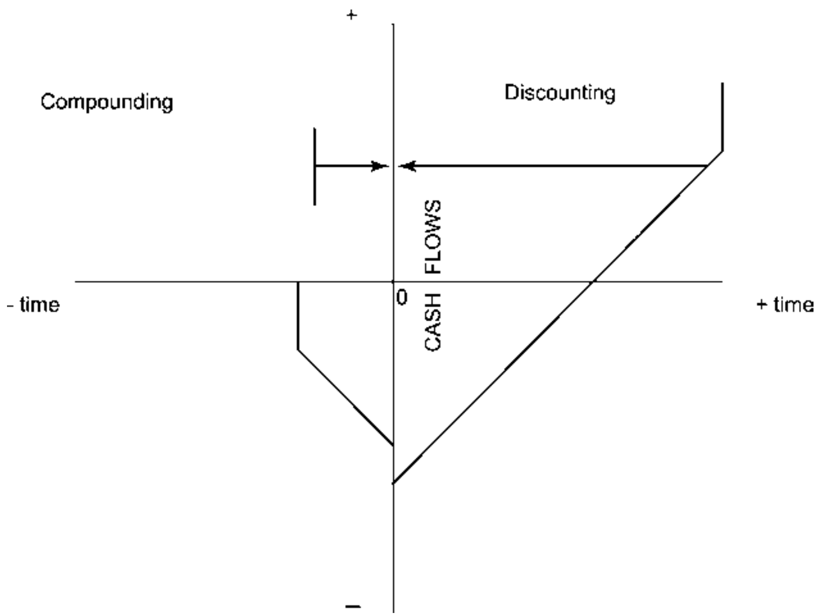

FIGURE 9.2 Cash flow diagram with time zero at start-up.

The fixed capital investment is purchased and installed over a period of time prior to start-up. For the purpose of this discussion, it will be assume that the construction occurs uniformly over a period of time. Both land and the fixed capital investment are compounded to time zero using the appropriate compounding factors. At time zero, working capital is charged into the project. At this point, there has been no revenue generated and from the figure, the net present worth is negative. Once the project start-up commences, further expenditures are necessary to bring the plant on stream that causes the present worth to become more negative, but at the same time some quality product may be produced and sold. As time proceeds, salable product in manufactured and the cash flows to the project are discounted back to time zero. In Figure 9.2, it is assumed that the cash flows uniformly over the life of the project. This is an ideal model but will suffice to explain the present worth method. The process continues for the life of the project, and at the end land and working capital are recovered instantaneously (capital recovery). One might consider that the land and working capital were "loaned" to the project by the company. In the above description, the present worths of all cash inflows are calculated as are the present worths of all investment items. The difference between these present worths is the net present worth of the project. In equation form,

$$\text{Net present worth (NPW)} = \text{present worth of all cash inflow} \\ -\text{present worth of all investment items} \tag{9.5}$$

If the net present worth is positive, the project will earn more than the interest (discount) rate used in the calculations. If the NPW is negative, then the project earns less than that rate.

When this method is applied to two or more alternative cases, the project with the higher NPW will produce a greater future worth to a company and, therefore, is preferred. Caution must be exercised that projects to be compared have equal lives or that lives can be adjusted to a common time base. Humphreys [8] describes how projects of different lives may be made equivalent for comparison purposes. In Chapter 12, this topic is considered further.

Management sets the interest (discount) rate for projects based upon the cost of capital and the project risk, as was discussed earlier in this chapter. The calculations may be made using discrete or continuous interest. If discrete interest is used, the cash flows may be discounted to the beginning of a year, end of a year, or at mid-year depending on company policy. The justification for using continuous interest is that all cash flows are assumed to occur continuously, and it is assumed that all cash inflows are continuously reinvested. As long as a basis is established for making these calculations, all projects should be compared on

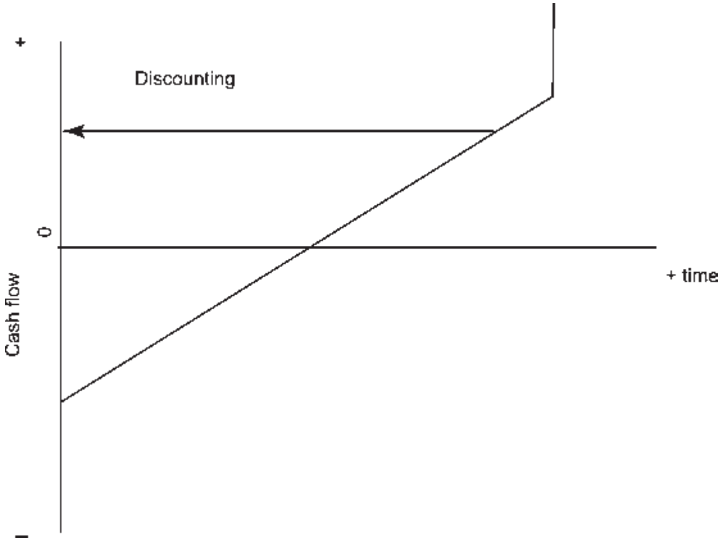

FIGURE 9.3 Cash flow diagram with time zero when first funds spent.

the same basis. Example 9.1 presented later in this chapter illustrates how this method is used for a hypothetical project (Figs. 9.3 and 9.4).

The advantages of this method are that the timing of all cash flows and capital recovery at the end of a project are considered properly. The major disadvantage is that the capital investment is hidden in the calculations and needs to be stated clearly in any report of the results. In order to rank projects using the NPW method, an indexing method involving the NPW and the investment is developed and will be discussed in Section 9.4.1.6.

9.4.1.6 Net Present Worth Index (NPWI)

The NPWI method is also known as the *profitability index*. The index is the ratio of the present value of the after-tax cash inflows to the present value of the cash outflows or capital items. An index greater than 1 indicates that a project has a yield greater than the discount (interest) rate. When more than one project is considered, that project with the highest net present worth index is to be preferred, provided it is greater than 1.

9.4.1.7 Internal Rate of Return

The internal rate of return (IRR) is the interest rate that will make the present worth of the cash proceeds expected from an investment equal to the present

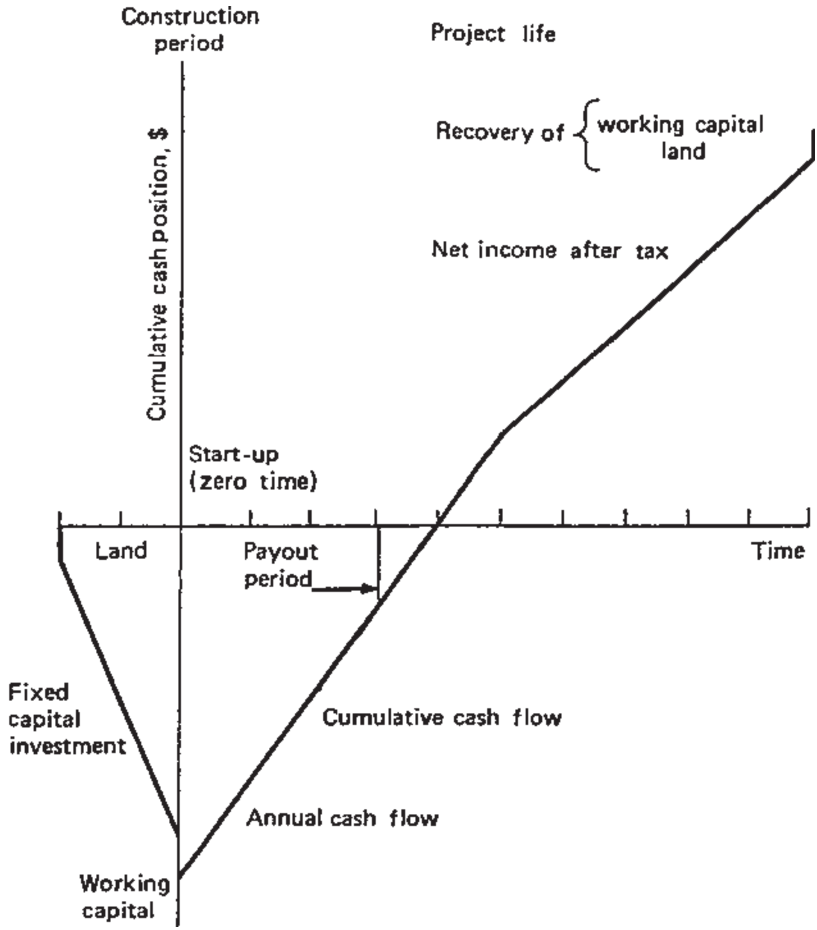

FIGURE 9.4 Cumulative cash position plot, showing payout period at 0% interest.

worth of the required cash outlays required by the investment [9]. Therefore, it is discount rate that results when the net present worth is equal to zero. The internal rate of return is also known as the *discounted cash flow rate of return*.

In principle, the technique is similar to the NPW method. In the latter method, the discount rate is set by management based upon factors listed in Table 9.1, and the NPW is calculated. However, in the IRR method, the result is the interest rate that will produce an NPW of zero. This is a trial-and-error calculation and commercial computer programs are available to solve for the result. The result obtained is then compared with management's criteria for funding a project at the level of risk.

There are many disadvantages to using this method and they will be discussed in Section 9.4.1.9.

9.4.1.8 Other Measures of Profitability

Ward [2,3] discussed several variations on the NPW and IRR methods such as the *overall rate of return* (ORR) and the *net rate of return* (NRR).

The overall rate of return calculation starts by discounting the investment cash flows to the present and the revenues to the end of the project. An assumed discount rate is used in both calculations. The ORR is then computed in another encounting calculation that relates the discounted cash flow to the encounted revenue flow at an assumed discount rate.

The net rate of return (NRR) is defined by the following equation:

$$\text{NRR} = \left\{ \frac{\text{net present worth}}{(\text{discounted investment})(\text{project life})} \right\} \times 100 \tag{9.6}$$

Ward stated that the cost of capital has been taken care of in the NPW calculation so that the NRR is then a true net return rate.

9.4.1.9 The NPW–IRR Controversy

For many years, industry used the internal rate of return to measure profitability, but this method has inherent disadvantages when compared to the net present worth method. Many critical articles continue to appear in the literature. In this section, the major points in the controversy will be presented. For more detailed information, it is recommended that the reader consult Weaver [10], Winston [7], Ruegg [11], Bingham [12], and Ward [2,3].

The main limitations of the IRR method are:

- *Multiple rates for return*. Unusual cash flow forecasts can lead to more than one answer for the IRR
- *Reinvestment rate*. Inherent in the IRR calculation is the assumption that funds received during the project can immediately be reinvested at the same interest rate as the IRR. This is not always possible. The higher the return, the lower the probability that additional projects are available for reinvestment at that rate.
- *Comparison of two are more projects*. When comparing two or more mutually exclusive projects will not necessarily lead to the correct choice [9]. One has to select the best from the pair and compare it with another project, and thus by elimination the best project will be selected.
- *Size of the investment*. The IRR method can't differentiate between differences in the size of the investment.

- *Timing of cash flows*. Because of the uncertainty in forecasts, the nature of the cash flow and timing, there is the possibility that the discounted value of the net cash flows can equal zero at more than one interest rate. This causes problems in analyzing the meaning of the results.

The net present worth method is superior to the IRR method since it has none of the above problems. The NPW measures test when a specific investment meets, beats, or falls short of the return that one should obtain for a proposed venture. As stated earlier, if the NPW is positive, the project earns more than the interest (discount) rate. If the NPW is negative, it earns less. An NPW of zero means the investment produces an interest rate equal to the one used in the calculation. A rule of thumb is that the best investment is the one with the higher or highest NPW.

9.4.1.10 New Economy Measures

A firm's investment portfolio consists of many projects, both ongoing and new. Each project contributes to the company's profitability. From the late 1980s to the present, a "new" management concept, *economic value added* (EVA) has been adopted by numerous companies. Far from being new, EVA has been one of the long-standing pillars of financial theory. EVA is an important financial tool in addition to the traditional profitability measures. It is the after-tax net operating profit minus the cost of capital. Until a company posts a profit greater than the cost of capital, it is not making money for the owners, no matter how good the accounting looks. It is a company's wealth predictor [13].

In periods when the economy is strong and sales are growing, the bottom line, the net profit after taxes, still might not show good results. EVA analysis helps firms identify waste in operating expenses and in the use of capital. In other words, EVA is an indicator of how efficient management is at turning investors' money, namely capital, into profits [14]. It relates the principles in this chapter to those of the financial concepts in Chapter 3.

Another indicator of company is the *market value added* (MVA), which is the difference between what the capital investors put into a company and the money taken out. Good EVA performance builds MVA and is a gain for investors.

Diversified chemical companies in the late 1980s and early 1990s had failed to earn the cost of capital [15]. As of the late 1990s, few chemical companies have implemented EVA, but it is expected that this will change as the concept is more universally used by industry.

9.4.2 Qualitative Measures

Authors of texts on engineering economics would have the reader believe that quantitative financial criteria are the sole basis for investment decisions. This author's experience has shown that other factors enter into or perhaps control the decision-making process. There are instances in which major investment decisions based upon intangible or qualitative factors oppose the results of a quantitative study; therefore, both must be considered.

9.4.2.1 Intangible Factors

The results of a study of intangible investment criteria was conducted by Perry, Scott, and Bird [16], based upon responses from selected companies in the Fortune 500 list. The factors most often listed by the management executives will be discussed in this section.

9.4.2.1.1 Employee Morale. This factor is directly related to efficiency of operation. If an employee does not consider that working conditions are favorable, this will surely affect not only the amount of material produced but also its quality. Quality circles and other employee input groups have done much to improve workers' interests in their immediate jobs, giving them an opportunity to make constructive comments about the working environment. Management, in turn, has an obligation to listen, digest and, if possible, put into action employees' suggestions. Employees who feel that they "belong" to an organization will take more interest in it, be more content, and display high morale.

9.4.2.1.2 Employee Safety. Safety should be regarded as a joint venture between labor and management. Unsafe conditions cause accidents to personnel and equipment that result in increased costs for capital equipment, losses of production, utilities, and raw materials, as well as associated increased insurance expenses. Refineries, chemical plants, steel mills, paper mills in recent years have improved their safety record but constant vigil must be exercised. A plant must be designed and constructed with safety considerations early in the planning stages with the result in operating cost savings and increased employee morale.

9.4.2.1.3 Environmental Constraints. Increasingly tight restrictions on water, air, land, and noise pollution have forced management to reconsider existing operations, as well as future investments. There are daily examples of plants being under scrutiny for not complying with environmental standards. Like the two preceding intangibles, it is impossible to determine dollar effects, that is, cost versus benefits. While it may be a relatively simple matter to calculate the capital requirements, operating expenses, and change in cash flow to meet environmental standards, the benefits are continued operation and recognition that the company is a good citizen. A return is meaningless but the options are clear.

9.4.2.1.4 Legal Constraints. Local, state, and federal laws must be considered whenever an investment decision is made. A proposed venture that infringes upon statutes is doomed. Fines or large capital expenditures to avoid legal action can quantitatively affect the firm's finances. It is therefore essential to review existing laws and seek advice on locating a plant. Zoning ordinances, potential antitrust actions, and potential licensing or patent infringements are examples. Most firms want to avoid litigation as such proceedings are long, costly, and damage a firm's image.

9.4.2.1.5 Product Liability. In recent years this intangible has received considerable public attention. Consumer advocates and the public demand that a product, be it a pharmaceutical or a child's plastic toy, must be safe to use. Management must consider this intangible early in a project development stage. It would be a wise decision to forego the installation of a plant until there is a high probability that the product will meet safety requirements. Management must take a responsible posture with regard to this intangible.

9.4.2.1.6 Corporate Image. How a company is perceived by the public is an important factor in capital investment decisions. A poorly maintained plant is an eyesore to the community and indicates an indifference not only to the locale around the plant but also to the employees. General housekeeping within the plant and its immediate environs is indicative of the type of management.

Corporate image also is expressed in how much positive interest a company takes in community affairs. Social responsibility, such as corporate giving, sponsoring scholarships and programs that benefit society and the community contribute to a company's image. Corporate image is considered in any investment decision because capital expenditures are often required to maintain a good image. Like the other intangibles, it is difficult to calculate a return since a benefit cannot be assigned to such an expenditure.

9.4.2.1.7 Management Goals. This is a complex intangible because it involves not only the corporate goals but subjectively personal goals of individual managers. Although corporate goals were mentioned earlier in this chapter, it is advisable to point out that company growth and cash flow are two indicators of management effectiveness. They are important to the survival of a company.

Managers may make investment decisions on the basis of personal interests that may not enhance the well-being of the firm. On a personal level, managers may make decisions that influence job security or as part of "empire" building that gives them greater visibility within the company. These points promote personal gain. Although most organizations have checks and balances, it is doubtful that the personal aspect can be eliminated entirely.

9.4.2.2 Attempts to Quantify Intangible Factors

Numerous methods have been proposed in an attempt to present multiple criteria in an explicit format. These criteria could include those factors that might be quantified, such as price, payout period, NPW, but also might include safety, environmental criteria, and company image. In the 1960s and 1970s, there was a spate of activity attempting to develop an ordinal or ranking system. Such methods were complex and often led to subjective judgments. Most of the methods forced the manager to assign weighting factors to each intangible factor and thus far have not been successful.

9.5 CONCLUDING COMMENTS

In this chapter, the current measures of profitability were presented. Where decision conflicts between methodologies occur, rules for resolving the conflicts were discussed. Consistency in the application of profitability measures is necessary to prevent incorrect decision being made. Only these measures involving the time value of money are recommended.

The author has been in company positions where he observed the strong influence of intangible factors upon the decision-making process. There are no formulas or cookbook methods for ordering these factors in a value judgment array. Perhaps in the future, a reliable methodology will be developed, but in the meantime, the mental exercise of attempting to prioritize intangibles may be worthy of consideration.

9.6 ILLUSTRATIVE PROBLEM

Example 9.1

Problem Statement:

Acme Chemicals, Inc. is a newly organized company that had formerly been a division of Triangle Petroleum Company. The petroleum company sold the division to a group of investors, some of whom were former employees of Triangle. The new dynamic aggressive management of Apex is seeking new ventures in the specialty and electronic chemicals business areas. In searching for new ventures, the manufacture of a liquid intermediate with potential use in the etching of metals appears to be attractive.

A process to manufacture this new chemical called "ETCHIT" was developed. A preliminary estimate of the fixed capital investment of $7,500,000 was obtained for a 20MM lb/yr plant capacity. It may be assumed that the fixed capital investment was purchased and installed uniformly over a 2-year period. Land valued at $200,000 was charged to the projected instantaneously two years prior to start-up. Working capital at 15% of the fixed capital investment was charged to the project instantaneously at time zero. Start-up expenses may be assumed to be 6% of the fixed capital investment uniformly spread over the first year of operation. In order to produce the chemical, a proprietary catalyst was licensed for a one-time charge of $150,000. For the purpose of this analysis, the cost is charged instantaneously 1 year prior to start-up.

The marketing department of Apex provided the following information for a 10-year project life.

Year	Sales, MM lb/yr	Selling price, \$/lb
1	13.0	0.50
2	17.5	0.48
3	20.0	0.46
4	22.0	0.46
5	25.0	0.47
6	25.5	0.48
7	23.0	0.49
8	21.5	0.43
9	19.0	0.42
10	16.0	0.40

Cash operating expenses for the 10-year period were estimated by the manufacturing group to be as follows:

Year	Cash operating expenses, \$lb
1	0.27
2	0.25
3	0.24
4	0.24
5	0.26
6	0.26
7	0.27
8	0.28
9	0.28
10	0.30

For operating expense estimation use 7-year straight-line depreciation, and for cash flow use the 7-year MACRS depreciation factors.

The company's after-tax cost of capital is 10.2% and the administration requires at least a 20% after-tax return for projects of this risk level.

For this proposed project, determine the following:

a. ROI
b. POP
c. Cumulative cash flow analysis and a cumulative cash position plot at 20% continuous interest

d. POP + interest
e. PW at 20% continuous interest
f. IRR

What do you recommend to management about this project. Substantiate your recommendation(s) with numerical results.

Solution:

a. The Total capital investment in:

Land	$200,000
Fixed capital investment	7,500,000
Working capital	1,125,000
Start-up expenses	450,000
Catalyst license	150,000
Total capital investment	$9,425,000

The definition of the ROI is annual net profit after taxes divided by the total capital investment expressed as a percentage. When the net profit varies from year to year, an average annual after-tax net profit may be used in the calculation.

$$\text{ROI} = \frac{\text{average annual net profit after taxes}}{\text{total capital investment}} \times 100$$

$$= \frac{\$20,803,00010}{\$9,425,0000} \times 100 = 22.2\%$$

Note: The average annual net profit after taxes is found in Table 9.3.

b. $$\text{Payout period (POP)} = \frac{\text{(fixed capital investment)}}{\text{(average annual after-tax cash flow)}}$$

$$= \frac{\$7,500,000}{\$28,402,0000/10} = 2.6\,\text{years}.$$

Note: The average annual after-tax cash flow is found in Table 9.3.

c. Cumulative cash flow analysis is found in Table 9.4, and the cumulative cash plot is shown in Figure 9.1 (p.225).

d. The payout period plus interest is found in Figure 9.1 and is 3.7 years. Sum all the capital items except the fixed capital investment. Where this value intersects the cumulative cash position line on Figure 9.1 is the payout period plus interest. (For information on the on the construction of a cash position plot, see Chap. 8.)

TABLE 9.3 Net Income and Cash Flow Analysis for Example 9.1

ITEM/Year	−2	−2 to −1	−1	−1 to 0	0	1	2	3	4	5	6	7	8	9	10	Total
Total capital investment:																
Land	−200															
Fixed capital investment		−3,750		−3,750												
Working capital					−1,125											
Start-up expense						−450										
Catalyst license			−150													
Income and operating data:																
Production, MM lb/yr						13	17.5	20	22	25	25.5	23	21.5	19	16	
Sales, $M						6,500	8,400	9,200	10,120	11,750	12,240	11,270	9,245	7,980	6,400	
Cash operating expenses, $M						3,510	4,375	4,800	5,280	6,500	6,630	6,210	6,020	5,320	4,800	
Operating income, $M						2,990	4,025	4,400	4,840	5,250	5,610	5,061	3,225	2,660	1,600	
Depreciation, $M						535	1,072	1,072	1,072	1,071	1,071	1,071	535	0	0	
Net income before taxes, $M						2,455	2,953	3,328	3,768	4,179	4,539	3,990	2,690	2,660	1,600	
Federal income taxes, 35%						859	1,034	1,165	1,319	1,463	1,589	1,397	942	931	560	
Net income after taxes, $M						1,596	1,919	2,163	2,449	2,716	2,950	2,593	1,748	1,729	1,040	20,903
Depreciation, $M						535	1,072	1,072	1,072	1,071	1,071	1,071	535	0	0	
Cash flow, $M	−200	−3,750	−150	−3,750	−1,125	1,681	2,991	3,235	3,521	3,787	4,021	3,664	2,283	1,729	1,040	28,402
Cumulative cash flow, $M	−200	−3,950	−4,100	−7,850	−8,975	−7,294	−4,303	−1,068	2,453	6,240	10,261	13,925	16,208	17,937	18,977	

Table 9.4 Cumulative Cash Position Table for Example 9.1

Time, yr	Cash flow, 0% interest	Cumulative cash flow, 0% interest	20% Interest factors	Present worth, 20% interest	Cumulative cash flow, 20% interest
−2	−200	−200	1.492	−298	−298
−2 to −1	−3,750	−3,950	[a]	[a]	[a]
−1	−150	−4,100	1.221	−183	−481
−1 to 0	−3,750	−7,850	[a]	−9,225	−9,706
0	−1,125	−8,975	1.000	−1,125	−10,831
1	1,681	−7,294	0.906	1,523	−9,306
2	2,991	−4,303	0.742	2,219	−7,089
3	3,235	−1,068	0.608	1,967	−5,122
4	3,521	2,453	0.497	1,750	−3,372
5	3,787	6,240	0.407	1,541	−1,831
6	4,021	10,261	0.333	1,339	−492
7	3,664	13,925	0.273	1,000	508
8	2,283	16,208	0.224	511	1,019
9	1,729	17,937	0.183	316	1,335
10	1,040	18,977	0.150	156	1,491
End 10	1,325	20,302	0.135	179	1,670

[a] Instead of splitting the time −2 to −1 and −1 to 0, a combined factor of −2 to 0 of 1.230 may be applied to the fixed capital investment of $7,500,000.

e. For the present worth at 20% continuous interest, see Table 9.5. When making these calculations, one must be careful in selecting the correct interest factors from Appendix C. This table is divided into six sections depending on how the cash flows. Sections A and B are for compounding instantaneously or uniformly, respectively. Sections C through F are for discounting. In this problem, section C is for instantaneous discounting, and section D is for uniform discounting in each individual year. By carefully reading the table and analyzing how the cash flows, the proper factors may be obtained.

This project has a positive net present worth at 20% continuous interest of $1,670,000, which indicates the project will earn more than 20%, interest; therefore it exceeds management's requirement for projects of this risk level.

f. The data for the present worth calculations are found in Table 9.5. The resulting return is found by interpolation to be 23.3%. Although the NPW is $1,670,000, the POP + interest is greater than the 3 years required by management. This project therefore meets one requirement but not both, so it will probably will be rejected for funding at this time. It is suggested that the marketing data and the manufacturing expenses be reviewed to determine if these

TABLE 9.5 Present Worth Calculation for Example 9.1

Time	Cash flow	20% Interest	Present worth, 20% interest	25% Interest	Present worth, 25% interest
2 years before	−200	1.492	−298	1.649	−330
2 yr before to 0	−7,500	1.23	−9,225	1.297	−9,728
1 yr before	−150	1.221	−183	1.284	−193
0	−1,125	1	−1,125	1	−1,125
1	1,681	0.906	1,523	0.885	1,488
2	2,991	0.742	2,219	0.689	2,061
3	3,235	0.608	1,967	0.537	1,737
4	3,521	0.497	1,750	0.418	1,472
5	3,787	0.407	1,541	0.326	1,235
6	4,021	0.333	1,339	0.254	1,021
7	3,664	0.273	1,000	0.197	722
8	2,283	0.224	511	0.154	352
9	1,729	0.183	316	0.120	207
10	1,040	0.150	156	0.093	97
End 10	1,325	0.135	179	0.083	109
NET PRESENT WORTH			1,670		−875

$\text{IRR} = (20) + (5)(1,670)/[(1,670)/(1,670) - (-875)] = 23.3\%$

data are realistic; if they are to be revised, then another economic analysis should be performed. Management will have to make the decision regarding whether another analysis is appropriate at this time.

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PROBLEMS

9.1 You are employed in an economic analysis and planning section of a small specialty chemical company and are asked to evaluate the following proposed project:

Fixed capital investment	\$3,600,000
Plant capacity	5,000,000 lb/yr
Construction period	One year beginning January 2004
Land	\$100,000
Working capital	\$300,000
Project life	10 years
Depreciation life	7 years, straight-line
Potential sales	4,000,000 lb/yr in 2004, increasing at 10% per year for each year of the project life
Selling price	\$0.80/lb in the first 2 years, increasing at 3% per year for the next 5 years and then decreasing by by 5% per year for the last 3 years
Cash operating expenses	\$0.25/lb in 2004, increasing at 5% per year for the first 5 years and then increasing at 3% per year the for for the final 5 years
Income tax rate	35%

a. Prepare a cumulative cash position plot.
b. Calculate the payout period without interest.
c. What is the internal rate of return?
d. In today's economy, is this project likely to be funded? Support your answer with numerical justifications.

9.2 Your company is considering the installation of a small inert gas generator to blanket reactions with an unreactive gas. It is possible to lease or purchase the equipment.

For the purchase case:

Fixed capital investment	$1,000,000
Land	100,000
Working capital	100,000

The operating income for this venture is expected to $600,000 per year. The equipment will be purchased and installed over a 2-year period to start-up of the facility. Depreciation on the capital equipment is based on 7-year straight-line. The project life is expected to be 10 years at which time the plant will be shut down. Net proceeds for dismantling and selling the equipment is estimated to be $50,000 before taxes.

For the lease case:

In order to lease the equipment, a yearly lease charge of $150,000 is required. This is in addition to the operating expenses in the purchase case. All other data are the same as in the purchase case.

The company requires a minimum return of 25% after taxes and a payout period of not more than 3 years to justify capital expenditures at this stage of evaluation. Your supervisor has asked you to calculate the following for both cases:

a. Total capital investment
b. POP
c. NPW@25%
d. What is your recommendation to management? Be sure to justify your decision with numerical values. (*Note*: Be careful when applying profitability measures to this problem).

9.3 Albrecht, Inc. manufactures a diverse line of specialty products from pharmaceuticals to health care materials. An executive committee is scheduled to meet 3 days from now. At that time they will be considering new ventures for the next year's budget. Your immediate supervisor has asked you to prepare the necessary information for both products listed below. Currently, the company uses the net present worth and the payout period with interest methods for projects at this stage of consideration. The company's cost of capital is 11.2%, so the net present worth calculation is to be based on 25% continuous interest. A 3-year payout period is the maximum that the committee will consider for the project. Albrecht qualifies for a 7-year MACRS method of depreciation accounting. The expected life of the project is 10 years. A 35% federal income tax rate is in effect. Capital recovery at the end of the project will include only land and working capital.

No-Snooze Decongestant

Year	Sales, M lb/yr	Selling price, $/lb	Cash operating expenses, $/lb
1	15,000	0.38	0.18
2	17,000	0.40	0.17
3	19,000	0.41	0.16
4	20,000	0.41	0.16
5	22,000	0.42	0.16
6	20,000	0.37	0.18
7	18,000	0.37	0.18
8	17,000	0.35	0.19
9	15,000	0.33	0.19
10	12,000	0.32	0.20

Fixed capital investment = $6,000,000
Land = 100,000
Working capital = 1,000,000

The equipment is to be purchased and installed over a period of $1\frac{1}{2}$ years prior to start-up.

Vibrahair Growth Stimulant

Year	Sales, M lb/yr	Selling price, $/lb	Cash operating expenses, $/lb
1	6,000	0.86	0.32
2	6,500	0.87	0.31
3	7,000	0.87	0.30
4	8,000	0.89	0.32
5	10,000	0.90	0.33
6	11,000	0.88	0.35
7	10,000	0.87	0.35
8	9,000	0.86	0.36
9	7,000	0.86	0.36
10	5,500	0.85	0.35

Fixed capital investment = $10,000,000
Land = 100,000
Working capital = 2,000,000

The equipment is to be purchased and installed over a 2-year period prior to start-up.

Which project would you recommend to management and why? Be sure to justify your results.

10

Sensitivity and Uncertainty Analysis

In Chapter 9, it was assumed that all values of costs, expenses, revenues, economic lives, and acceptable rates of return were known with certainty. This was done to focus on the methodology of estimating profitability and ultimately decision making. This high degree of confidence is referred to as *analysis under assumed certainty*; therefore, decisions based on this analysis are *decisions under certainty* [1].

Whenever a project is proposed, market surveys, market price projections, market share, and ultimately revenues are estimated. Capital costs and operating expenses are estimated as in Chapters 4 and 5, respectively. From these data, profitability of a project is calculated. All these estimates are based on what is believed to be the best available data. Errors inherent in all estimates, and the effect of these errors on profitability, will be considered in this chapter.

Sensitivity analysis is used to determine the effect of technical and economic parameters on the profitability of a project. The potential error of each parametric variable is examined, as well as its effect on the project. Questions such as "What if the capital investment is 15% greater than the estimated value?" or "What if the market is 20% less than the best estimate?" can be resolved by determining the effect of percentage changes in these variables on profitability and will be addressed subsequently in this chapter.

In uncertainty analysis, probabilistic distributions are assigned to each variable to be considered and a methodology is used to determine the resulting profitability measure expressed as either the "probability of achieving more than or at least a specified return on investment or a net present worth."

Sensitivity analysis is easy to use but the results have definite limitations. Uncertainty analysis requires much more sophistication on the part of the person performing the analysis. The executives who will use the results need to be educated in the method used and the meaning of the results; otherwise wrong decisions could be made concerning the fate of a future venture.

10.1 SENSITIVITY ANALYSIS

Sensitivity analysis is concerned with the extent of change in a cost analysis resulting from variations in one or more elements of a cost study. It shows the influence of possible changes of significant variables upon profitability. From this analysis, those variables that have a critical effect are identified. Especially important are those variables that might alter a decision when only small changes occur.

The ordinary practice is to make a number of computations of profitability, varying each significant cost element over the most likely range of values. This process can be tedious unless a computer is used. A visual aid, e.g., a plot or graph, depicts the most sensitive variables in a cost study. Managers prefer a graphic illustration rather than tables of numerical values because significant results can be overlooked in tables.

10.1.1 Break-Even Analysis

Break-even analysis is a simple form of sensitivity analysis, and is a useful concept that can be of value to managers when a certain level of uncertainty exists. Break-even refers to the point at which operations break even, where income just equals expenses (see Fig. 10.1 for a typical break-even plot). It is widely used for financial studies because it is simple and extracts useful insights from a modest amount of data. In Figure 10.1, the revenue or expenses are plotted as a function of the production rate or production capacity. The production capacity at which the revenue line intersects the total expense line is the break-even point. Management, of course, wants to do better than break even; therefore, the break-even plots may be used as a profit planning tool, for product pricing, production capacity, incremental costing of equipment, etc. The shutdown point occurs where the revenue line crosses the fixed expense line. This says that if a company cannot make fixed expenses, it should shut down operations. For a short period of time a company may operate between the break-even point and the shutdown point to maintain customers.

Break-even analysis can be used to show, for example, the effect of various selling prices of a product on profit. Figure 10.2 is such a plot. Other possible uses may be to study fixed and variable expenses and production level scenarios.

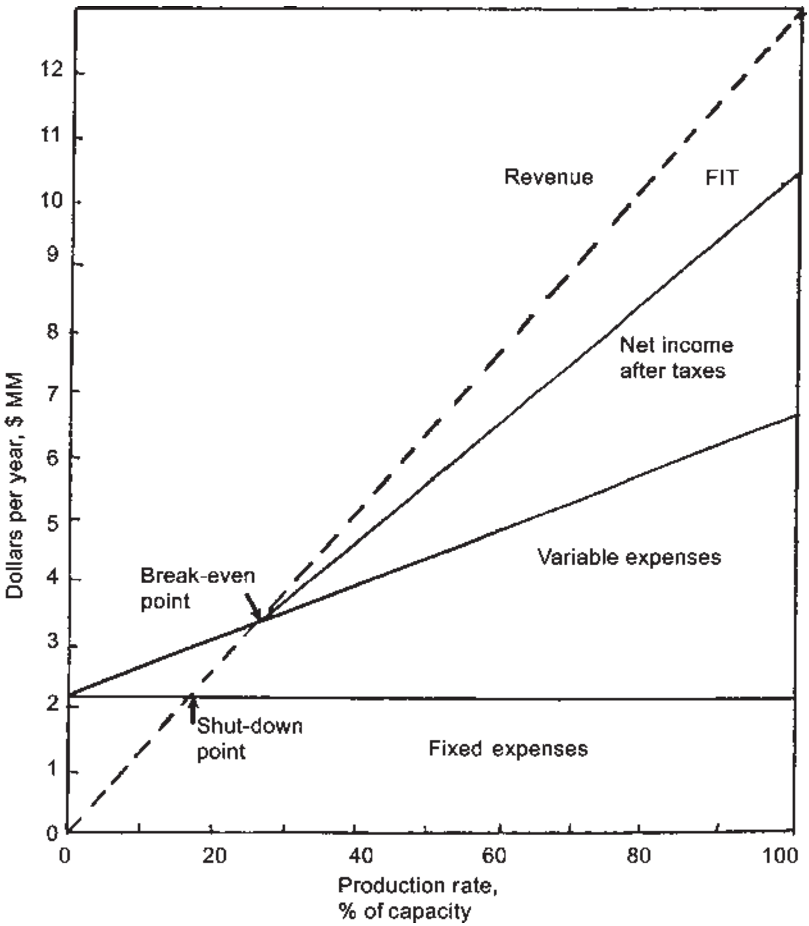

FIGURE 10.1 Typical break-even plot.

The slopes at any given point of the total expense and total revenue curves measure the marginal cost (MC) and the marginal revenue (MR), respectively. A line drawn from the origin of a break-even plot to any point on the revenue curve will have a slope equal to the average selling price (total $/units sold). A line drawn from the origin to any point on the expense curve will have a slope equal to the average unit expense (total $/unit produced). If a vertical line intersects both curves at points where the slopes of the two curves are equal, MR equals MC and profits are at a maximum.

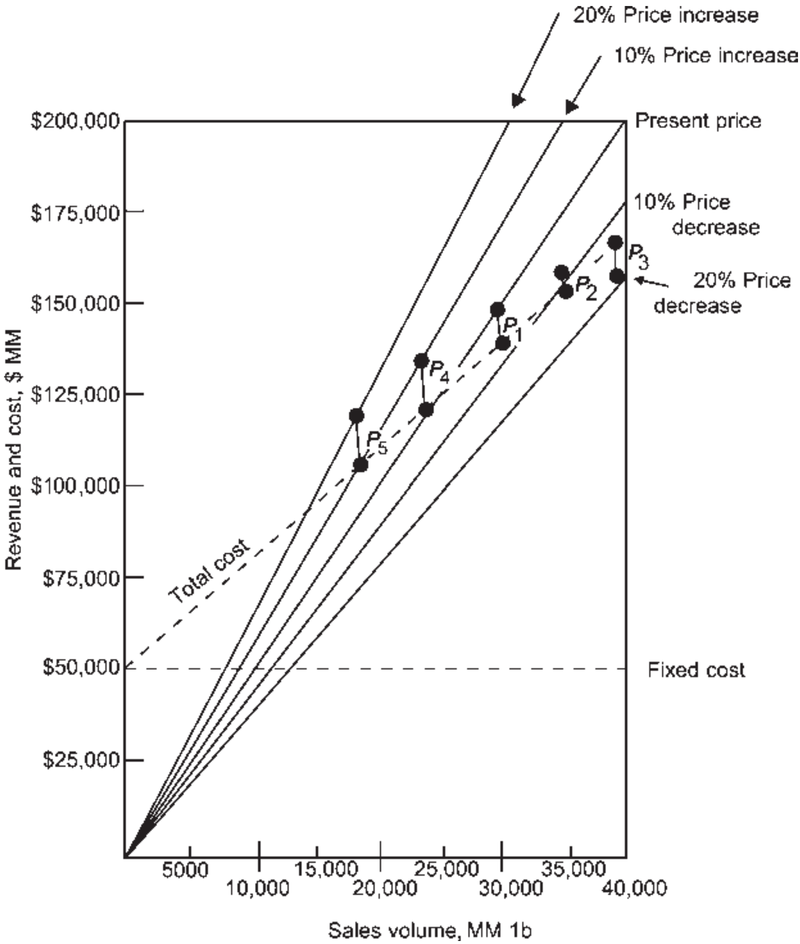

FIGURE 10.2 Break-even plot for pricing alternatives.

In Figures 10.1 and 10.2, straight lines represent revenue and expenses, whereas in actual practice, these might be curves. Figure 10.3 is an example of a more realistic break-even plot.

10.1.2 The Strauss Plot

Richard Strauss [2] developed a method for plotting the results of a sensitivity analysis in which the ordinate is the measure of profitability and the abscissa is

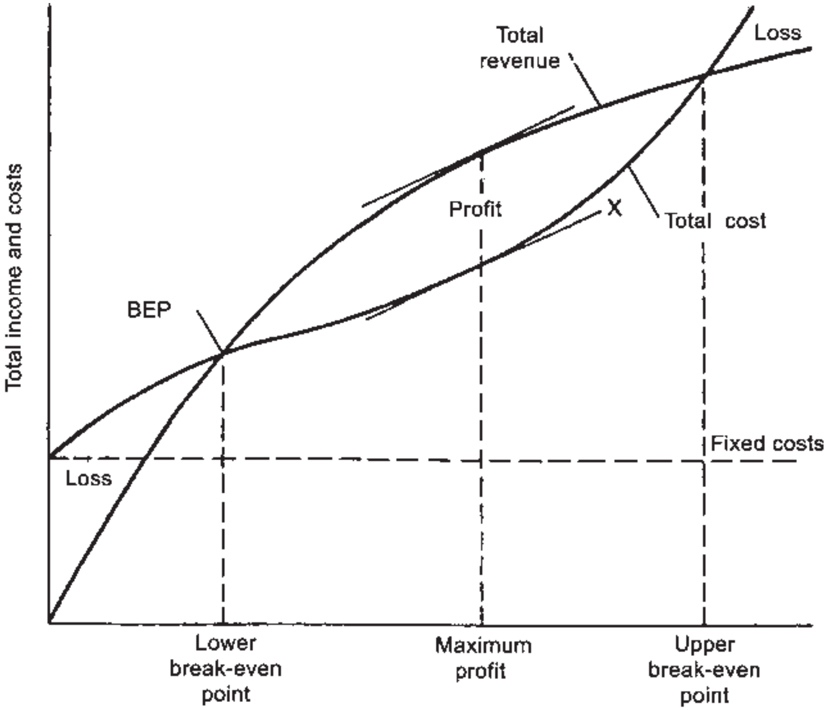

FIGURE 10.3 A realistic break-even plot.

the change in a variable greater or less than the base case. Where the abscissa crosses the ordinate is the base case value of the return, net present worth, net annual worth, etc. (see Fig. 10.4). This plot is also known as the "spider" plot due to its shape.

The slope of the line on this plot is the degree of change in the profitability resulting from a percentage change in a variable such as selling price or investment. The length of the line represents the sensitivity of the variable and its degree of uncertainty. The plot has been designed so that positive slopes are associated with variable related to income like selling price, sales volume, yields, market share. Negative slopes are related to cost or expense items such as investment, fixed and variable expenses.

In preparing a sensitivity plot, it is advisable to have the base case on a spreadsheet. Then one can determine the effect on profitability by varying the items in the study. One should be aware that variables, such as sales volume are reflected in operating expenses as raw material requirements, general

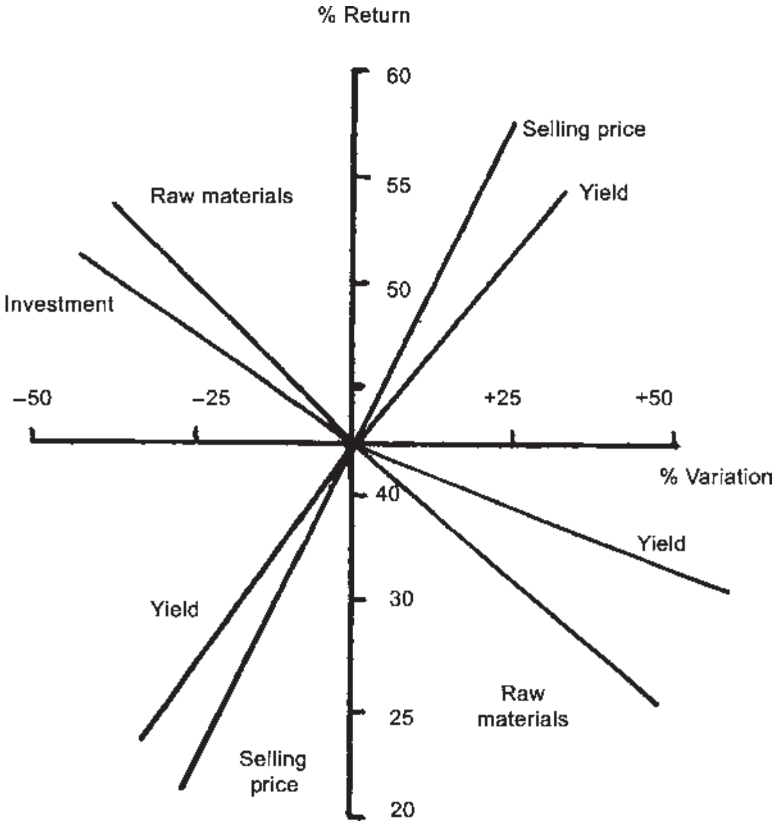

FIGURE 10.4 A typical Strauss plot.

overhead expenses, etc. Numerous scenarios may be prepared from the basic spreadsheet. A plot then may be developed from the spreadsheet results. A sensitivity analysis of the purchase of wire-line trucks and the resulting sales scenarios for a petroleum production application are found in Table 10.1 and Figure 10.5.

10.1.3 Relative Profitability Plot

Agarwal and Klumpar [3] developed a method of graphically presenting the results of a sensitivity study. The first step is to solve a base case to determine the profitability. Each variable's affect on profitability is calculated and indexed to the same variable and the profitability of the base case. Figure 10.6 is an example

TABLE 10.1 Results of Sensitivity Analysis—Wire-Line Trucks[a]

Variable	% Change	Decrease in DCFROR percentage points
Sales volume	+ 10	+ 2.4
	− 10	− 2.6
Sales price	+ 10	+ 10.2
	− 10	− 10.0
Capital investment	+ 10	− 3.7
	− 10	+ 3.7

[a] If decision is delayed 1 year, there will be a 6.3% decrease in the DCFROR. Base Case DCFROR = 28.2%.

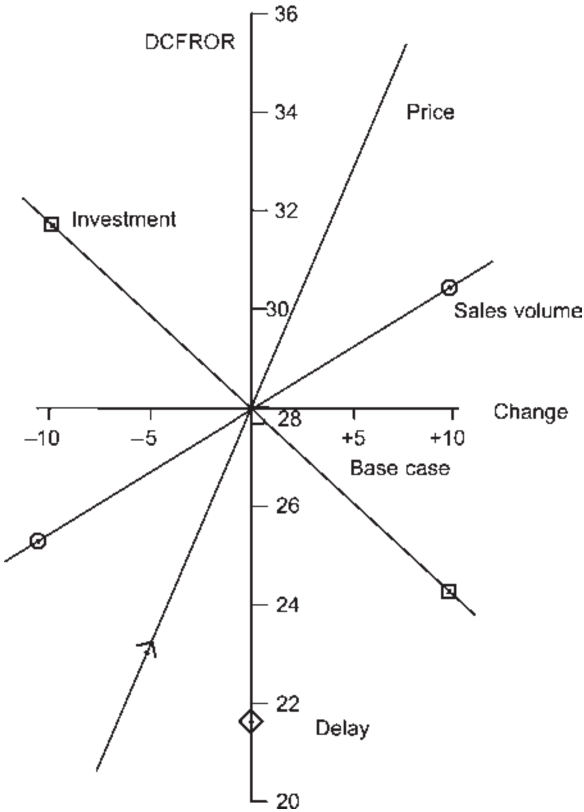

FIGURE 10.5 Strauss plot for wire-line truck study.

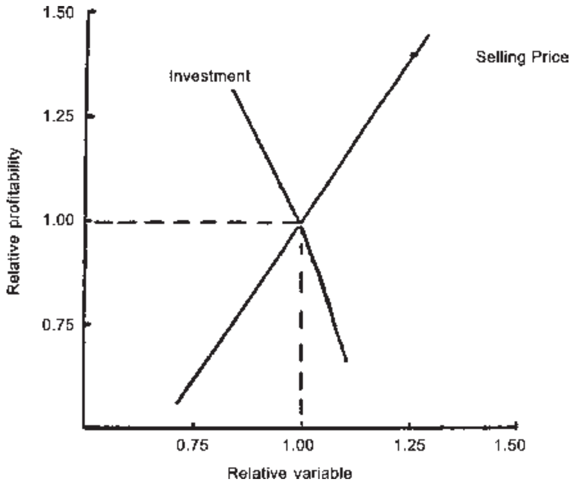

FIGURE 10.6 Relative profitability plot.

of a relative profitability plot. A 10% decrease in investment cost produces a 1.10 relative profitability or approximately a 10% increase. A 15% increase in selling price will yield a 25% in relative profitability.

The relative profitability plot clearly represents the affect of variables on the measure of profitability, but the method does require an additional step of indexing variables to a base case.

10.1.4 Tornado Plot

A popular graphical presentation of profitability is the so-called "tornado" or "Christmas tree" plot. This method derives its name from the shape of the resulting plot (see Fig. 10.7). A commercial computer program, @ Risk®, may be used to develop a tornado plot [4]. As in the previous methods, a base case must be solved first. Usually the net present worth method of expressing profitability is used. The base case is represented as a vertical line and variations in the elements that affect the study above and below the base case are solved and plotted. From Figure 10.7 the changes in sales volume, selling price, raw materials, capital investment, fixed and variable expenses are plotted. It is easy to observe that the sales volume and selling price have the greatest effect on the profitability of project. Note the shape of the resulting curve.

10.1.5 Discussion of Sensitivity Analyses

Although sensitivity analyses are easy to prepare and they yield some useful information for managers, there is a serious disadvantage to their use. Only one

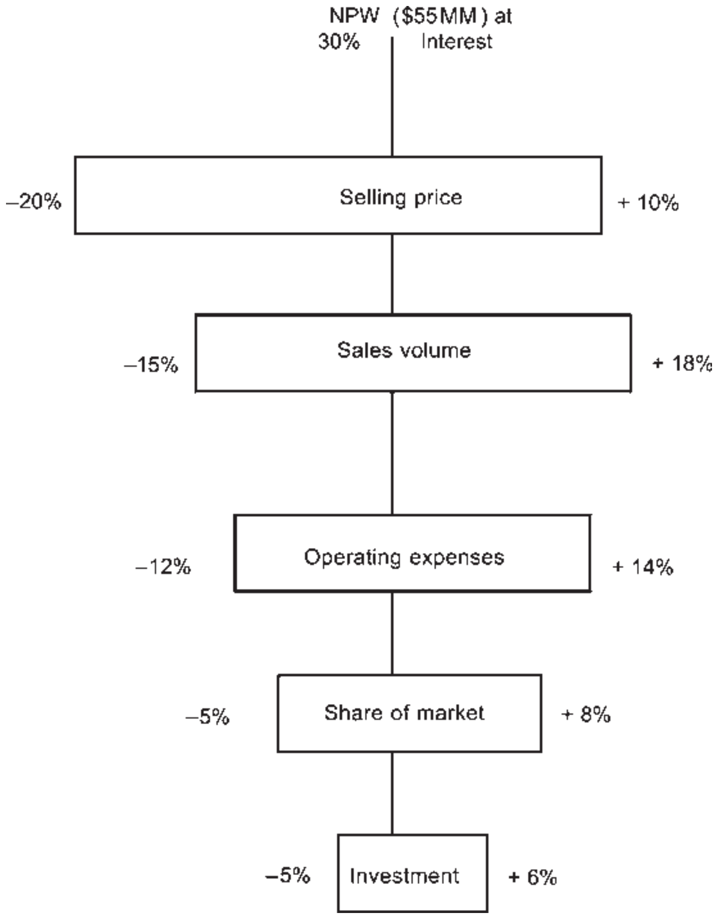

FIGURE 10.7 Typical tornado plot; interest shown at the base case.

variable at a time can be studied. Interrelated variables such as fixed capital investment, maintenance, and other investment items in operating expenses and their effect upon one another cannot be represented correctly. Synergistic effects particularly with respect to marketing variables such as sale volume, selling price, market share cannot be taken onto account.

10.2 UNCERTAINTY ANALYSIS

Investment in new ventures involves an element of risk no matter how well defined costs and markets may be. What makes the process of proceeding with a venture difficult is not the problem of projecting the profitability based upon a given set of assumptions; the problem lies in the assumptions made and their impact on profitability. Each assumption has its own degree of uncertainty, and when taken together these uncertainties can result in large potential errors. The objective of performing an uncertainty analysis is to obtain better, more reliable decisions.

There is a need to clarify two terms, risk and uncertainty. Uncertainty is exactly what the work means—not certain. An example is the price of crude oil. If crude oil price provides a basis for a project forecast, this subjective, geopolitical variable is indeed uncertain. Most input data to a study bear a degree of uncertainty. Risk seems to imply that the probability of achieving a specific outcome is known within certain confidence limits. Mortality rates, coin tosses, business interruptions, and fire insurance premiums all fall into this category of events.

Uncertainty analysis, if understood and performed with reasonable limits, can help the executive to sharpen his or her decisions by providing some measurement of risks. Uncertainty analyses can be performed with varying degrees of sophistication, but there is a trade-off of cost versus benefits obtained that must be carefully weighed.

10.2.1 Analysis of Risk

Up to this point, all values in calculations such as investment, operating expenses, cash flows have been treated as if they were correct or deterministic. From these data, decisions under certainty can be made. Economic analysis, however, requires the estimation of values sometime in the future. The farther into the future we venture, the greater the chance of error. Any number is selected with the best chance of being correct, but there is always the probability that the estimate will be above ore below the actual value. Although we prefer to deal with certainty, it seldom exists. To allow for a range of values around the average or best value, statistical decision theory is employed but that is beyond the scope of this text. Although important, only concepts useful in an applied manner will be treated.

10.2.2 Methods

10.2.2.1 Best Guess

One of the most common methods of evaluating projects involves the use of a single point, or best guess, estimate of a value for each important factor that might affect an investment decision. This is the starting point for any uncertainty analysis. Ross [5] wrote a classic article that still provides the foundation for the best guess, range, and Monte Carlo analysis.

What information can be gained from such an analysis? A project based upon the best guess may show a 20% return, but how is that figure to be interpreted? Does this mean the company can expect a 20% return? Perhaps that might be the case if each factor is exactly correct. What are the chances that the return might be better than 20%? What are the chances that money might be lost on this project? There is no way to answer these questions because the uncertainty of each factor has not been considered. This brings us to the range approach.

10.2.2.2 Range Approach

To remedy these shortcomings, a range of values may be tried. One estimates the most optimistic and the most pessimistic values for each factor. Returns are calculated for each scenario but the important questions posed in the previous section still remain unanswered. Ranges by themselves are not effective in all but the simplest cases. When combining a set of estimates based upon range values, the financial yardstick computed becomes very wide and is uninformative.

What is needed in the decision-making process is some way to quantify uncertainties in each assumption made, along with a calculation technique that will yield a curve for each return and its uncertainty. This approach will give the manager a far more reliable estimate of risks involved in a project investment and will provide a realistic basis for decisions. Therefore, this leads to the Monte Carlo technique.

10.2.2.3 Monte Carlo Method

From the previous methods in this chapter, it is apparent that they have shortcomings. In the Monte Carlo simulation, each variable is represented by a probability distribution model. This requires the gathering of enough data to develop a reasonable probability model. There are probability models of various shapes, for example, normal, Gaussian, Poisson, beta. Not all variables in the simulation follow the normal distribution curve. If that were the case, the final profitability model would also be a normal distribution. The normal distribution curve may be used to represent sales-related items, and it has been found that the beta distribution is a good model for capital investment estimates. Conceivably, several people might be involved in gathering the data and this could introduce further biases and inconsistencies.

Figure 10.8 is schematic of the Monte Carlo procedure [5]. In the figure, the steps are numbered, the first step being to determine the probability distribution for each of the variables in the simulation. The next step is by means of a random number generator, random values are selected from the probability models and a profitability measure for each set of values is

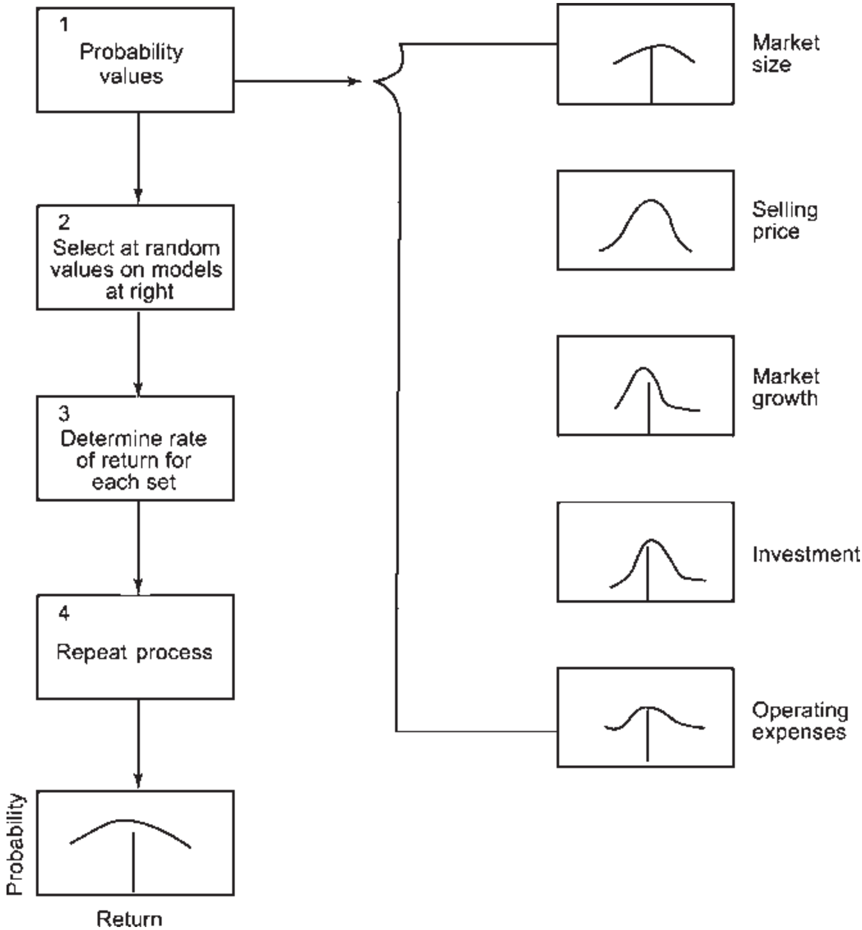

FIGURE 10.8 Schematic diagram of the Monte Carlo procedure. (From Ref. 5.)

determined. This process is repeated until a plot of return versus the probability of that return being achieved is obtained (see Fig. 10.9). In simple terms, this is the way the Monte Carlo simulation operates. After the analysis has been performed, the next task is to interpret the results. The management must clearly understand clearly what the results mean and the reliability of the results. Experience can only be obtained by performing uncertainty analyses. One or two attempts will not permit management to gain confidence in this decision-making tool [6]. The bottom line is: Are the stakes high enough and

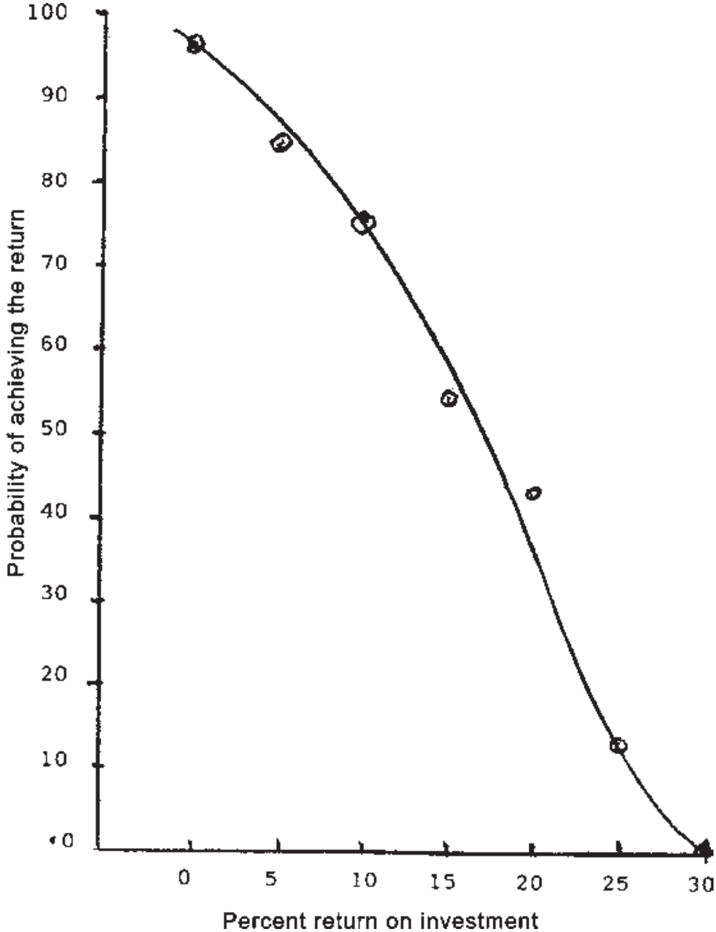

FIGURE 10.9 Typical uncertainty analysis plot.

the benefits great enough to spend the time and money on this sophisticated method?

Software companies market programs that permit the user to perform probability distribution models and Monte Carlo simulations, like SAS and @RISK.

An example of a simplified Monte Carlo simulation is found in the following example. This will be a three-point simulation of a capital investment study for capital investment. C. A. Miller [7] proposed a cost estimation method using the highest, lowest, and most likely values of various costs for the simulation.

Example 10.1

A company is involved in specialty chemical manufacturing. A new chemical is to be produced and flowsheets and an equipment list has been prepared for a pilot plant. A deterministic estimate of capital requirements based upon equipment cost estimates and best guesses for the factors in the Miller method [7] predicts a total investment of about \$7.8MM.

To use the probabilistic approach, low, best guess, and high values are specified for the input variables. The high and low values were selected based upon the estimator's judgment and from scatter diagrams that correlate the factored estimates with actual plant construction. The appropriate ranges for equipment costs, buildings, auxiliary equipment depend upon the reliability of the cost correlations, the precision of equipment sizing, and many other considerations. Figure 10.10 illustrates the input distribution for f_1 an overall contingency factor. Using computer graphics software, plotting output distribution curves for the estimated investment is possible. Simple

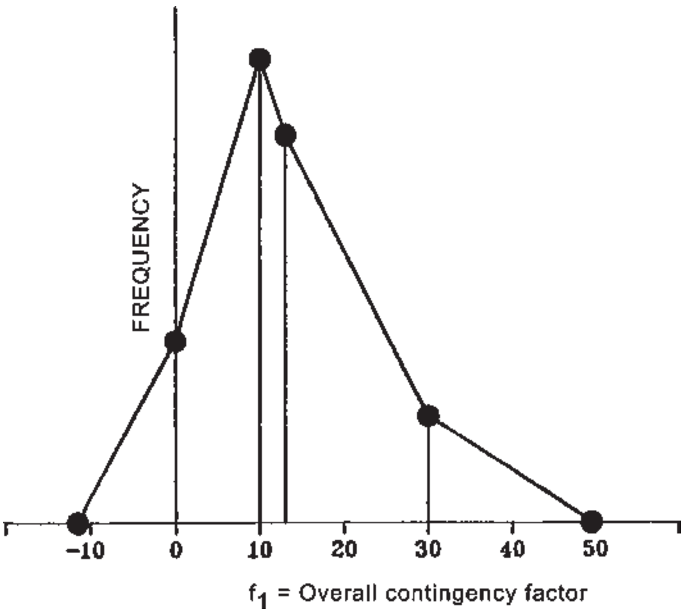

FIGURE 10.10 Six-point contingency distribution for Example 10.1.

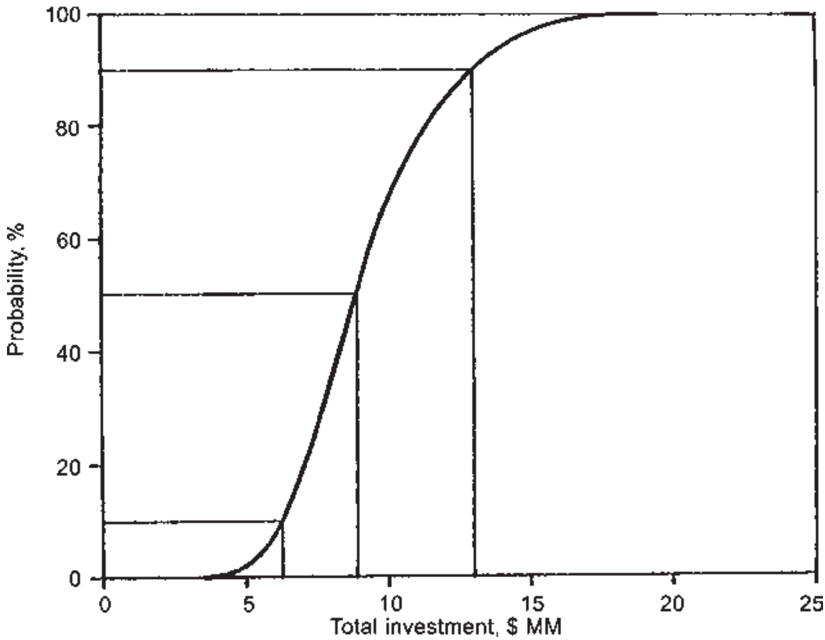

FIGURE 10.11 Cumulative probability for Example 10.1.

assumptions concerning the location of endpoint values and cumulative probability data are obtained from Monte Carlo trials.

Cumulative probability and probability distribution curves are shown in Figures 10.11 and 10.12. A number of quantitative statements can be made; for example, from Figure 10.12, the most probable value for the pilot plant investment is \$7.9MM and the mean value is \$8.8MM. The 10 and 90% probabilities are \$6.3MM and \$13.0MM, respectively, in Figure 10.11. Further, there is a 95% probability will be between \$5MM and \$15MM and a 35% probability that the investment will exceed \$10MM [8].

The advantages of probabilistic analysis for factored capital investment estimates are maximum utilization of available information and the ability to quantify uncertainty.

The incentives for performing an uncertainty analysis are greatest when the size of the investment is large and when the decision maker has no way to modify or reverse his or her decisions once construction has started. Judgment is not replaced by uncertainty analysis. The decision maker is,

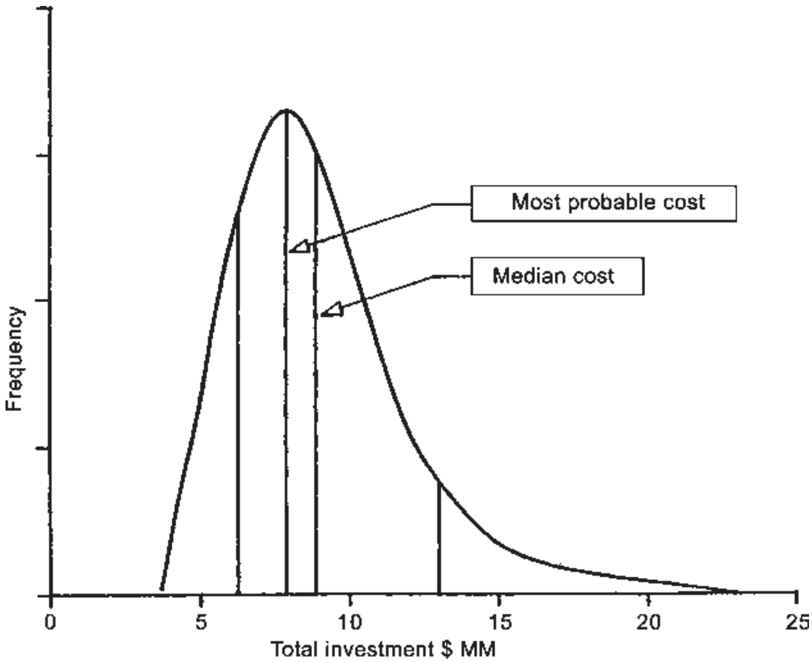

FIGURE 10.12 Probability distribution for Example 10.1.

however, supplied with a means to determine the probability of the risk the manager is taking.

One major problem is the understanding of how uncertainty analysis is to be used. There is an educational problem. People have to be trained in the development of probabilistic models and managers would have to learn to interpret the results. Uncertainty analysis is another tool to help managers become more effective in their role of guiding the fortunes of a company [5].

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PROBLEMS

10.1 Rustic Wood Products manufactures a line of children's toys. The following is an analysis of their accounting data:

Fixed costs	$90,000 per year
Variable costs	$5.00 per toy
Capacity	25,000 toys per year
Selling price	$18.50 per toy

a. Compute the break-even point in number of toys.
b. Find the number of toys the company must sell to show a profit of $40,000 per year.
c. At 75% of capacity, what is the fixed cost per toy? At that capacity what are the variable cost per toy?
d. What is the shutdown point?

10.2 A producer of electronic equipment is considering the installation of one of two types of manufacturing machinery. A long-term sales forecast indicates that the sales will not fall below 8200 units per year for the next 5 years, the expected life of each machine. Machine 1 will increase fixed costs by $20,000 per year but reduce variable costs by $6 per unit produced. Machine 2 will increase the fixed costs by $4000 per year but will reduce the variable costs by $4 per unit. Variable costs now amount to $20 per unit. At what point are you indifferent as to which machine to purchase? Which machine should be bought?

10.3 Plastics Projects, Inc. considered the manufacture of a plasticizer for potential customers in the plastics industry. At that time, a market survey was made but the results did not appear promising. The project was shelved.

Four years later, the company was acquired by Fusible Plastics Corporation, a large plastics manufacturer which wanted to integrate backwards. Since the acquisition, the surviving company has been reviewing the profitability of all projects of the former company. The marketing department of Fusible Plastics has prepared a 10-year market survey for the product:

Year	Potential sales, MM lb/yr	Estimated sales price, $/lb
1	20.0	0.52
2	20.5	0.52
3	21.0	0.51
4	22.0	0.50
5	23.0	0.50
6–10	25.0	0.48

Four years before the acquisition, the total fixed capital investment for the hydrocarbon was estimated to be \$5MM for a 20 MM lb/yr plant. The cost index to update this investment is 12% more over the 4-year period. Working capital may be taken at 15% of the total capital investment. For purpose of this evaluation, land may be ignored.

To manufacture the plasticizer, raw material *A* is required and it may be obtained from Plastics Products, Inc. plant. The requirements of this raw material are 5% of PP's capacity and the total capital investment of that plant is \$10MM.

The operating expenses for the proposed plasticizer plant have been estimated as follows:

Raw materials	\$0.12/lb product
Labor and supervision	\$0.05/lb product up through 21 MM lb/yr and \$0.04/lb product above this rate
Maintenance	6%/yr of the fixed capital investment
Utilities	\$0.03/lb product up through 21 MM b/yr and \$0.02/lb product above this rate
Other direct expenses	\$0.01/lb product
Depreciation	7-year straight-line
Other indirect expenses	\$0.01/lb product
General overhead expenses	\$0.02/lb product

At the screening stage, unless a proposed project yields a rate of return of 20% calculated by the DCF method, the venture will not be considered further. A federal income tax rate of 35% may be assumed. The fixed capital investment will be purchased and installed uniformly over a 2-year period prior to start-up that is expected to be from − 2 years to 0 before sales begin.

In order to conform to the standard evaluation procedure of Fusible Plastics, please prepare the following:

a. An estimate of the total capital requirements for a 25 MM lb/yr plant updating the costs to the start of year 1
b. An annual operating expense sheet using the data above and assuming that the potential sales in each year is manufactured and sold
c. An estimate of the profitability using the DCFROR Method
d. Prepare a Strauss sensitivity plot to determine the effect of the following variables on the return:
   1. $\pm$ 10%, $\pm$ 20% variation in sales price.
   2. $\pm$ 10%, $\pm$ 20% variation in sales volume.
   3. $\pm$ 5%, $\pm$ 15% variation in raw material expenses.
   4. $\pm$ 10%, $\pm$ 20% in fixed capital investment.
   5. Based upon your calculations, what recommendations would you make to management about this proposed venture?

10.4 Using the data in Problem 10.3, prepare an uncertainty analysis for the proposed venture. Probabilities for sales related items may be by normal distribution, capital investment by beta distribution, and raw material costs by Poisson distribution. What is the probability of achieving a 20% DCF return?

11

Feasibility Analysis

A feasibility analysis is prepared for the purpose of determining that a proposed investment meets the minimum requirements established by management. This analysis is in sufficient detail and quality to provide management with the facts necessary to make an investment decision. In this chapter, a detailed solution for a proposed investment will be presented to demonstrate the necessary steps in the preparation of a feasibility analysis. Personnel responsible for the development of this analysis should have an appreciation of the factors that affect the reliability and the expected accuracy of the information.

11.1 INFORMATION REQUIRED

The amount of information necessary to prepare a feasibility analysis will depend upon the intended use and management's desire. If the analysis is prepared to determine whether further research and/or pilot plant studies are necessary, then preliminary capital cost and operating expense estimates may be satisfactory with their inherent accuracies. However, if the objective is to request appropriation of funds, then more firm information is necessary to prepare definitive or detailed estimates.

The minimum information required to prepare a feasibility analysis is:

- Fixed capital investment estimate
- Total capital investment
- Total operating expense estimate

- Marketing information
- Cash flow analysis
- Estimate of profitability

In addition, management may also require break-even information, sensitivity and uncertainty analyses [1].

11.1.1 Fixed Capital Investment

In order to prepare an estimate of fixed capital, it is recommended that a form be developed and used as a checklist to be sure that no items have been omitted. A list including the purchased or delivered equipment costs be prepared as a first step. From this basic information, it is then a simple matter to calculate the fixed capital investment using the Lang, Hand, Wroth, or Brown methods as described in Chapter 4. These methods are used for study or preliminary estimates. If the Chilton method is to be used for a preliminary estimate, it is recommended that a form similar to Table 4.14 is recommended. The use of the Chilton form is illustrated in Example 11.1. For a definitive or detailed estimate, a code of accounts format similar to that in Chapter 4 is suggested (Table 4.21).

The forms used in a feasibility analysis should state clearly the dollar amounts and the date of each estimate. All forms are designed so that data for other cases of scenarios may be reported by extending the tables to the right of the page.

11.1.2 Total Capital Investment

The major items constituting the total capital investment are found in Table 11.1. Blank spaces have been included to allow the user the flexibility to include other capital items not listed in Table 11.1.

Table 11.2 may be used for estimating the working capital requirements using the inventory method described in Chapter 4. If the percentage method is used, the result may be inserted directly into Table 11.1.

11.1.3 Total Operating Expenses

The total operating expenses may be estimated using two forms, Tables 11.3 and 11.4. The first table is for the Total Product Expenses discussed in Chapter 5 and includes raw material expenses, by-product credits, direct and indirect expenses, as well as packaging, and shipping expenses. The bottom line in Table 11.3 is the expense involved in the manufacturing, packaging, and loading a product on a

TABLE 11.1 Total Capital Investment

Project Name:	
Project Number:	
By:	
Date:	
	$MM
Land	
Fixed capital	
Working Capital	
Off-site capital	
Allocated capital	
Start-up expenses	
Catalysts & chemicals	
Licenses, patents, and royalties	
Interest on borrowed funds	
____________________	
____________________	
Total capital investment	

TABLE 11.2 Working Capital (Inventory Method)

Project Name:	
Project Number:	
By:	
Date:	
	$MM
Raw material inventory	
Goods-in-process inventory	
Finished goods inventory	
Stores & supplies inventory	
Cash	
Accounts receivable	
Accounts payable	
____________________	
____________________	
Total working capital	

TABLE 11.3 Total Product Expense

Product:			Total annual sales:	
Rated capacity:			Location:	
Fixed capital investment:			Operating hours per year:	
Date:			By:	
Raw materials:				
Material	Unit	Annual amount	$/unit	$/year
Gross material expense:				
By-products:				
Material	Unit	Annual amount	$/unit	$/year
By-product credit:				
Net material expense:				
Direct expenses:	Unit	Annual	$/unit	$/year
Utilities:				
Steam, low pressure				
Steam, medium pressure				
Steam, high pressure				
Gross steam expenses:				
Steam credit:				
Net steam expenses				
Electricity				
Cooling water				
Fuel gas				
City water				
Total utilities:				
Labor:				
Person/shift				
Annual labor rate per person				
Labor expense:				

Table 11.3 (*Continued*)

Supervision:	
% of labor expense	
Payroll charges, fringe benefits, etc.:	
% of labor plus supervision	
Maintenance:	
% of fixed capital investment	
Maintenance expense:	
Supplies:	
% of labor	
Supplies expense:	
Laboratory charges:	
Hours per year	
Expense per hour	
Laboratory expense:	
Clothing and laundry:	
% of labor	
Clothing expense:	
Environmental and waste disposal expense:	
Tons/year	
Charge/ton	
Total environmental expense:	
Royalties (running):	
Other:	
Total direct expense:	
Total direct and net material expense:	
Indirect expenses	
Depreciation:	
% fixed capital investment	
Depreciation expense:	

(*Continued*)

Table 11.3 (*Continued*)

Plant-indirect expense:	
% of fixed capital investment	
Plant indirect expense:	
Total indirect expenses:	
Total manufacturing expense:	
Packaging and shipping expense:	
Annual production	
Expense per ton	
Packaging and shipping expense:	
TOTAL PRODUCT EXPENSE	

conveyance for delivery to the customer. To these expenses in Table 11.3, the general overhead expenses must be added. Table 11.4 may be used for this purpose but if the overhead expenses are calculated as a percentage of annual sales, Table 11.4 may not be needed and the result inserted in the summation of the total operating expenses at the appropriate place.

Table 11.4 General Overhead Expense

Project Name:
Project Number:
By:
Date:

	$MM
Sales expense	
Administration expense	
Research & engineering expense	
Finance	
Total general overhead expense	

TABLE 11.5 Marketing Data

Profit center:	Project title:	Appropriation No.:

Basis: Sales and market projections are not inflated (20_dollars)

	20_ Amount % Total	20_[b] Amount % Total
Total market:		
Units		
Average realistic price, \$/unit		
Value, \$M		
Estimated product sales (with AR[a]):		
Units		
Average realistic price, \$/unit		
Value, \$M		
Current product sales (without AR):		
Units		
Average realistic price, \$/unit		
Value, \$M		
Incremental product sales: (with AR):		
Units		
Average realistic value, \$/unit		
Value, \$M		
Current product sales displaced by improved product sales:		
Units		
Value, \$M		
Total improved product sales:		
Units		
Value, \$M		

[a] AR = appropriation request.
[b] Table extends to the right for the number of project years.

11.1.4 Marketing Information

A major part of all feasibility studies is the marketing data so that income projections may be made. It is essential to have the latest estimate of the company's market position for management's consideration. A tabulation of projected sales volume, sales price, and share of the market not only domestically but also globally is considered minimal information. Table 11.5 is a sample of such marketing information.

Table 11.6 Cash Flow Analysis

	Cash flow summary		
	200X	200Y	200Z, etc.[a]
Investment			
Land			
Fixed capital investment			
Offsite capital			
Allocated capital			
Working capital			
Start-up expenses			
Interest			
Catalysts and chemicals			
Licenses, patents, etc.			
Total capital investment			
Income statement			
Income			
Expenses			
Cash operating expenses			
Depreciation			
Total operating expenses			
Operating Income			
Net income before taxes			
Federal income taxes			
Net income after taxes			
Cash flow			
Capital recovery			
Cumulative cash flow			

[a] Table extended to the right for the number of project years.

11.1.5 Cash Flow Analysis

A cash flow analysis similar to Table 11.6 is useful in presenting the cash flow items in a clear, concise format. This table may be modified to include a choice of time zero and to allow management to add or delete certain items.

11.1.6 Measures of Profitability

The profitability of a project may be included as part of the cash flow analysis or it may be given in a special form like Table 11.7. The classical methods

TABLE 11.7 Profitability Analysis

Project Name:
Project Number:
By:
Date:
Net present worth (%)
Discounted cash flow rate of return
Payout period
Internal rate of return
____
____
Economic value added
Market value added

have been included, but some of the contemporary measures such as economic value added (EVA) and market value added (MVA) may also be presented. A company may only compute certain values, so Table 11.7 may be modified for specific uses. In this table, the interest rate used in the calculation of the net present worth is noted.

11.1.7 Break-even Analysis

Frequently management requests a break-even chart as part of the feasibility analysis. Such charts are predicated on numerous assumptions but will give some indication of the sensitivity of production rates on profitability. The assumptions should be clearly stated in the analysis. This type plot may be constructed like Figure 11.1 not only to indicate the break-even and shutdown points but also to be of use in marketing and production planning.

11.1.8 Sensitivity Analysis

The effect of errors and inaccurate information upon the profitability of a proposed venture is determined by means of a sensitivity analysis. The author prefers a graphical format similar to that shown in Figure 11.2, which was developed by Strauss [2]. At a glance, busy executives can quickly note those variables that

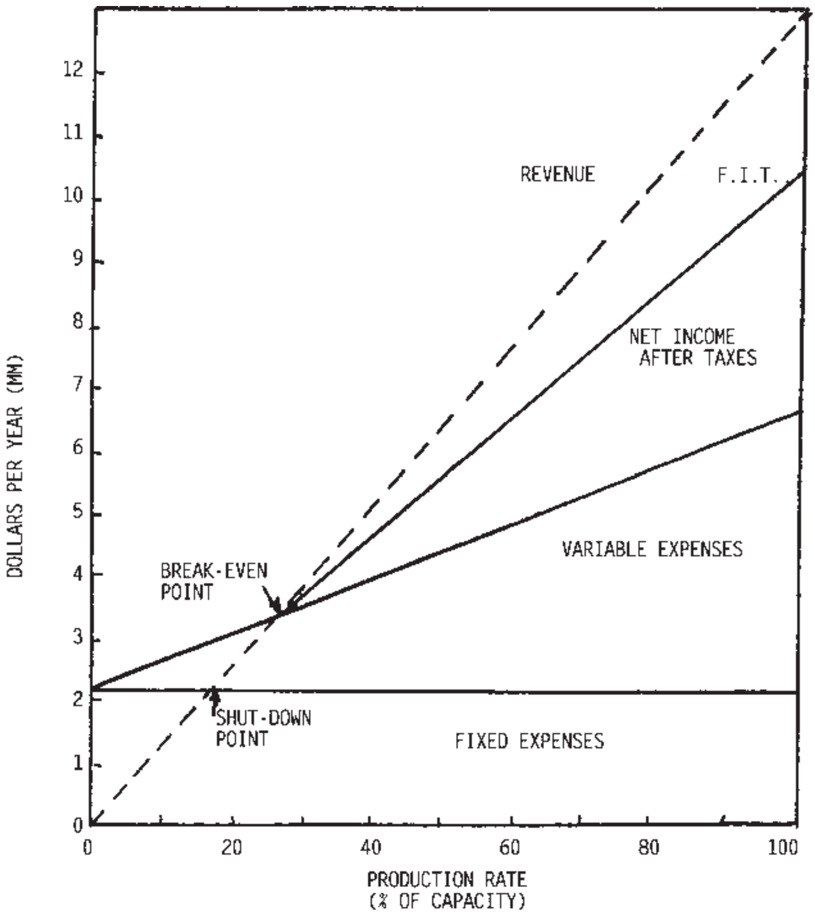

FIGURE 11.1 Typical break-even plot.

affect profitability the most. If the data are presented in tabular format, searching through such tables can be time consuming and tedious, whereas a sensitivity plot clearly indicates the variables that need further attention.

11.1.9 Uncertainty Analysis

Some companies include uncertainty analysis as part of the feasibility analysis package. The objective is to determine the probability of the risk of receiving a

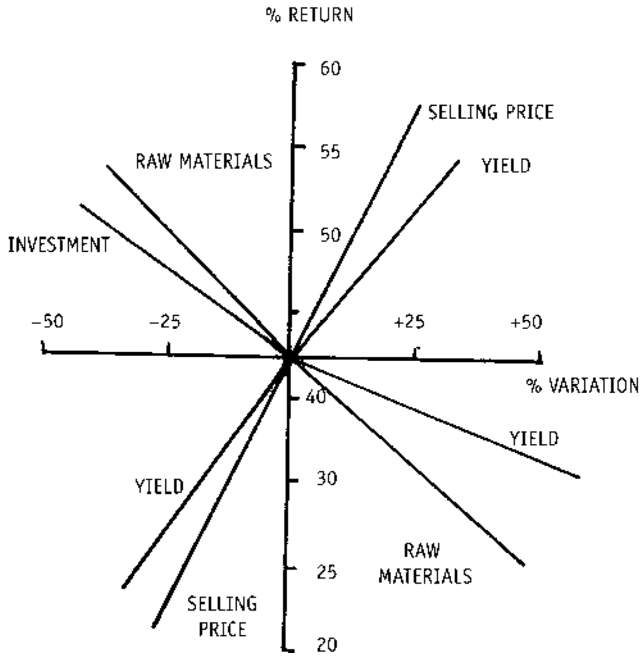

FIGURE 11.2 Typical sensitivity analysis plot.

greater (or lesser) return on the investment predicted by the measures of profitability used. Probabilities are assigned to each variable in the analysis based upon past experience. For example, what is the probability that the proposed sales pattern will develop? Some executives believe that such studies are exercises in futility since little information regarding accurate probability distribution models for a given variable are known or can be proposed. The results of an uncertainty analysis may be presented in a plot like Figure 11.3. There are computer programs that are available that do the calculations, but the person preparing this analysis still must tell the program what probability distribution fits a certain variable.

11.2 PROCEDURE

It is essential that management establish a procedure for the preparation of a feasibility analysis to ensure uniformity in reporting. The following outline of steps that might serve as a guide in gathering information for the analysis:

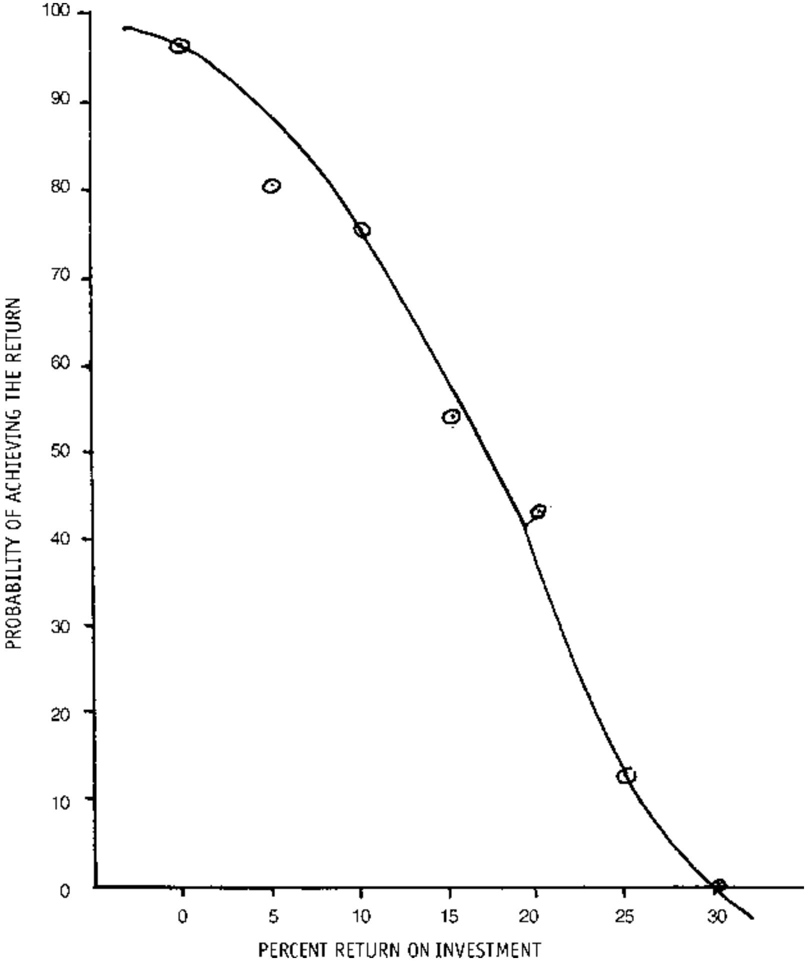

FIGURE 11.3 Typical uncertainty analysis plot.

1. Assemble all the necessary forms that company policy requires for a feasibility analysis.
2. Determine the quality of the fixed capital investment estimate that is appropriate considering the time frame and funds available for the preparation of the analysis.
3. Develop or gather the data necessary for substitution in the appropriate places in the various forms.

4. From step 3 above, determine the economic feasibility of the venture as required.

The use of standardized forms cannot be emphasized strongly enough since they serve as a check to ensure that all requisite items have been included and that stepwise results are presented in a logical, orderly, and organized manner.

11.3 FACTORS THAT AFFECT THE ACCURACY OF A FEASIBILITY ANALYSIS

11.3.1 Capital Cost Estimates

The various types of cost estimates and their purported accuracies are found in Chapter 4. For example, an order-of-magnitude estimate accuracy is -30 to $+50\%$, a preliminary estimate is -20 to $+30\%$, and a detailed estimate is -5 to $+10\%$. The basis for any estimate is equipment costs, so it is essential to use the latest cost information available and to know the data accuracy. The fixed capital investment estimate is critical since is used in the estimate of working capital, in certain items of the operating expenses, and in start-up expenses. In the preparation of this estimate, a well-defined scope must be developed consistent with the estimate data. A poorly defined scope potentially contributes to serious errors and considerable uncertainty regarding the project's feasibility.

11.3.2 Operating Expense Estimates

In the preparation of this estimate, it is wise to seek the advise of manufacturing personnel. Their input will help temper the estimates, minimizing guesses. These people are valuable sources with respect to labor requirements for a process. Raw material requirements can be obtained with reasonable accuracy from material balances, research reports, or pilot plant data. Utilities may be estimated from material and energy balances and the guidance of utilities supervisors with respect to prices and projected costs at a plant site.

11.3.3 Marketing Data

One of the largest potential sources of error is the quality of marketing information used in a feasibility estimate. Market volume is sometimes difficult to predict accurately because customers may change their requirements, use substitute products, or perhaps purchase a competitor's product. Any one of these items can deal a devastating blow to the estimate of sales volume. Sales price is a volatile variable since it is affected by sales volume as well as competition in the marketplace from similar or substitute products. Market volume and market price affect the return on investment to a great extent. Sensitivity analyses will show the effect of these variables on the economics of a project. Therefore, a substantial amount of effort and time should be expended to obtain the best market data possible.

11.3.4 Inflation

In the mid-to late 1970s, inflation was rampant in part due to the Middle-East oil crises. If inflation is not handled properly, it can cause considerable errors in feasibility analyses. Smith [3], Jones [4], and Griest [5] are classical texts published in the late 1970s and early 1980s that deal broadly with the subject. In that time period, inflation was double digit as high as 13.5%. In the current period (2002–2003) it is 1–2% and therefore is not a source of serious error.

One school of thought suggests that a specific time be selected and all economic data for a proposed project be corrected and reported on a constant-dollar basis as of that date. An alternative would be to project the inflation rate based upon past experience and near-recent trends, and then to apply to the economics of the project. Inflation rates are reported by the federal government and may be found frequently in the *Wall Street Journal*. One company the author knows projects inflation rates on a 6-month basis and then corrects the rate as current data become available using a moving-average forecasting technique. Whatever approach is used, company policy will dictate a method, but inflation should not be glossed over as serious consideration must be given to its affect on capital cost and operating expense estimates.

Griest [5] summarized the effects of inflation upon evaluations as follows:

- Inflation does affect the profitability of a project, reflecting unfavorably upon the net present worth.
- Inflation can change the order of preference of project selection in a capital budgeting decision.
- Inflation may be built into the discount rate used in calculating the net present worth.
- If inflation is a variable in an analysis, then it can be handled statistically in an uncertainty analysis.
- High rates of inflation tend to improve the attractiveness of a lease alternative relative to capital investment in a lease-purchase study.
- Higher rates of inflation, in general, tend to favor lower capital projects.

11.3.5 Depreciation

Through the years depreciation methods have been revised by Congress and the Internal Revenue Service. These revisions occurred whenever the economy was depressed, and the intent of the revisions was to stimulate the economy by hopefully encouraging capital spending. Write-off periods were shortened, which increased the cash flow in the early years of a project. The depreciation model used can drastically alter the cash flow patterns affecting the feasibility analysis. As of 2003, straight-line or the Modified Accelerated Cost Recovery System (MACRS) are the methods presently used [6].

11.3.6 Production Rate

The amount of material produced by a company is highly dependent on the marketing data. From these data, production schedules are prepared. Should the market volume decrease, the company will quickly build inventories that may result in an economically unhealthy situation unless the production is decreased. Such a move may be below an economically attractive operating rate. Many processes require operation at 50–60% of rated capacity to break even, and operation at 100% of capacity may not always be possible. A break-even chart is often included in a feasibility analysis so that at a glance management may observe the effect of changing production rates upon the profitability of a project.

11.3.7 Tax Credits

Investment tax credits have been allowed by the Internal Revenue Service under specified conditions at various times. Although tax credits based upon investment in manufacturing equipment did alter the cash flow of a project, in many cases it did not have the strong influence that revisions to depreciation had upon a project's feasibility. The reader should be aware of the latest tax credits since they have been allowed and discontinued frequently over the past several decades.

11.3.8 Concluding Comments

In this chapter, the information needed to prepare a feasibility analysis has been presented. This information includes a capital cost estimate, operating expense estimate, cash flow analysis, project profitability, sensitivity and uncertainty analysis. It should be mentioned that the information may be modified depending upon management's requirements, so not every feasibility study will contain the information in this chapter. One should recognize that all the calculations are based upon estimates that are subject to error. It is therefore essential to determine what affect potential errors have upon the results of the study. Such information is obtained from sensitivity and an uncertainty analysis.

As mentioned previously in Chapter 9, besides the quantitative results, qualitative factors must be considered in the decision-making process.

11.4 EXAMPLE OF A FEASIBILITY ANALYSIS

Example 11.1

Problem Statement:

Nue Chemical, Inc. is a small company that produces a wide variety of specialty chemicals for various customers. In 1999, it was considering the manufacture of an additive for use in the plastics industry. At that time, a market survey indicated that the project did not meet Nue's profitability requirements so the project was shelved.

In late 2002, Nue Chemical was acquired by Fusible Plastics, a large plastics manufacturer. Fusible wanted to integrate backward to raw materials so that the company could gain a better market and profitability position. Since the acquisition, Fusible has been reviewing the profit picture for all products in the acquisition. The marketing department of Fusible has prepared the following 10-year market information for the additive.

Year	Potential sales, MM lb/yr	Estimated sales price, $/lb
2004	40.0	0.50
2005	42.0	0.50
2006	45.0	0.52
2007	48.0	0.52
2008	50.0	0.55
2009	50.0	0.56
2010	47.0	0.50
2011	45.0	0.48
2012	40.0	0.47
2013	35.0	0.45

The process to manufacture the additive involves fluids only. The delivered equipment cost of the process equipment as of January 1, 2003 is as follows:

Item	Delivered equipment cost
Tanks	$230,000
Pumps	75,000
Heat exchangers	525,000
Filters	120,000
Reactors	1,200,000
Miscellaneous equipment	350,000
Total	$2,500,000

(*Note*: The delivered equipment cost includes cost differentials for materials of construction).

The company uses the *Chemical Engineering* cost index to update costs. For the future, management suggests a 5% per year inflation rate. Land for this project may be considered negligible but working capital may be taken as 15% of the total capital investment. Apex Contractors, Inc. has prepared a definitive estimate of the fixed capital investment of $12 million for a 50MM lb/yr plant. The equipment is to be purchased and installed over a 2 year period prior to start-up which is expected to be in early 2004.

Chlorine is used in the manufacture of the additive and is supplied by Fusible's old small 200 ton/day plant located adjacent to the proposed new additive. Ten tons of chlorine per day is used in the manufacture of the additive. The total capital investment of the chlorine facility is carried on the books at $10 million.

Operating expenses for the proposed new additive unit are:

Raw materials	$0.12/lb product
Utilities	$0.03/lb product through 2007 and $0.045 thereafter
Labor and supervision	$0.05/lb product through 2008 and $0.06 thereafter
Maintenance	6%/yr of the fixed capital investment
Other direct expenses	$0.01/lb product
Depreciation	7-year straight line for operating expenses and 7-year MACRS for cash flow analysis with half-year convention
Other indirect expenses	$0.01/lb product
General overhead	$0.02/lb product

You may assume all product made is sold.

At this stage of consideration, unless a project has a positive 25% NPW after taxes, the venture will not be considered further. The federal income Tax rate is 35%.

To conform to Fusible's company standard evaluation procedure, the following components of a feasibility study are required:

a. An estimate of the total capital investment for the venture as of January 1, 2004
b. Annual operating expenses for all production rates
c. An estimate of the profitability by the DCF rate of return method using the 7-year MACRS depreciation and continuous interest
d. The NPW at 25% for the venture
e. Cash position chart for the proposed project
f. Payout period at 25% interest
g. A sensitivity analysis based upon a 50 MM lb/yr plant capacity to determine the effect of the following variables upon the rate of return:
    1. Sales price with a $\pm$15% variation
    2. Sales volume with a $\pm$15% variation
    3. Raw material costs with a $\pm$15% variation
    4. Fixed capital investment with a $\pm$15% variation

Based upon your analysis, what recommendation would you make to management concerning the proposed venture? Substantiate your answer(s) with numerical results.

Solution:

a. *Estimate of the total capital investment as of January 1, 2004.* Apex Contractors, Inc. have submitted a detailed estimate of the fixed capital investment in the amount of \$12 million that may have an inherent error of −5 to +15%. As a matter of policy, it would be wise to also estimate the fixed capital investment using the Lang, Hand, Brown, and Chilton methods and compare the result with the Apex figure. (These shortcut methods can be used to obtain a preliminary figure before the outside contractor submits his estimate.)

LANG METHOD: Because the date of the delivered equipment price was January 1, 2003, an inflation factor of 1.05 must be included in the following methods. The Lang factor for a fluid processing plant is 4.74 (Table 4.9) times the delivered equipment costs. Therefore the fixed capital investment by this method is

$$(\$2.5\text{MM})(4.74)(1.05) = \$12.5\ \text{MM}$$

HAND METHOD: This method involves the use of different factors for each type of equipment. The factors are found in Table 4.10.

Item	Delivered price	factor	Component cost
Tanks	$230,000	4.0	$ 920,000
Pumps	75,000	4.0	300,000
Heat exchangers	525,000	3.5	1,838,000
Filters	120,000	4.0	480,000
Reactors	1,200,000	4.0	4,800,000
Miscellaneous	350,000	4.0	1,400,000
Total	$2,500,000		$9,738,000

The total component cost is multiplied by the inflation factor to bring costs to January 1, 2003:

$$(\$9,738,000)(1.05) = \$10,225,000$$

The fixed capital investment will be rounded off to $10,200,000.

BROWN METHOD: The Brown method has factors for materials of construction, but in this problem statement mention was made that the costs of the materials of construction were included in the delivered equipment cost. This method is described in Section 4.3.2.4, and the factors are presented in Table 4.12.

Item	Delivered equipment cost	Factor	Component cost
Tanks	$230,000	3.5	$805,000
Pumps	75,000	5.0	375,000
Heat Exchangers	525,000	3.5	1,838,000
Filters	120,000	2.4	288,000
Rectors	1,200,000	4.2	5,040,000
Miscellaneous	350,000	4.0[a]	1,400,000
Total	$2,500,000		$9,746,000

[a] Estimated factor.

The fixed capital investment by this method is

$$(\$9,746,000)(1.05) = \$10,233,000$$

CHILTON METHOD:

Item no.	Item	% of item	Factor	Component cost
1.	Delivered equipment	1	1.0	$2,500,000
2.	Installed equipment	1	1.43	3,575,000
3.	Process piping (fluid)	2	0.60	2,145,000
4.	Instrumentation (extensive)	2	0.20	715,000
5.	Buildings and site development	2	0.20	715,000
6.	Auxiliaries (minor)	2	0.03	107,000
7.	Outside lines (minor)	2	0.03	107,000
8.	Total physical plant cost			$7,364,000
9.	Engineering (simple)	8	0.25	1,841,000
10.	Contingencies (firm)	8	0.15	1,105,000
11.	Size > $2.5 MM	8	0.03	221,000
12.	*Total fixed capital investment*			$10,531,000

The fixed capital investment may be rounded to $10,500,000.

The estimates of the fixed capital investment by the various methods are:

Lang	$12,500,000
Hand	10,200,000
Brown	10,233,000
Chilton	10,500,000
Apex Contractors	12,000,000

The costs obtained by the Hand, Brown, and Chilton methods produce similar results and this might be expected as the methods are somewhat similar in nature. If the errors in each method are considered, the estimates of the fixed capital investment are close. The Lang method gives a result very similar to the one from Apex Contractor, but the errors in the Lang method are greater than the method used by Apex. Because Apex's is a more detailed estimate, its figure will be used in the rest of the feasibility study. These results may be a coincidence.

Therefore, the total capital investment is

Item	Investment
Land	$0
Fixed capital investment	12,000,000
Allocated capital	
(10/200)($10,000,000)	500,000
Working capital	2,200,000
All other items	0
Total capital investment	$14,700,000

b. *Operating expenses*. The most efficient way to present the results of these calculations is in an electronic spreadsheet. In this form, it permits the user to develop many different scenarios. The results may be found in Table 11.8.

c and d. *Cash flow analysis and NPW and IRR calculations*.

The next step in a feasibility study is to develop a cash flow analysis. Again, like the operating expenses, it is advisable and more efficient to present this analysis as an electronic spreadsheet. The cash flow analysis is found in Table 11.9.

Fusible requires a NPW method at a 25% interest rate to consider a project for funding at this stage. From Table 11.10, the NPW at 25% is a positive $9,858,000; therefore, the projects meets the company's profitability requirements. Also, from Table 11.10, the IRR is 36.40% and this is very good. Detailed calculations are summarized in Table 11.10.

e. *Cash position chart*. A cumulative cash position chart can be constructed for this project from the cash flow analysis, Table 11.9. The plot is presented in Figure 11.4.

f. *Payout period at 25% interest.* The payout period with interest can be obtained by interpolating in the cumulative cash flow in Table 11.9 or from the plot, Figure 11.4. The payout period with 25% interest found by interpolation is 2.2 years. A 2 to 3 year payout period is reasonable for this project at this time.

g. *Sensitivity analysis*. With the aid of electronic spreadsheets for the operating expenses and the cash flow analysis, a sensitivity analysis can be prepared. Some companies prefer the results as a plot, similar to the Strauss chart or as a "tornado" plot [see Chap. 10 for the details of these charts.] Some companies prefer the results in both tabular and graphical format but Fusible prefers the result in the form of a sensitivity plot, like the Strauss chart, Figure 11.5.

h. *Uncertainty analysis.* Fusible does not require a Monte Carlo uncertainty analysis for this problem.

i. *Concluding comments*. The project meets Fusible's criteria for investment with respect to NPW and POP. The recommendation to management is to confirm the marketing, capital investment, and operating expense estimates and if

TABLE 11.8 Operating Expenses for Example 11.1 (All Monetary Amounts are in $M)

Production (MM lb/yr):	40.0	42.0	45.0	48.0	50.0	50.0	47.0	45.0	40.0	35.0
Fixed capital, $M	12,000									
Date:	07/12									
By	JRC									
Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Raw materials	4,800	5,040	5,400	5,760	6,000	6,000	5,640	5,400	4,800	4,200
Utilities	1,200	1,260	1,350	1,440	2,250	2,250	2,115	2,025	1,800	1,575
Labor and supervision	2,000	2,100	2,250	2,400	2,500	3,000	2,820	2,700	2,400	2,100
Maintenance	720	720	720	720	720	720	720	720	720	720
Other directs	400	420	450	480	500	500	470	450	400	350
Total directs	9,120	9,540	10,170	10,800	11,970	12,470	11,765	11,295	10,120	8,945
Depreciation	857	1,715	1,715	1,714	1,715	1,714	1,715	856	0	0
Other indirects	400	420	450	480	500	500	470	450	400	350
Total indirects	1,257	2,135	2,165	2,194	2,215	2,214	2,185	1,306	400	350
Total manufacturing expense	10,377	11675	12,335	12,994	14,185	14,684	13,950	12,601	10,520	9,295
General overhead	800	840	900	960	1000	1000	940	900	800	700
Total operating expense	11177	12515	13235	13,954	15185	15,684	14890	13501	11320	9995
Depreciation	857	1,715	1,715	1,714	1,715	1,714	1,715	856	0	0
Cash operating expense	10,320	10,800	11,520	12,240	13,470	13,970	13,175	12,645	11320	9995

TABLE 11.9 Cash Flow Analysis for Example 11.1 (All Cash Flow Items are in $M)

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Production, MM lb/yr	40.0	42.0	45.0	48.0	50.0	50.0	47.0	45.0	40.0	35.0
Fixed capital investment, $M	$12,000									
Sales	20,000	21,000	23,400	24,960	27,500	28,000	23,500	21,600	18,800	15,750
Cash operating expenses	10,320	10,800	11,520	12,240	13,470	13,970	13,175	12,645	11,320	9,995
Operating income	9,680	10,200	11,880	12,720	14,030	14,030	10,325	8,955	7,480	5,755
Depreciation	1,715	2,939	2,099	1,499	1,072	1,070	1,072	535	0	0
Net profit before taxes	7,965	7,261	9,781	11,221	12,958	12,960	9,253	8,420	7,480	5,755
Federal income tax, 35%	2,788	2,541	3,423	3,927	4,535	4,536	3,239	2,947	2,618	2,014
Net profit after taxes	5,177	4,720	6,358	7,294	8,423	8,424	6,015	5,473	4,862	3,741
Depreciation	1,715	2939	2,099	1,499	1,072	1,070	1,072	535	0	0
Cash flow	6,892	7,659	8,457	8,793	9,495	9,494	7,086	6,008	4,862	3,741
Capital recovery										2,200
End of project value										5,941

TABLE 11.10 Profitability Analysis for Example 11.1

Time, yr	Item	Cash flow	Factor at 25% interest	Cash flow 25%	Factor at 35% interest	Cash flow 35%	Factor at 40% interest	Cash flow 40%
−2	Fixed capital investment	−12,000	1.297	−15,564	1.448	−17,376	1.532	−18,384
0	Work + allocation capital	−2,700	1.000	−2,700	1.000	−2,700	1.000	−2,700
1	Cash flow	6,592	0.885	5,834	0.844	5,564	0.824	5,432
2	Cash flow	7,230	0.689	4,981	0.595	4,320	0.552	3,991
3	Cash flow	8,322	0.537	4,469	0.419	3,487	0.370	3,079
4	Cash flow	8,868	0.418	3,707	0.295	2,616	0.248	2,199
5	Cash flow	9,720	0.326	3,169	0.208	2,022	0.166	1,614
6	Cash flow	9,719	0.254	2,469	0.147	1,429	0.112	1,089
7	Cash flow	7,312	0.197	1,440	0.103	753	0.075	548
8	Cash flow	6,120	0.154	942	0.073	447	0.050	306
9	Cash flow	4,862	0.120	583	0.051	248	0.034	165
10	Cash flow	3,741	0.093	348	0.036	135	0.022	82
End 10 yr	Capital recovery	2,200	0.082	180	0.030	66	0.018	40
	Net present worth:			9,858		1,011		−2,539
	Internal rate of return:		IRR = 35 5[(1,011)/(1,011 + 2,539)] = 35.0 + 1.40 = 36.40%					

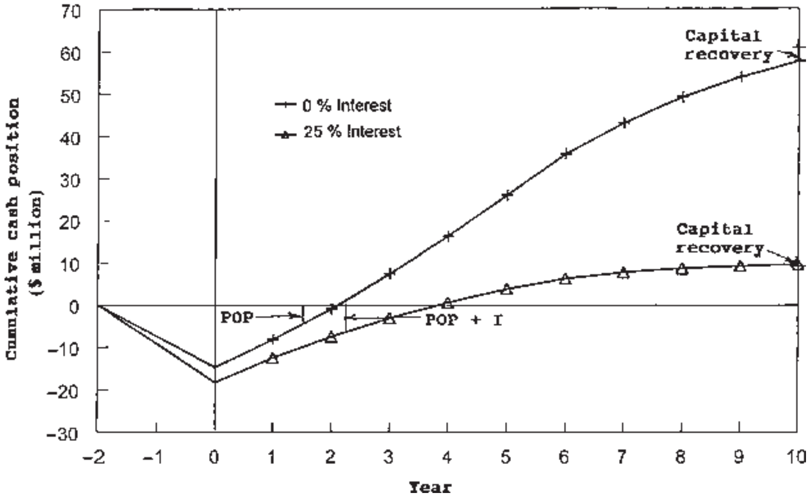

Figure 11.4 Cumulative cash position plot for Example 11.1.

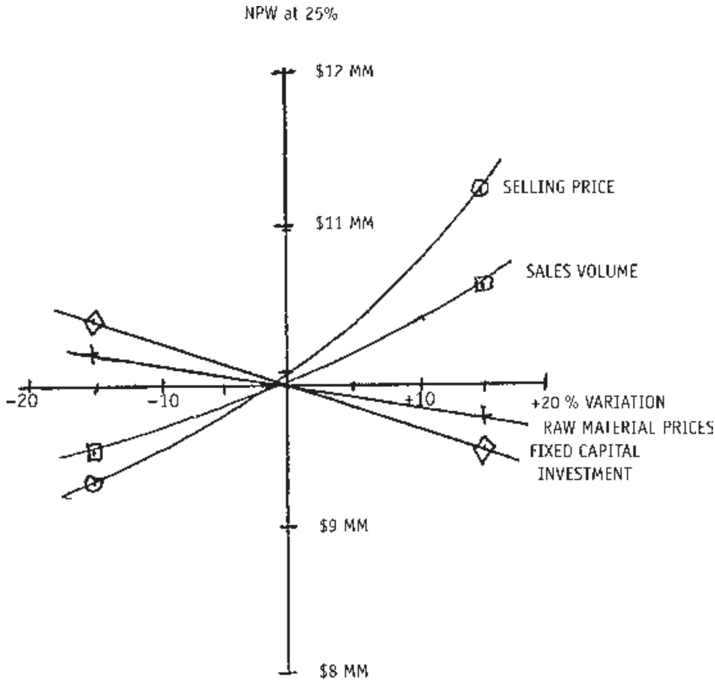

Figure 11.5 Sensitivity analysis plot for Example 11.1.

the project is still profitable, a detailed capital investment should be prepared. If at any time, the estimates fall below Fusible's criteria for investment, the project should be terminated.

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PROBLEMS

11.1 You are employed in the planning and economics section of ROCK Chemicals, a company that produces large-volume inorganic chemicals. The marketing department has a customer who will purchase 100 tons per calendar day of 50% caustic at a price of \$200/ton. Since the current caustic production facilities are operating at 100% capacity, you have been asked to do a feasibility study for a new unit to produce the 50% caustic. You have gathered the following information:

1. The process is the electrolytic decomposition of a brine solution according to the following reaction:

$$2NaCl + 2H_2O = 2NaOH + Cl_2 + H_2$$

2. Design capacity shall be 120 tons per calendar day to accommodate the future needs of customers.
3. The process flow diagram is found in Figure 11.6.
4. The unit will operate 330 days/yr.
5. Fixed capital investment for the complete process is based on total feed to the dissolver and is given by

$$\mathrm{FCI} = (5,000,000)\frac{\text{feed to dissolver, tons/stream day}}{200 \text{ tons/stream day}^{0.7}}$$

6. Construction period is 1 year.
7. There is no charge for land, but working capital is \$400,000.
8. The electrolytic cells require 2500 kWh/ton Cl_2 produced at a cost of \$0.07/kWh.

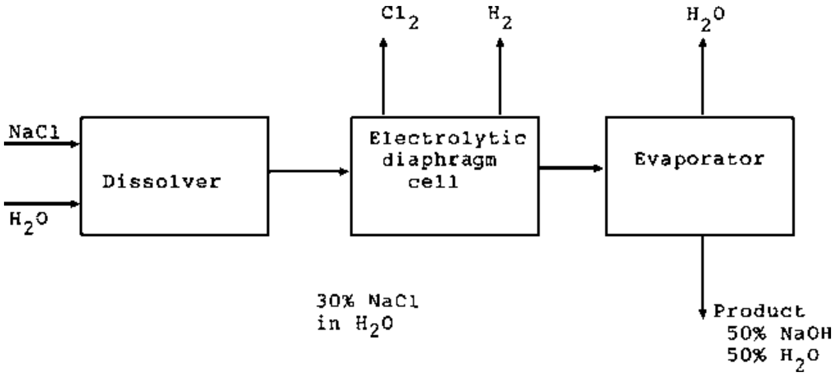

FIGURE 11.6 Flow diagram for Problem 11.1.

9. The evaporator economy is 0.8 lb water per lb steam. Steam cost is \$4.50/1000 lb.
10. Depreciation is 7 years straight-line. Project life is 7 years.
11. The total of all other operating expenses including raw materials is \$40/ton of product.
12. The chlorine has a value of \$60/ton in another process.
13. The hydrogen may be sold to an adjacent refinery for \$5/100 SCF.
14. The tax rate is 35%.
15. Your company requires a 25% IRR for projects.

You have been asked to submit the following information for management's consideration:

a. A process material balance based on 100 tons per calendar day production.
b. An economic analysis in tabular format giving the fixed capital investment, Revenue in \$/yr; operating expenses, in \$/yr; cash flow, \$/yr.
c. Determine the present worth at 25%.
d. What is your recommendation to management? Discuss a plan of action.

11.2 You are an engineer in the economics section of AG Products, Inc., and you are asked to prepare a feasibility study on a new product, FASTGRO, that is produced as a water slurry. It will then be concentrated in an evaporator as a 50% thick liquor and sold. A flow sketch of the process is found in Figure 11.7.

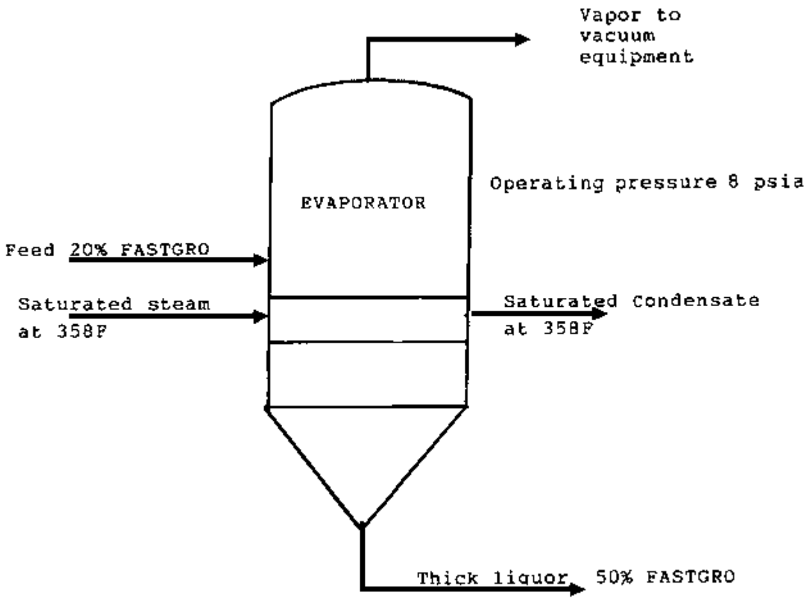

FIGURE 11.7 Flow diagram for Problem 11.2.

The following data apply:

1. The feed is 240 tons/day (330 days/yr) of 20% FASTGRO in water. The transfer price for this stream is \$10/ton (treat as a raw material cost).
2. The feed is at 80 F and has a heat capacity of 0.9 Btu/lb F.
3. The 50% thick liquor is the product.
4. All storage tanks and pumps are available for this project at no cost.
5. The only significant capital cost is the evaporator.
6. The evaporator will operate at 8 psia. At this pressure the boiling temperature is 227 F, the heat of vaporization is 1000 Btu/lb and the cost of operating the vacuum equipment is \$2.50/ton of condensed vapor. The evaporator may be assumed as 100% efficient for this study.
7. The overall heat transfer coefficient is 300.
8. The only significant operating expenses are raw materials, steam expenses, operating expenses for the vacuum equipment, and the expenses associated with storage, transportation, and sale of the product. This later expense is estimated to be \$12/ton of product.
9. Saturated steam is available at 358 F at a cost of \$5.00/1000 lb and has a latent heat of 863 Btu/lb.

10. Depreciation is 7 years straight line and project life is 7 years. The combined state and federal tax rate is 40%.
11. The construction period is 6 months with an on-stream date late this year.

Determine the sales price ($/ton) that will be required to achieve a 25% IRR for this project.

11.3 You are employed as a project manager in the planning section of West Plaines Refinery. This refinery process sour crude and produces 530 tons/day of H_2S on a continuous round-the-clock basis. Currently, the H_2S is sent to SURCO, a sulfur recovery company located adjacent to our refinery. SURCO charges West Plaines $80/ton to process H_2S under the present contract which expires 2 years from now. Your assignment is to prepare a feasibility study of doing our own H_2S processing. You have gathered the following information:

1. West Plaines recently completed a 400 ton/day H_2S recovery plant at one of its other locations. The fixed capital investment for this plant was estimated to be $21.6MM and the construction period was 1 year. A new plant could be constructed to go on-stream by the end on the current contract with SURCO.
2. Operating expenses for a 530 ton/day plant have been estimated to be $20/ton H_2S processed. This figure does not include depreciation.
3. The process chemistry is

$$H_2S + \tfrac{3}{2}O_2 = H_2O + SO_2 \tag{a}$$

$$2H_2S + SO = 2H_2S + 3S \tag{b}$$

   Preliminary negotiation have indicated that we will be able to obtain a 3-year contract to sell by-produce sulfur at $12/ton.
4. Equation (a) above is an exothermic reaction with a heat of reaction of 211,000 Btu/lb mole. Equation (b) is exothermic with a heat of reaction of 101,000 Btu/2 lb mole H_2S. The energy may be used to generate steam at an efficiency of 70%. (Assume that 70% of the energy from the reaction goes to produce steam with a value of $4.50/MM Btu).
5. We will need 100% backup in H_2S recovery facilities. This would require a duplicate plant to be built. However, SURCO has offered to provide the backup service for a maximum of 10 days/yr for a fee of $500,000/yr. This would negate our having to build a second unit to provide the 100% backup required.
6. Our company requires a 20% IRR for projects of this type. Permission has been grated from the IRS to use a 3-year straight-line depreciation and a 35% tax rate.

Please prepare answers to the following questions:

a. Will the proposed H_2S recovery plant realize a 20% IRR?
b. Should we build the plant or contract with SURCO?
c. What should be the course of action for West Plaines?

11.4 The Spurious Company is a medium-sized relatively young chemical producer of high-quality organic intermediates. The management of this company is aggressive in their investment policy. When Spurious enters a new marketing venture, they evaluate their profitability by cash flow generated, payout period with interest, and the internal rate of return measures of merit. The engineering economics staff has prepared a preliminary fixed capital cost estimate by the Chilton method of $5MM. Land allocated for this project is worth $200,000. Working Capital is $900,000 and start-up expenses are $400,000.

As a member of staff you have been asked to prepare an economic evaluation to be acted upon by the executive committee and ultimately by the board of directors. The following operational guidelines for feasibility studies are:

1. The project must yield a 20% IRR.
2. A payout period must be less than 3 years.
3. MACRS 7-year depreciation is used.
4. Federal income tax rate is 35%.

It is expected that the construction will take $1\frac{1}{2}$ years and that start-up, if the project is approved, is to be January 200Y. If the board approves the project at next month's meeting, construction could not begin before July 200Y.

After consulting with representatives of manufacturing, marketing, and engineering, you estimate that the net profit before taxes over a 10-year project life is

Year	NPBT, $M
0	0
1	2,100
2	2,500
3	3,000
4	4,000
5	4,200
6	4,200
7	4,200
8	3,800
9	3,600
10	3,000

You must assume that all dollar figures have been corrected for inflation to January 1, 200Y.

In order for the executive committee to review this project for possible funding, please prepare the following information:

a. An estimate of the total capital requirements
b. The payout period with interest
c. The NPW of the project
d. A sensitivity analysis of the effect on the NPW for the following variables:

    1. Fixed capital investment with a $\pm 20\%$ variation
    2. Net profit before taxes with a $\pm 20\%$ variation

e. Be sure to substantiate your recommendations to management with numerical values.

11.5 Tumbleweed, Inc., located in Texas, is considering the manufacture of a new specialty chemical. The market for this product is in the eastern part of the United States, but the plant is to be located in the southwestern part of the United States because of the proximity of raw materials and the availability of a reliable source of labor. The marketing department has just completed a preliminary survey which revealed the following sales potential and sales prices:

Sales volume, lb/yr	Sales price, $/lb
1,000,000	0.32
2,000,000	0.30
3,000,000 or more	0.26

For intermediate sales volume, a straight-line interpolation of sales price may be assumed.

On November 1, a preliminary report was issued by the development department based upon a promising developed by the research department. As a result of this study, the following expenses were estimated for a plant producing 1,000,000 lb/yr of product based upon 300 days of operation.

Item	Operating expense, $/day
Raw materials	200
Labor	170
Sales overhead	40
Depreciation	75
Maintenance	50
Utilities and fixed expenses	40
Total	675

The total fixed capital costs exclusive of land is 3,000,000. The plant is assumed to have a 10-year technical life. For intermediate plant capacities, the total fixed capital investment will very directly as the 0.7 power of the capacity. For this study, you may ignore the cost of land that the company owns. Working capital is estimated at 15% of the total capital investment.

Raw material expenses will be directly proportional to the amount of product manufactured. The labor expense will be constant between 1,000,000 and 2,000,000 lb/yr but for mare than 2,000,000 lb/yr the labor expense will be 1.4 times that of the 1 million rate.

Sales and overhead expenses are 1 cent/lb plus $40/day. Maintenance is 6.7% of the fixed capital investment. Depreciation is on a 7-year straight-line basis. Utilities and fixed operating expenses will be 5.34% of the total fixed capital costs. Income tax is 35%.

The following information for a feasibility analysis is required to present to the planning board:

a. Summaries of the total capital requirements, operating expenses, and profit loss statement for 1.0,1.5,2.0, and 3.00MM lb/yr rates
b. The optimum plant size calculated by the IRR method
c. The break-even point
d. A sensitivity analysis showing the effect on the optimum case of the following variables:

    1. Sales price with ± 10 and $\pm 25\%$ variation.
    2. Fixed and working capital investment with ± 10 and $\pm 25\%$ variation.

(*Note*: Several variations might be explored on these last two problems. For example, rather than straight-line depreciation, the MACRS method might be used to observe the effect on cash flow. Cumulative cash positions charts might be required. These problems could also be modified to include uncertainty analysis.)

12

Choice Between Alternatives and Replacement

Engineers are frequently confronted with making choices among alternative equipment, designs, procedures, plans, and methods. In fact, in our daily lives outside the workplace, we make decisions and often do so on whimsy, failing to apply the techniques that will be discussed in the chapter. Available courses of action may require different amounts of capital and different operating expenses, as well as different incomes. The bottom line is, "Will the course of action selected pay?" Other questions also need to be considered, for example:

- Why do it this way?
- Why do it now?
- Why do it at all?

There are some basic concepts that must be considered before an attempt is made to apply mathematical methods for solutions:

- Decisions are among alternatives; therefore, it is necessary that alternatives be clearly defined and that the merits of appropriate alternatives be considered.
- Decisions should be based on the expected consequences of various alternatives, recognizing that all such consequences will occur in the future.
- Before procedures are established for project formulation and evaluation, it is essential to decide whose viewpoint is to be adopted—management, customer, etc.

- In comparing alternatives, it is essential that consequences be commensurable insofar as possible. In engineering, money units are the only units that meet the requirements.
- Only differences among alternatives are relevant in their comparison.
- Insofar as practicable, separate decisions should be made separately.

Alternatives may be grouped into three broad categories:

- Independent alternatives
- Mutually exclusive alternatives
- Dependent alternatives

An *independent* alternative is not affected by the selection of another alternative. Each proposal is evaluated on its own merit and is approved if it meets the criteria of acceptability by management [1].

Alternatives are *mutually exclusive* when the selection of one alternative eliminates the opportunity to accept any others.

Individual investment opportunities are often linked to other alternatives through legal, administrative, political, or physical plant requirements. The acceptance of one alternative depends on the simultaneous acceptance of one or more related alternatives. Such alternatives are *dependent* alternatives. Examples of these alternatives are found in environmental control proposals where an alternative depends on government regulations.

12.1 THEORETICAL DISCUSSION

12.1.1 Significant Considerations

There are several significant considerations that must be addressed before an economic evaluation between alternatives can be made:

1. The flows of money take the form of expenditures or income. Savings from operations are considered as income or as a reduction in expenses.
2. Time value of money is considered.
3. A reasonable rate of return (profitability) must be included in the calculations.
4. Income taxes and, when applicable, inflation must be included.
5. A methodology must be developed to reduce the above information to a manageable format [2].

The five considerations will be discussed in the next section and certain conventions adopted.

12.1.2 Flows of Money

Only those flows must be considered that differ for the alternatives being compared. The handling of cash flows is the same as that employed in Chapters 8 and 9. Most cases in this chapter are simpler, and a calculation format will be used to organize the information and the calculations.

1. Expenditures are of two kinds:
   a. Instantaneous, for example, land, working capital, and capital recovery
   b. Uniformly continuous, for example, plant investment, wages, utilities
2. Income is not generally introduced; however, a saving should be considered a reduction in operating expenses. Forgoing (giving up) a capital recovery, e.g., not realizing a salvage value, is to be handled as a capital cost. Prior to the passage of the 1981 tax revision, salvage value was considered in depreciation calculations. Since 1981, if a facility is dismantled, removed, and the equipment sold, the net capital recovery as it is now called is taxed like income. Hereinafter, any equipment sold will be referred to as capital recovery.
3. Money spent is negative and money saved or generated is positive.

An expression is developed for the cash flow that can be applied to each of the alternatives to be compared. Figure 12.1 is really the lower part of Figure 8.1. The diagram illustrates the movement of cash and noncash items in a venture.

Cash flow as previously defined in Chapter 8 is *net income after taxes plus depreciation*. An equation for the annual cash flow generated in a venture is

$$\text{Cash flow} = \text{depreciation} + \text{net income after taxes}$$

$$\mathrm{CF} = D + (1 - t)(S - C - D) \tag{12.1}$$

If Eq. (12.1) is algebraically rearranged, then

$$\mathrm{CF} = tD + (1 - t)(S - C) \tag{12.2}$$

where

CF = after-tax cash flow
D = depreciation
t = tax rate
S = revenue
C = cash operating expenses

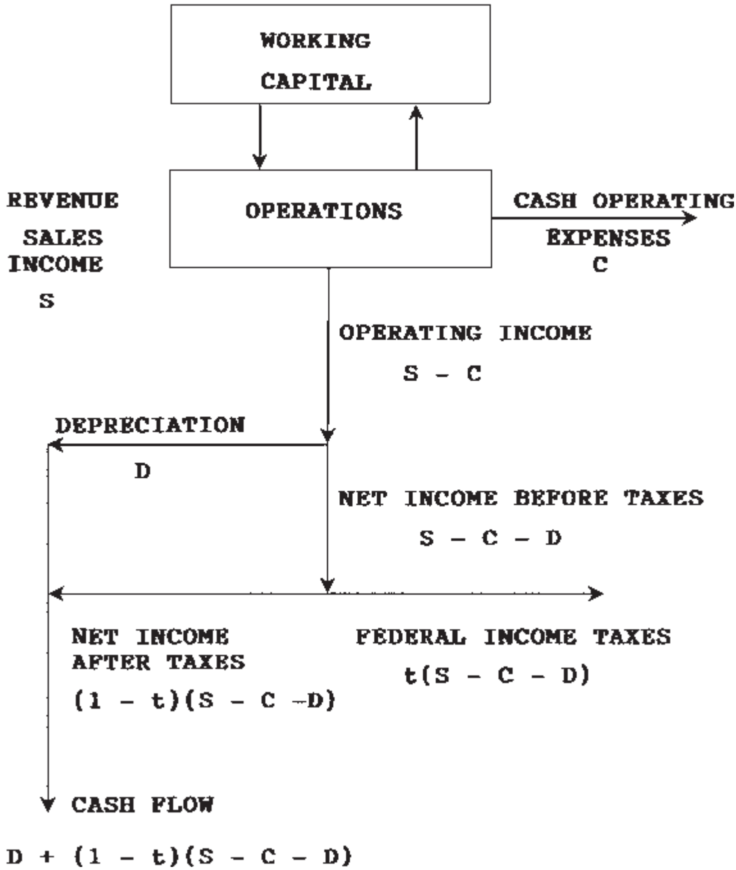

FIGURE 12.1 Cash flow model.

For the case in which revenue remains constant, i.e., when the alternative gives the same benefit or produces the same amount of product, $S = 0$ and

$$\mathrm{CF} = tD + (1 - t)(-C) \tag{12.3}$$

or

$$\mathrm{CF} = tD - (1 - t)(C) \tag{12.4}$$

In the cash flow equations (12.3) and (12.4), the first term is $t \times D$. This results from an algebraic rearrangement of Eq. (12.1) and no other significance should be assumed.

For the case when a comparison is made between a candidate case and a base case, the difference form of Eq. (12.2) may be used:

$$\mathrm{CF} = t(\Delta D) + (1 - t)(\Delta S - \Delta C) \tag{12.5}$$

where Δ = the value of the candidate case minus the value of the base case.

12.1.3 Interest Factors

Although it makes no difference whether discrete or continuous interest factors are used, discrete interest is often used when all the case flows are instantaneous; otherwise continuous interest should be used. The minimum acceptable rate of return and the cost of capital are the guidelines for the interest rate used.

For calculating the present worth of cash flows in this chapter, the Hirschmann–Brauweiler continuous interest tables are very useful. They may be found in Appendix E. To use the tables, one must first decide how the cash flows into the proposed project—instantaneously, uniformly continuous, or declining uniformly to zero (sum-of-the-digits). Next, enter a table with the argument $R \times T$, where R is the interest rate expressed as a whole number and T is the time in years. Therefore, for an interest rate of 20% for 4 years, the argument is $20 \times 4 = 80$.

12.1.4 Profitability

For comparisons of alternatives, any venture selected must return to the investors some reasonable value for their investment. A number of factors affect this value, for example, capital investment, operating expenses, cash flow, source(s) of funds. Although the blanket term used is “return on investment,” the internal rate of return or the net present value may be the measure used.

12.1.5 Income Taxes

Income taxes affect the cash flow which in turn affect the return on investment. The cash flow diagram, Figure 12.1, is a device that permits the reader to follow the affect of income taxes on cash flow. Generally, only the federal income tax rate is used in the calculations, but the tax rate could include also the state and local taxes.

12.1.6 Inflation

Prior to 1970, economic evaluations did not include inflation because the rate was low, of the order of 2–4%. Under these conditions, the simplification was justified because inflation influenced the flows of money only slightly and then more or less to the same extent. Therefore, inflation did not critically affect the conclusions of a preliminary economic study. However, with the Middle East oil crises in the 1970s, inflation rose to a high of 13% per year and was a significant factor in economics for project ventures.

Depreciation charges are usually expressed in current dollars and are not adjusted for inflation. Future sums can be adjusted by applying the corresponding interest factors. For example, a service costing \$50,000 now can be adjusted for a 4% per year average for 5 years would be

$$\$50,000(1 + 0.04)^5 = \$50,000(1.217) = \$60,850$$

using discrete interest

or

$$\$50,000\left(\frac{1}{0.8187}\right) = \$50,000(1.221) = \$61,050$$

using continuous interest

The factor 0.8187 is obtained from the instantaneous Hirschmann–Brauweiler continuous interest table.

12.2 CALCULATION METHODS

When a schedule for the flows of money for each alternative is prepared and the barrier ROI, income tax rate as well as the inflation rate are defined, it is possible to reduce the cash flows to a single dollar figure using interest factors. A number of numerical methods are available for determining the choice between alternatives, the most common being:

Net present worth
Rate of return
Capitalized cost
Equivalent uniform annual cost

Jelen and Black [3] have shown that each of these methods would result in the same decision although the numerical results may differ.

12.2.1 Net Present Worth

The net present worth method allows the conversion of each flows into money units, e.g., dollars, an arbitrary time called the "present." Different interest factors are used depending upon how and when the cash flow enters the venture. Cash flows may be assumed to be instantaneous as in the purchase of a property or uniformly distributed over a period of time, e.g., operating expenses.

All cash flows (in and out) are treated with appropriate interest factors to bring the cash flow item to the "present time." An awkward feature of this method arises from the requirement that each alternative provides the same service or the same duty for the selected time period. The alternative yielding the more positive net present worth is preferred.

If one alternative has a different life than others, the program for each must be for the number of years that is the least common multiple of the estimated life of the various alternatives. For example, if cases *A* and *B* have estimated lives of 7 and 9 years, respectively, the program for each must be calculated for the least common multiple of 63 years. This is a complication that is avoided by the three methods. An example of the net present worth method is found in Example 12.1.

Example 12.1

Problem Statement:

Filtration equipment must be installed in a plant to remove solids in order to meet EPA regulations for the liquid discharge. Assume that the service life is 7 years and there is no capital recovery. Data for two possible systems follow:

System	*A*	*B*
Fixed investment	\$25,000	\$15,000
Annual operating expenses	6,000	11,000

The equipment is to be depreciated over a 7-year period by the straight-line method. Each equipment item provides the same service. The income tax rate is 35% and the interest rate to be used is 15%. Using continuous interest, which alternative is to be preferred and why?

Solution:

SYSTEM *A*

Year	Item	Cash flow	Factor	Present worth
0	Investment	− \$25,000	1.0	− \$25,000
0–7	Contribution to CF from depreciation	(0.35)(\$25,000)	0.6191*	+ 5,416
0–7	Contribution to CF from operating expenses	(1−0.35)(7)(6,000)	0.6191*	− 16,901
			Net present worth *A*:	− \$36,485

SYSTEM *B*

Year	Item	Cash flow	Factor	Present worth
0	Investment	−$15,000	1.0	−$15,000
0–7	Contribution to CF from depreciation	(0.35)($15,000)	0.6191*	+3,250
0–7	Contribution to CF from operating expenses	(1−0.35)(7)(11,000)	0.6191*	−30,986
			Net present worth *B*:	−$42,736

*The factor is from the continuous uniform interest table for 7 years at 15% interest or $R \times T = 7 \times 15 = 105$ (Appendix E).

On the basis of net present worth, the case with the greater positive (less negative) net present worth is preferred; therefore, unit *A* is preferred.

12.2.2 Rate of Return

This method and variations of it are known by various names, e.g., internal rate of return, interest rate of return, discounted cash flow rate of return, and profitability index. The simplest case occurs when capital costs are to be balanced against cash flow. Another use of this method is to compute the rate of return on improved cash flow, i.e., lower operating expenses and larger credit for depreciation charges, against a greater net investment when comparing a candidate case against a base case.

Example 12.2

Problem Statement:

For the purpose of illustration, the previous example, Example 12.1, will be used. Figure 12.2 is a cash flow diagram for Example 12.1.

Solution:

For an investment of $10,000 more for unit *A*, there is more

Net income after taxes = $2321/year

After tax cash flow = $3750/year

a. The return on the extra investment for unit *A* compared with unit *B* is

$$\text{ROI} = \left[\frac{\Delta\text{net income after taxes}}{\Delta\text{fixed investment}}\right] \times 100 = \left[\frac{\$2321}{\$10{,}000}\right] \times 100$$

$$= 23.2\% \text{ without accounting for time value of money.}$$

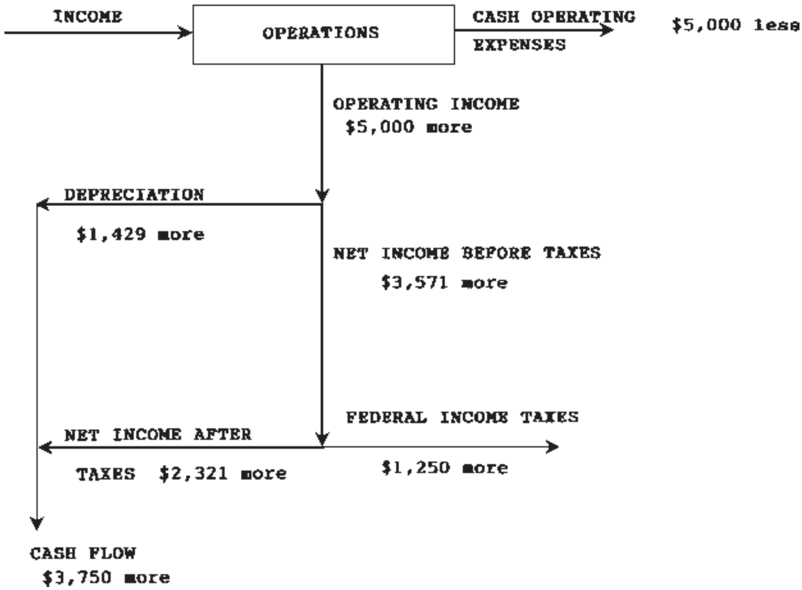

FIGURE 12.2 Case *A* vs. Case *B*.

b. If the time value of money is considered and if the cash flows are continuous, the return on investment is about 34%. Therefore, unit *A* is preferred based upon incremental capital and lower operating expenses.

12.2.3 Capitalized Cost

The term "capitalized cost" is the first cost of an investment plus the present worth of a program to support an infinite number of investment renewals. In other words, it is the cost of providing an investment for a specified duty or service on a perpetual basis or forever.

The "forever" duration serves only to provide a common denominator so that all service lives may be compared on a common basis. The relationship between this method, present worth, and annual cost can be appreciated when it is realized that the annual cost for this perpetual program is the same as the annual cost for the same program for the duration of the least common multiple of years used in the present worth method or for the duration of the estimated life of the investment in question. In fact, the annual cost equals the interest rate used times the capitalized cost. This simple relation makes it easy to convert from one method to another, i.e., capitalized cost to annual cost.

Capitalized cost has been used in certain industries such as utilities and railroads. Humphreys [3] in the revision of Jelen and Black's [4] book has demonstrated its use in the process industries and showed how the method can be modified to account for income tax and inflation along with the rate of return. The alternative with the lower (lowest) capitalized cost is preferred.

The equation to calculate capitalized cost is

$$K = P_n\left[\frac{(1+i)^n}{(1+i)^n - 1}\right] \qquad \text{or} \qquad K = F_n\left[\frac{e^{in}}{e^{in} - 1}\right] \tag{12.6}$$

Example 12.3

Problem Statement:

Let's apply this method to the previous pollution problem, Example 12.1

$$\mathrm{PW}_A = -\$36,485$$

$$\mathrm{PW}_B = -\$42,736$$

If discrete interest is used, then

$$K_A = -\$36,485\left[\frac{(1.15)^7}{(1.15)^7 - 1}\right]$$

$$K_A = -\$31,655\left[\frac{2.660}{2.660 - 1}\right] = -\$58,464$$

$$K_B = -\$42,736\left[\frac{(1.15)^7}{(1.15)^7 - 1}\right]$$

$$K_B = -\$33,833\left[\frac{2.660}{2.660 - 1}\right] = -\$68,481$$

If continuous interest is used, then

$$K_A = -\$31,655\left[\frac{2.858}{2.858 - 1}\right] = -\$56,122$$

$$K_B = -\$33,833\left[\frac{2.858}{2.858 - 1}\right] = -\$65,737$$

This is a trivial example but from the above, the unit with the lower capitalized cost is preferred—unit A. Now let's consider an example with unequal lives.

Example 12.4

Problem Statement:

Two filters are being considered for a research facility. If money is worth 10%, which filter is more economical?

	A	*B*
First cost	$18,000	$28,000
Annual maintenance	4,000	3,000
Capital recovery	500	1,500
Service life, yr	3	5

Under current tax laws, this equipment may be depreciated over a 3-year period.

Solution:

FILTER *A*

Year	Item	Cash flow	Factor	Present worth
0	First cost	−$18,000	1.0	−$18,000
0–3	Contribution to CF from depreciation	(0.35)($18,000)	0.8639*	+5,443
0–3	Contribution to CF from operating expenses	(1−0.35)(3)($4,000)	0.8639*	−6,738
End 3	Capital recovery	(1−0.35)(500)	0.7408**	+241
			Net present worth *A*:	−$19,054

*This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 3 years at 10% interest or R × T = 30.

**This factor is from the Hirschmann-Brauweiler continuous interest table, Appendix E, for an instantaneous cash flow for 3 years at 10% interest or R × T = 30.

FILTER *B*

Year	Item	Cash flow	Factor	Present worth
0	First cost	−$28,000	1.0	−$28,000
0–3	Contribution to CF from depreciation	(0.35)($28,000)	0.8639*	+8,446
0–5	Contribution to CF from operating expenses	(1−0.35)(5)(3,000)	0.7869***	−7,672
End 5	Capital recovery	(1.0.35)(1,500)	0.6065****	+591
			Net present worth *B*:	−$26,615

*This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 3 years at 10% interest or R × T = 30.
***This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 5 years at 10% interest or R × T = 50.
****This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for an instantaneous cash flow for 5 years at 10% interest or R × T = 50.

$$\mathrm{PW}_A = -\$19,054 \ \text{ and } \ \mathrm{PW}_B = -\$26,615$$

$$K_A = -\$19,054 \quad \left[\frac{(1.10)^3}{(1.10)^3 - 1}\right] = -\$19,054\left[\frac{1.331}{0.331}\right] = -\$76,619$$

$$K_B = -\$26,615\left[\frac{(1.10)^5}{(1.10)^5 - 1}\right] = -\$26,615\left[\frac{1.611}{0.611}\right] = -\$70,175$$

or using continuous interest $K_A = -\$76,619$ and $K_B = -\$70,175$. Unit *B* is preferred based on lower capitalized cost. In cases such as these where the results are close, other factors may be deciding. It should be remembered that although first costs are from bids or quotes and they are often firm, operating expenses, especially maintenance, and capital recovery are only estimates. Changes in either or both of these items could affect the final decision.

12.2.4 Equivalent Uniform Annual Cost

This method is also known as the uniform annual cost or "unacost" method [4]. The uniform annual cost is obtained by calculating the present worth of all cash flows associated with the operation through the use of assigned interest rate for discounting purposes. The present worth is then converted (at the same interest rate) to an equivalent uniform annual cash flow over the life of the project. It can be calculated either as a uniform end-of-year payment, using discrete interest, or as a continuous flow, using continuous interest throughout the year. As with the rate of return method, the timing of all cash flows over the life of the project and their nature (instantaneous or continuous) must be taken into account. In this text, this method will be called the uniform annual cost (UAC).

The UAC can be calculated for a cost program over the entire estimated life. It need not be calculated for cost programs having a least common multiple of estimated lives as for the present worth method. Here is one of the advantages the UAC; the other is that the dollar amount for the uniform annual cost is more meaningful and tangible than the figures calculated by other methods. It is most readily understood and simplest to use. It is the preferred method when continuous flows of money are involved requiring continuous interest factors.

The procedure is as follows:

1. Using the estimated life for each alternative, calculate the present worth.
2. For the case using discrete interest, the value of the end-of-year annual cost R is obtained by multiplying the present worth P by the discrete factor which can be found for values of n, the number of periods, and i, the interest rate.
3. When continuous interest is used to compute the present worth, the UAC is found by

$$\text{UAC} = \frac{\text{(net present worth)}}{\text{(years life)(interest factor)}}$$

   The interest factor is the uniform interest factor found in the Hirschmann-Brauweiler tables (Appendix E) or by continuous interest equations.
4. The preferred alternate is the one with the least (or less) negative uniform annual cost or the greatest (or greater) positive uniform annual cost that reflects the most (greater) net gain. Remember the convention that costs are negative.
5. In the UAC equation, the "factor" is always the uniform factor; hence the name *uniform annual cost*. In effect, all the various cash flows are "annualized" by applying the uniform factor.

Examples 12.4 and 12.5 are used to illustrate the use of the UAC method.

Example 12.5

Problem Statement:

Again the pollution abatement example, Example 12.1, will be used.

Solution:

See Example 12.1 for the net present worths. The net present worth of Unit A was $-\$36{,}485$.

$$(\text{UAC})_A = \frac{\text{PW}_A}{(\text{years life})(\text{uniform factor})} = \frac{-\$36{,}485}{(7)(0.6181)} = -\$8433$$

The net present worth of unit B was $-\$42{,}736$.

$$(\text{UAC})_B = \frac{\text{PW}_B}{(\text{years life})(\text{uniform factor})} = \frac{-\$42{,}736}{(7)(0.6181)} = -\$9877$$

Unit A is preferred because it is the more positive uniform annual cost (less negative). This is the same decision that has been reached in the pollution treatment problem solution of Examples 12.1 to 12.3.

Now let's consider an example with unequal service lives.

Example 12.6

Problem Statement:

The problem statement is the same as Problem 12.4.

Solution:

FILTER *A*

Year	Item	Cash flow	Factor	Present worth
0	First cost	−$18,000	1.0	−$18,000
0–3	Contribution to CF from depreciation	(0.35)($18,000)	0.8639*	+5,443
0–3	Contribution to CF from operating expenses	(1−0.35)(3)($4,000)	0.8639*	−6,738
End 3	Capital recovery	(1−0.35)(500)	0.7408**	+241
			Net present worth *A*:	−$19,054

*This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 3 years at 10% interest or $R \times T = 30$.

**This factor is from the Hirschmann-Brauweiler continuous interest table, Appendix E, for an instantaneous cash flow for 3 years at 10% interest or $R \times T = 30$.

$$(\text{UAC})_A = \frac{(\text{NPW}_A)}{(\text{years life})(\text{factor})} = \frac{(-\$19{,}054)}{(3)(0.8639)} = -\$7352$$

FILTER *B*

Year	Item	Cash flow	Factor	Present worth
0	First cost	−$28,000	1.0	−$28,000
0–3	Contribution to CF from depreciation	(0.35)($28,000)	0.8639*	+8,466
0–5	Contribution to CF from operating expenses	(1−0.35)(5)(3000)	0.7869***	−7,672
End 5	Capital recovery	(1−0.35)(1500)	0.6065****	+591
			Net present worth *B*:	−$26,615

*This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 3 years at 10% interest or R × T = 30.
***This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for a uniform cash flow for 3 years at 10% interest or R × T = 50.
****This factor is from the Hirschmann-Brauweiler continuous interest tables, Appendix E, for an instantaneous cash flow for 5 years at 10% interest or R × T = 50.

$$(\mathrm{UAC})_B = \frac{(-\$26615)}{(5)(0.7869)} = -\$6765$$

Unit *B* is preferred because the $(\mathrm{UAC})_B$ is more positive than the $(\mathrm{UAC})_A$ and is the same decision as in Example 12.4.

In the foregoing examples, any method used will result in the same decision, namely, that the same case is preferred to the alternate, although the numerical values obtained by each method may be different. In the rest of this chapter, the UAC method will be used since the various cash flows may be reduced to a single that is a distinct advantage over the other methods.

A form similar to the ones used in the UAC examples is Table 12.1. It is useful in organizing the UAC calculations and as an easy check to ensure that all cash flow items have been included in the analysis.

12.3 OUT-OF-POCKET EXPENSES

In this chapter, the examples and the problems at the end of the chapter are concerned with choice between alternates for corporations. The methods may be used to select alternates for personal use with the exceptions that depreciation and the corporate income tax rate are not applicable. The choice has to be made on the basis of "out-of-pocket" expenses only. Often the techniques for making personal choices are ignored in these cases because in the final analysis personal preference overrides a preferred calculated alternative.

TABLE 12.1 Calculation Form for Choice Between Alternatives

Year	Item	Cash flow	Factor	Present worth
	First cost			(−)
	Contribution to cash flow from depreciation			(+)
	Contribution to cash flow from operating expenses			(−)
	Capital recovery			(+)
		Net present worth		

$$\text{Uniform annual cost} = \frac{\text{(net present worth)}}{\text{(years life)(uniform factor)}}$$

12.4 INCREMENTAL ANALYSIS

When alternates are compared, the analysis used acts as a screen. The alternate with the most promising future is compared to other competitors. Riggs and West [1] point out "two-logically sound selection criteria" that sometimes lead to inaccurate conclusions:

1. Selecting the alternate that offers the highest return on the total investment
2. Selecting the alternative with the largest investment that meets the minimum acceptable rate of return

They state that the "first criterion may bypass alternatives that earn lower rates of return which may still be higher than other options available. The second criterion could lead to a larger investment than is desirable which prevents a portion of the funds from earning higher returns available through substitute investments."

These are the criteria that are erroneously used, recognizing that the first includes comparisons of NPW, ROI, or EUAC [5].

Why are these wrong? Let's consider some alternatives looking at the lowest cost choice. We see that the second alternative is really the same as the cost of the first plus some increment.

$$\text{Cost } 1 = \text{Cost } 2 + \text{increment} \tag{12.7}$$

If we consider only Cost 2 and Cost 1, the incremental cost may be a real loser. Management may have been better off to select the first alternative and put the incremental cost in an investment to return the MARR rather than choose the second investment even though the NPW, ROI, or UAC calculations indicate the second alternative was a good one.

Let's consider an example to illustrate the incremental cost method. This example is adapted from an article by Rose [5].

Example 12.7

Problem Statement:

Four designs for a product and their associated costs are presented in Table 12.2. A 10-year life is used and a 10% MARR (before taxes), which is an expected rate of return from other investments of similar risk, is required. Based upon cash flow, which of these four alternatives appears to be most attractive?

Solution:

ALTERNATIVE A

$$\text{PW} = 0 = [-\$170,000 + (\$114,000 - \$70,000)](P/A\ \ i, 10)$$

where

$$(P/A\ \ i, 10) = \frac{\$170,000}{\$44,000} = 3.8636$$

At 20%: $(P/A\ \ 20, 10) = 4.1924$
At 25%: $(P/A\ \ 25, 10) = 3.5705$

By interpolation, $I = 22.6\%$ which is greater than 10%, so A is acceptable.

The preferred methodology for incremental analysis is to arrange the alternatives in order of increasing cost. The rate of return (ROR) is then calculated for the least-cost alternative. If the ROR exceeds the MARR, the incremental analysis is started. On the other hand, if the ROR is less than the MARR, the low-cost alternative is not acceptable and the next higher cost alternative is tested.

TABLE 12.2 Problem Data

	A	*B*	*C*	*D*
Investment	\$170,000	\$260,000	\$300,000	\$330,000
Receipts	114,000	110,000	130,000	147,000
Disbursements	70,000	71,000	64,000	79,000

TABLE 12.3 Increment Table

	B-A	*C-B*	*D-C*
Investment	\$90,000	\$40,000	\$30,000
Return	\$5,000	17,000	2,000

In the example, however, the low-cost alternative *A* is acceptable so the *B-A* increment must be tested. (*B* is the next higher cost alternative). The increment may be calculated and the increment Table 12.3 is prepared.

TEST THE *B-A* INCREMENT. The annual net return for alternative *B* is compared to alternative *A*:

$$\begin{aligned}\text{Annual net return of increment } A - B &= (\$120{,}000 - \$71{,}000) \\ &\quad - (\$114{,}000 - \$70{,}000) \\ &= \$5000/\text{yr}\end{aligned}$$

The incremental investment is \$90,000 and the 10-year return is 10 × \$5000, or \$50,000. This alternative can be eliminated because the investment will not be paid back in 10 years.

CONSIDER THE NEXT INCREMENT, *C-A*. Alternative *C* is compared with the last acceptable alternative which is *A*.

$$\begin{aligned}\text{PW} =&\{[-\$300{,}000 - (-\$170{,}000)] + [(\$130{,}000 - \$64{,}000)\} \\ &- \$44{,}000](P/A\ \ i, 10) = 0\end{aligned}$$

$$(P/A\ \ i, 10) = \frac{\$130{,}000}{\$22{,}000} = 5.9090$$

At 10% : $(P/A\ \ 10, 10) = 6.1445$
At 11% : $(P/A\ \ 11, 10) = 5.8992$

$$i = 10.9\% > 10\%$$

Therefore, *C* is acceptable.

The rule for acceptance is that if the incremental rate of return, 10.9% in this case, is greater than the MARR, the higher cost alternative is accepted, alternative *C* in this case. If the incremental rate of return is less than the MARR, the lesser cost alternative is accepted.

NEXT CONSIDER THE *D-C* INCREMENT. Alternative *C* is the last acceptable alternative.

$$\text{PW} = \{[-\$330,000 - (-\$300,000)]\} + [(\$68,000 - \$66,000)]\}$$
$$\times (P/A\ \ i, 10) = 0$$

$$(P/A\ \ i, 10) = \frac{\$30,000}{\$2,000} = 15$$

The incremental investment is \$30,000 but the annual return is only \$2000; therefore, alternative *D* can be eliminated since the IRR does not meet the MARR requirements. The lesser cost alternative *C* is the acceptable alternative. Also, the rate of return on the total capital invested for alternative *C* is

$$(P/A\ \ i, 10) = \frac{\$300,000}{\$130,000 - \$64,000} = 4.5454$$

which is an IRR of 18.9%.

In Table 12.4 the results for this example are presented. If the ROR is used as the only selection criteria (incorrectly), the choice would be alternative *A*. Riggs and West [1] point out that

> "One type of mistake would have been to select alternative *A* which has the greatest return on the total investment. This choice would prevent the additional investment of $\$300,000 - \$170,000 = \$130,000$ in alternative *C* which returns 10.9% on the incremental capital. This percentage is higher than the 10% expected from investments of similar risk, a loss of about 1% of \$130,000 would occur. It is wise to remember that high returns are possible through an investment in alternative *A* in case there is insufficient capital to fund alternative *C* or if there is another opportunity of investing \$130,000 at a return greater than 10.9%.

TABLE 12.4 Rate of Return for Each Alternative

Design	Total investment	Annual return	ROR%	ΔROR
A	\$170,000	\$44,000	22.5	
B	260,000	49,000	13.5	
C	300,000	66,000	18.9	10.9
D	330,000	68,000	15.9	

Table 12.5 Present Worth Analysis

	Investment		Annual return		PW at 10%	
	Total	Delta	Total	Delta	Total	Delta
A	$170,000		$44,000		$100,358	
		$90,000		$5,000		($59,278)
B	260,00		49,000		$41,080	
		40,000		17,000		64,457
C	300,000		66,000		105,537	
		30,000		2,000		(17,711)
D	330,00		68,000		87,826	

> "Another type error would be to select the largest investment that meets the 10% rate of return requirement. The unsatisfactory IRR for the extra investment in alternative *D* over *C* was apparent in the incremental analysis. Therefore, putting $\$330,000 - \$300,000 = \$30,000$ into alternative D forces the amount of capital to earn less than 10% that it could receive if invested elsewhere [1]."

Since ROR is a poor criterion, could NPW or UAC be used for this analysis? In Table 12.5, the results of the NPW analysis are presented. The higher NPW is for *C*, the preferred choice as shown by the incremental NPW (the only positive result). This is coincidental.

This presentation of incremental analysis is to illustrate a method when two or more alternatives are compared. Recommending an investment when incremental cost over another alternative does not satisfy the MARR can be a serious error.

12.5 REPLACEMENT THEORY

During the lifetime of a physical asset, the continuation of its use may be open to question and it may be a candidate for replacement. The reason for such consideration might be equipment deterioration or technical obsolescence. For an existing physical asset under scrutiny, the term "defender" has been applied and the corresponding term for the contending replacement is "challenger". This terminology was developed by Terborgh [6] and is still in use today. The uniform annual cost method is preferred for the defender-challenger comparison since all capital costs and operating expense items are reduced to a single UAC.

12.5.1 Rules for Computation

The purpose of this analysis is to determine if the defender's life may be extended one more year. It is important that the following rules be observed when making the computation of the uniform annual costs for both the defender and the challenger.

1. The value of the defender asset is considered in a different light from the challenger that is not owned yet. The defender asset is a sunk cost (paid for). It is irrelevant except insofar as it affects cash flow from depreciation for the remainder of the asset life and a tax credit for the book loss if replaced earlier than its depreciation life. This book loss is the book value of the asset minus capital recovery (salvage value), if any. Grant et al. [7] discuss the book loss further.
2. The uniform annual cost for the challenger is handled in the same manner as the comparison of alternatives.
3. A capital cost for the defender is the net capital recovery foregone (salvage value foregone) and the tax credit from the book loss of the defender asset that was not realized.
4. The uniform annual cost computed for each case uses the time period most favorable to each. Usually this is 1 year for the defender and the full economic life of the challenger.
5. Item rather than group depreciation accounting is used for the handling of losses from early replacement of physical assets. (See Grant et al. [7].)
6. The tax credit that accrues from a book loss by the early retirement of a replaced physical asset is based on the prevailing income tax rate and not the capital gain rate.

12.5.2 Replacement Example

In order to demonstrate how the above rules apply, an updated example based upon a problem from Maristany [8] will be solved as Example 12.8.

Example 12.8

Problem Statement:

A plant has a 3-year-old reciprocating compressor for which the original investment was $150,000. It was depreciated over a 7-year period by the straight-line method. If replaced now, the net proceeds from it sale is $50,000 and it is estimated that 1 year later the net proceeds will be $35,000. A centrifugal compressor can be installed for $160,000 which would save the company $2000 per year in operating expenses for the 10-year life of the investment. Its net proceeds at the end of the tenth year are estimated to be zero. The 7-year straight-line depreciation applies to the centrifugal compressor. A 35% federal income tax rate may be assumed. The company requires an after tax return of 15% on capital invested for this type project. Should the present compressor be replaced at this time?

Solution:

The uniform annual cost method will be used as a basis for comparison. It is assumed that there are continuous flows of money, so continuous interest will be used.

DEFENDER CASE

The basis for this calculation will be 1 year. If the defender is not replaced now, the rules above indicate that there is the equivalent of a capital cost for two benefits foregone (given up).

- Net proceeds now at 3 years of $50,000
- Tax credit for the loss that will not be realized

This net loss is calculated as follows:

Net loss foregone = book value at end of 3 years minus net capital recovery (salvage value) now, or

$$NLF_3 = BV_3 - NCR_3$$

where

$$\begin{aligned} NLF_3 &= \text{net loss foregone at end of 3 years} \\ BV_3 &= \text{book value at end of 3 years} \\ NCR_3 &= \text{net capital recovery at end 3 years} \end{aligned}$$

$$NLF_3 = \$150,000\left[1-\frac{3}{7}\right] - \$50,000 = \$85,714 - \$50,000 = \$35,714$$

$$\text{Depreciation for the fourth year} = (\$150,000)\left[\frac{1}{7}\right] = \$21,429$$

$$NLF_4 = BV_4 - NCR_4$$

$$NLF_4 = \$150,000\left[1-\frac{4}{7}\right] - \$35,000 = \$64,286 - \$35,000 = \$29,286$$

UAC Calculations:

Year	Item	Cash flow	Factor	Present worth
At 0[a]	Tax credit for net loss foregone	(0.35)(− \$35,714)	1.0	− \$12,500
At 0[a]	Net cash recovery foregone	− \$50,000	1.0	− \$50,000
0–1	Contribution to CF from depreciation	(0.35)(− \$21,429)	0.9286[b]	+ \$6,965
0–1	Contribution to CF from operating expenses	(1−0.35)(− \$15,000)	0.9286[b]	− \$9,054
End 1	Tax credit for net loss	(0.35)(+ \$29,286)	0.8607[c]	+ \$8,822
End 1	Net cash recovery	+ \$35,000	0.8607[c]	+ \$30,125
			Net present worth	− \$25,642

$$\text{UAC} = \frac{\text{net present worth}}{(\text{years life})(\text{uniform factor})}$$

$$\text{UAC} = \frac{(-\$25{,}642)}{(1)(0.9286)} = -\$27{,}614$$

CHALLENGER CASE

Year	Item	Cash flow	Factor	Present worth
0	First cost	− \$160,000	1.0	− \$160,000
0–7	Contribution to CF from depreciation	(0.35)(\$160,000)	0.6191[d]	+ \$56,000
0–10	Contribution to cash flow from operating expenses	(1−0.35)(10)(− \$13,000)	0.5179[e]	− \$43,763

(*Continued*)

Year	Item	Cash flow	Factor	Present worth
			Net present worth	−$147,763

$$\text{UAC} = \frac{\text{net present worth}}{(\text{years life})(\text{uniform factor})}$$

$$\text{UAC} = \frac{-\$147{,}763}{(10)(0.5179)} = -\$28{,}531$$

[a] For the defender case, zero year is taken as the end of the third year.
[b] From the Uniform Hirschmann-Brauweiler Table, Appendix E, for argument $R \times T = 15 \times 1$.
[c] From the Instantaneous Hirschmann-Brauweiler Table, Appendix, E, for the argument $R \times T = 15 \times 1$.
[d] From the Uniform Hirschmann-Brauweiler Table, Appendix E, for the argument $R \times T = 15 \times 7$.
[e] From the Uniform Hirschmann-Brauweiler Table, Appendix E, for the argument $R \times T = 15 \times 10$.

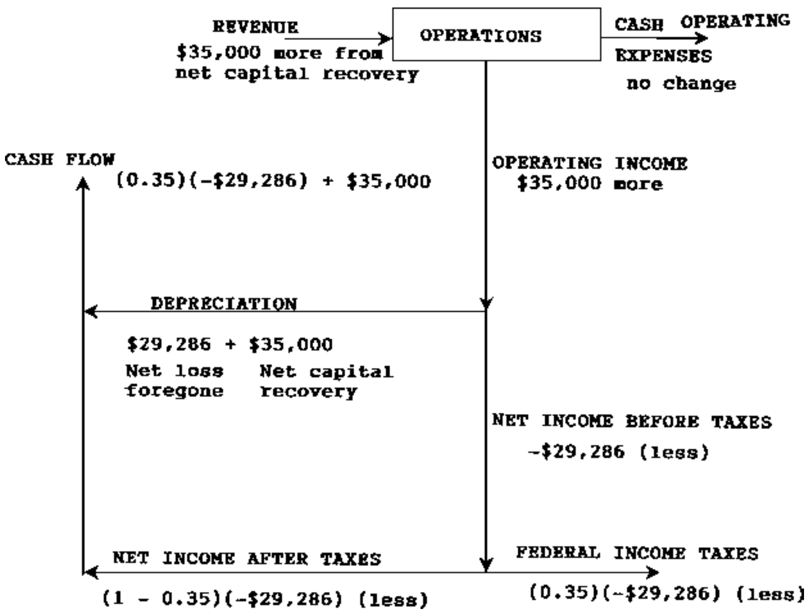

FIGURE 12.3 Cash flow diagram for year 4 of Example 12.8.

The UAC for the defender case is less negative (more positive) than the UAC for the challenger case, i.e., −$27,614 compared to −$28,531; therefore, the defender case is favored and the reciprocating compressor should not be replaced now.

It may be difficult understand why a tax credit applies to end of year 1 for the defender case and why the net capital recovery is counted at full value. These cash flow streams at the end of the first year (and similar cash flow streams at zero time but negative in value represent benefits foregone, given up, or denied) can be understood with the aid of a cash flow diagram, Figure 12.3, and the following discussion.

First, it must be recognized that business as well as income tax accounting procedures provide for charging over the life of an asset an amount exactly equal to the fixed capital investment (sometimes called "first cost"). This procedure is called "enter to cost" and the charging process is generally taken care of by depreciation.

If equipment is retired early, the depreciation reserve (i.e., the sum of the depreciation to date) plus the loss foregone and the net capital recovery will equal the first cost.

For the defender case, the sum of the three values in any year must total to $150,000, the first cost (Table 12.13).

Item	Year 3	Year 4
Depreciation reserve	$64,286	$85,714
Capital recovery	50,000	35,000
Net loss foregone	35,714	29,286
Total	$150,000	$150,000

Both the net loss foregone and the net capital recovery are handled as depreciation on the cash flow diagram. It is helpful in determining the pertinent cash flow stream for this type problem. The benefits denied at time zero can also be determined by using a cash flow diagram but the corresponding streams will have opposite signs.

12.6 OPPORTUNITY COST

In general, there is more than one opportunity to invest capital. Each time an investor accepts one of several opportunities, the opportunity of investing in others is foregone. Therefore, the "opportunity cost" can be defined as the cost of the best opportunity given up or foregone. Alternatively, the opportunity cost also can be defined as the rate of return of the best rejected alternative proposal.

12.7 SUMMARY

In this chapter, the methods for comparing choices between alternatives were presented. With simple conventions, it is possible to handle a wide variety of problems, not only for industrial but also for personal applications. The author suggests the uniform annual cost method be used to assist in the decision-making process, since all cash flows are reduced to a single number. It is also useful to sketch cash flow diagrams for each alternative to envision how the cash flows. The time value of money, taxes and inflation can be included in the calculations.

Previously in this chapter, mention was made that whichever interest method is used, discrete or continuous, the decision is not affected, only the numerical results will be different. The key to which method is to be used depends on the cash flow patterns of the company. Because some companies encounter continuous inflows and outflows of cash, continuous interest is used in their computations.

When performing incremental analyses, the accepted methodology is to arrange the alternatives in order of increasing cost. A measure of profitability used is then calculated for the least-cost alternative and compared to the minimum acceptable rate of return. In using this approach, proper criteria for accepting an alternative is used without introducing serious errors.

The chapter closes with a treatment of replacement as a special case. With the few rules listed in Section 12.5.1, it is possible to solve replacement evaluations, regardless of their complexity. The skill lies more in setting up the problem for solution. Usually there are factors other than costs that need to be considered when making a replacement decision. Each of these factors should be written and insofar as possible quantified. In any event, they should be assessed. The case with the least negative uniform annual cost is often the preferred one but upon considering other factors that may not be the case. A case for replacement of equipment must be strong because of the reluctance of management to authorize an expenditure of capital. For another viewpoint on replacement analysis, and article by Sprague and Whittaker [9] might be considered.

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PROBLEMS

These problems are arranged in order of increasing difficulty. Problems 12.9–12.13 are on replacement. Anyone who can work these exercises should feel confident that they can solve problems of considerable difficulty involving choice between alternatives and replacement.

12.1 A capital expenditure for the installation of an item of equipment is being considered for performing an operation that is presently performed by hand labor. The costs for each case are found below.

System	*A*	*B*
Labor and labor extras	\$8,200	\$3,300
Power		400
Maintenance		1,100
Property taxes and insurance		300
Equipment cost including installation		15,000
Estimated equipment life, yr		10

The depreciation rate will be 7 years straight-line and the income tax rate is 35%. A 15% return on investment is required by management. Indicate which scheme is preferred from a cost standpoint.

12.2 A gasoline-driven and an electrically powered pump are being considered for service in a remote location. Pertinent data are as follows:

Item	Gasoline	Electric
First cost	\$2500	\$4500
Estimated life, yr	5	10
Capital recovery at end of life	300	550
Annual utility expense	900	600
Annual maintenance	300	200
Annual property tax and insurance	2% of the first cost	

The income tax rate is 35% and the acceptable return is 15%. Assuming straight-line depreciation applies over the life of the investment, determine which of these installations is more attractive.

12.3 A wooden floor costs $5000 and is expected to last 2 years. When it wears out the next time, it is proposed to replace it with a more durable floor that is expected to cost $16,500. The minimum acceptable return is 10% and the income tax rate is 35%. What life should the more expensive floor have to justify its installation? Use straight-line depreciation. Solve this problem as a corporate case and as an out-of-pocket expense.

12.4 A certain item of processing equipment is required for the manufacture of a dye intermediate. Batch or continuous methods of operation are technically feasible. Using the data below, determine which mode of operation is to be preferred economically.

Item	Batch	Continuous
Equipment cost	$18,000	$50,000
Useful life, yr	7	10
Depreciation, straight-line, yr	7	7
Capital recovery at end of useful life	$1,500	0
Annual power costs	$1,500	$3,000
Annual labor costs	$11,200	$1,800

Return on investment is based upon 15% continuous interest and the income tax rate is 35%.

12.5 A contractor has offered to install a copper roof on a small office building for $60,000. The life of this roof is expected to be 40 years with annual maintenance expenses of $1000. As an alternative, a composition roof can be installed for $32,000 and it is expected to last 20 years. The annual maintenance for this roof is estimated to be $500. Depreciation is taken as 7 years straight-line in each case. A continuous interest rate of 8% may be assumed and the tax rate is 35%. Based upon this information, which roof should be installed and why?

12.6 A storage tank in a highly corrosive atmosphere lasts five years and costs $10,000. It is estimated that the life of this tank may be extended to 10 years by painting it at the beginning of each year. How much can be spent on painting this tank yearly if the minimum acceptable return is 15%, and the income tax rate is 35%. Straight-line depreciation over the full life is to be used.

12.7 The life of tubes in an evaporator is such that they need to replaced every 8 years if the evaporator is operated under scaling conditions; however, for the scaling operation there is a cleaning cost of \$2000/yr. On the other hand, operating under essentially non-scaling conditions should reduce the cost of cleaning to \$500/yr and give an estimated saving of \$1200/yr because of better heat transfer. The nonscaling operation will shorten the life of the tubes. If tube replacement costs \$8000, how long must the tubes last to justify the proposed nonscaling operation? Seven-year straight-line depreciation is to be used when replacing the tubes. Minimum acceptable return is 15% and the income tax rate is 35%.

12.8 An investor hired a consultant to analyze what he might do with a parcel of land in an expanding area of town. He bought the land for \$30,000 several years ago. The consultant suggested the following alternatives:

Alternative	Total investment including land	Net capital recovery at end of 10 yr	Net cash after taxes
a. Do nothing	0	0	0
b. Vegetable market	\$80,000	\$30,000	\$17,200
c. Candy store	\$165,000	\$40,000	\$31,000
d. Convenience store	\$275,000	\$60,000	\$49,500

You may assume a 10-year project life, 10-year straight-line depreciation, and 35% federal income tax rate and 10% continuous interest. Using present worth analysis, what should the investor do?

12.9 A short road to a tank farm in a Gulf Coast petrochemical facility was built 10 years ago and is being depreciated by the straight-line method over a period of 15 years. This road is in need of repairs. The maintenance department estimates that repairs will extend the life of the present road for three more years but the cost is \$45,000. These repairs are not depreciable.

A contractor has offered to replace the road for \$200,000 and it is expected to have a 20-year life. It can be depreciated over 15 years by the straight-line method. Maintenance expenses on the repaired road are estimated to average \$3,000 per year and on the new pavement to average \$1600/yr.

If the federal income tax rate is 35% and 10% return is required on capital invested, should the road be repaired or replaced?

12.10 A pump costing \$6000 was installed in a plant 2 years ago but it is not well suited to the duty due to excessive power costs. This pump was being depreciated over a 7-year period via the straight-line method. If the pump is replaced now, it is expected that a capital recovery of $1000 is possible, however, 1 year from now this recovery will drop to $250 and in 2 years to $100. It is expected that the operating expenses for the next year will be $700 and for the second and following years will be $800/yr. The cost of a replacement pump is $3800 and should last 7 years. At the end of its life, a capital recovery of $300 is estimated. The operating expenses for this pump should be about $400/yr. Management requires a 15% minimum acceptable return on invested capital. Straight-line depreciation over a seven-year period is to be used for the new pump. A 35% federal income tax rate is in effect. Should the present pump be replaced now? State any assumptions made.

12.11 A research laboratory has found that a product can be made by a new electrolytic process. It is now being made by what appears to be a more costly thermal process. The question is whether the new process should be installed immediately. The existing equipment was installed five years ago costing $100,000 and is being depreciated over ten years via the straight-line method. It has a net capital recovery of $10,000 now but will decrease to $8000 by next year. The annual operating expense is $60,000. The capital investment for the new electrolytic process if $150,000 and it is estimated to have a 12-year life with a capital recovery of $10,00. The annual operating expense including electricity is $75,000, but it will save $35,000 per year in raw material costs, resulting in a net annual operating expense of $40,000. At the end of every 3 years, the cells will need to be overhauled at an expense of $30,000 that you may assume is an operating expense. During the seventh year auxiliary equipment will need to be rebuilt at a cost of $25,000; this cost may be considered as a capital cost and it needs to be depreciated over the remaining 5 years. Further, a patent must be purchased for $50,000. The minimum acceptable rate of return is 15%, the income tax rate is 35% and straight-line depreciation is to be used. Should the company install the electrolytic process now?

12.12 A small used pickup truck for personal use may be acquired for $6,000 and its trade-in value at the end of each year is 75% of that at the beginning of the year. For this problem, it may be assumed that the maintenance expenses increase linearly above the base maintenance expense of $200. If money is worth 10%, how many years should the truck be kept before it is replaced? Use continuous interest and corporate income taxes do not apply.

12.13 A small bagging machine costs $30,000 and is expected to last 7 years with a capital recovery of $1,000 at all times. Past operating and maintenance expenses for this unit for each year are as follows:

Year	Expenses
1	$3,000
2	3,500
3	8,000
4	11,000
5	15,000
6	5,000
7	15,000

If depreciation is taken as 7-years straight-line, 10% continuous interest is used and the income tax rate is 35%, how long should the machine be kept. (Adapted from Ref. 1.)

13

The Economic Balance

An engineering cost analysis can be used to find either a minimum total cost or a maximum benefit, such as a maximum profit for a venture. Such a cost analysis is frequently called an *economic balance* because it involves the balancing of economic factors to determine an optimum design or optimum operating conditions. In engineering work, correct economic analyses of both designs and operations are essential skills. An understanding of the underlying concepts of such analyses is needed for the solution of many problems and forms the basis for decisions; these can be on-the-spot or detailed investigations.

In the early days of chemical engineering, the *process economics* course was a course in economic balance. In recent times, the economic balance part of a process economics course has been referred to as *simple optimization of process equipment*. Peters and Timmerhaus [1] call this topic *optimum design*.

The goal is to attain the "best" situation by applying simple optimum-seeking techniques. The major challenge is to recognize the existence of an economic balance problem and then to formulate the problem for a solution. An economic balance then is a study of all costs, expenses, revenues, and savings that pertain to an operation or equipment size.

Linear programming, dynamic programming, geometric programming, and other sophisticated optimum-seeking techniques are beyond the scope of this text. For more on these types of optimization methods, the author suggests the reader may wish to consult Refs. [1–5].

13.1 GENERAL PROCEDURE

The initial step in the development of an economic balance is to determine what variable(s) is to be optimized. Before we begin discussing the methodologies, there is terminology that needs to be defined.

The term *cost* refers to a one-time purchased price of capital equipment, such as a heat exchanger. If an item is a recurring "cost," it is called an *expense*, such as utilities or maintenance expense. Although this terminology is different from that found in some texts, at least it is consistent with the material in this text.

For the simplest case, all costs and expenses are related to an arbitrarily selected *controllable* variable. This variable might be the number of pounds of product manufactured, the area of a heat exchanger, the number of evaporator effects, the internal rate of return, etc. Those items in the cost analysis that increase with an increase in the *controllable* variable are balanced against those items that decrease as the *controllable* variable increases. Any costs or expenses that are constant, that is, independent of the *controllable* variable, do not need to be included in the analysis since they do not affect the final result of the analysis and only complicate the mathematics. Therefore, in an economic balance, the analysis is not limited to the sum of the fixed and variable expenses, although most examples are presented in this manner.

13.2 PRACTICAL CONSIDERATIONS

The various methods for determining optimum conditions described in this chapter are theoretical and they meet the required conditions for an optimum case. Often the solution may lead to a result for which industrial equipment is not available in the optimum size. Some equipment is manufactured in discrete sizes. For example, in the case of an optimum pipe size, a mathematical or graphical result may indicate that a pipe diameter of 2.67 in is optimum. If the fluid to be pumped is compatible with steel and Schedule 40 pipe is suitable, commercially available pipe sizes are $2\frac{1}{2}$ in (ID = 2.469 in) or 3 in (ID = 3.069 in) sizes. The engineer would be confronted with making a choice. The smaller diameter pipe would lead to higher pumping costs and lower pipe costs while the larger diameter pipe would have lower pumping costs but slightly higher pipe costs. Now we encounter an "engineering trade-off" that the engineer must resolve. In the author's experience, the 3 in pipe would be recommended since this allows for any potential errors in the theoretical calculations but also provides for increased production that will surely occur once the equipment is put in operation. Further, the company may have a standards program for piping such that only nominal 1, $1\frac{1}{2}$, 2, 3 in, etc. pipe will be stocked. These are practical considerations that the engineer must recognize.

Some equipment is available or can be manufactured in a continuum of sizes. In general, it is often cheaper to accept a slightly larger size rather than incur the expense of a tightly designed equipment item. For example, results of calculations indicate that a 2250 ft^2 is required for specific conditions but a fabricator has off-the-shelf exchangers of 2000 or 2500 ft^2. It is frequently cheaper to purchase the 2500 ft^2 unit rather than have a 2250 ft^2 exchanger designed and manufactured. Further, the larger unit permits more operating flexibility. An analysis of optimum conditions can only give approximate results but do serve the purpose of obtaining a minimum cost.

There are other factors that might affect an engineering recommendation, for example, the physical properties of a material. A material may be too viscous under the proposed operating conditions and a theoretical optimum may not attainable. Intangible features may also enter into the analysis like uncertain design or processing conditions or perhaps uncertain product selling price that might affect the optimization. Therefore, the economic analysis precludes the engineer from exercising extreme accuracy.

13.3 GENERAL PROCEDURE FOR FINDING OPTIMUM CONDITIONS

The first step is to determine what variable is to be optimized, and then it is necessary to determine what relationships affect the variable. Equipment designed to provide a specific duty or service should be sized so that the total annual expense, that is, the sum of the annual fixed and variable expenses, is a minimum. This ideal must be consistent with operating limitations and provide some flexibility. The essential elements of an economic balance are:

- Fixed and variable operating expenses
- An allowance for depreciation
- A term for an acceptable return on an investment

Prior to the 1960s, economic balances were performed without a term for the return on invested capital. Happel [6] identified the need to include such a term because funds for a proposed venture would have to be obtained from external sources or internally generated funds. In either case, the return term represents an expense to the corporation no matter from where the funds are obtained.

Two kinds of expenses are accounted for in an economic balance, namely, variable and fixed operating expenses.

13.3.1 Variable Operating Expenses

These expenses are recurring expenses and were discussed in Chapters 3 and 5. Table 13.1 is a list of those operating expenses that affect optimization of equipment size. Only those expenses that change with equipment size need be included in the analysis. Engineers will frequently complicate the mathematics by including variables that are of little or no consequence. A general rule is that as a first attempt, keep the analysis simple, and if more variables are thought to be required, then include them later.

In the case of equipment optimization, the major operating expenses are the utilities. Examples are

- Pipe size—electricity required to pump fluids
- Insulation thickness—the value of the condensed steam
- Multiple-effect evaporators—the cost of steam required

Other operating expenses that may be included are maintenance and waste disposal expense, and in the case of a chemical reactor, chemical raw materials may be a factor.

Table 13.2 is a guide for maintenance expenses.

TABLE 13.1 Operating Expenses in Equipment Optimization

Item	Comments
Raw materials	Generally only enters if the equipment is a reactor
Direct operating labor	Seldom affects the optimization
Supervision	Seldom affects the optimization
Maintenance	Can be a factor; usually expressed as a fraction of the fixed capital investment, (0.05–0.10) FCI
Plant supplies	Usually negligible
Utilities:	Usual variables
Steam	
Electricity	
Water	
Fuel	
Property taxes	Generally expressed as a fraction of the fixed capital investment, (0.02–0.04) FCI
Insurance	Generally expressed as a fraction of the fixed capital investment, (0.01–0.02) FCI

TABLE 13.2 Annual Maintenance Expense: Percentage of the Fixed Capital Investment

Type of equipment	Maintenance, %
Simple, light use	2–5
Average	5–8
Heavy or complicated	8–10

13.3.2 Fixed Operating Expenses

These expenses include depreciation and plant indirect expenses such as property taxes, insurance, fire protection. All these items are expressed as a fraction of the equipment cost or the fixed capital investment. The fixed capital investment represents the total money spent to purchase equipment and place it in operation. It is customary to include the return on investment on an after-tax basis using the federal rate but occasionally state and local taxes may also be included in the expression for the fixed expenses. Table 13.3 is a checklist of these items. To simplify the mathematics, annual expenses are considered to be constant, therefore; depreciation is calculated on a straight-line basis.

To estimate the total fixed capital investment, the Hand, Wroth, or Brown methods suffice for economic balances since most are of a preliminary nature.

As a general rule, variable operating expenses decrease with increasing equipment size while fixed expenses increase with increasing size, as shown in Figure 13.1.

TABLE 13.3 Checklist of Fixed Capital Items

Delivered equipment costs
Equipment installation
Automatic control equipment
Installation of automatic control equipment
Piping and ductwork
Insulation
Electrical equipment and installation
Auxiliary equipment
Engineering costs association with equipment installation

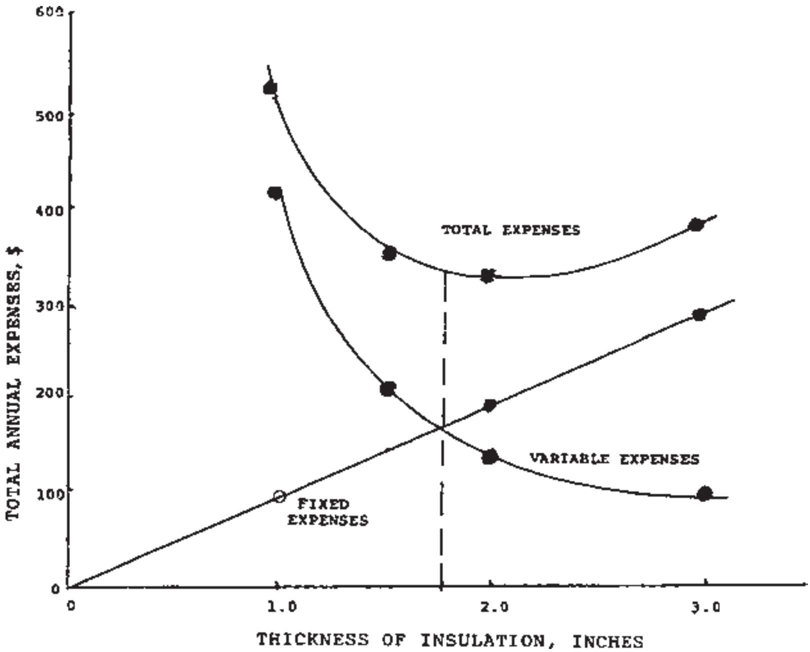

FIGURE 13.1 Optimum thickness of insulation—typical results.

13.4 PROCEDURE FOR SOLVING SINGLE-VARIABLE BALANCES

There are many instances where the optimization is based on a single variable. In that case, the procedure is simple. In Figure 13.1, the objective is to find the insulation thickness that gives the least total cost. The single variable then is the insulation thickness and variable and fixed cost relationships can be developed.

The general procedure for solving single-variable problems consist of the following steps:

1. Determine all expenses that need to be considered in the balance. These will be those expenses that vary as the size changes. For checklists, refer to Tables 13.1–13.3. Expenses that do not change need not be included but it is an error to exclude an expense that varies with equipment size.
2. Determine if any operating limitations exist. Some common examples are:
   - Limiting pressure drop in packed and tray towers above where flooding occurs.

- Limiting head for pipelines when flow is by gravity.
- A safety margin for reflux ratio in a distillation column above minimum reflux to ensure some tolerance because of inaccuracies in design and thermodynamic data

3. Mathematically express the expenses as a function of the variables, preferably those related to equipment size; otherwise use variables that define the operation, such as temperature, concentration, pressure. The final expression should include all pertinent expenses. The variables next need to be reduced to only those items that are significant. Frequently, only one variable is used in total expense equations e.g., pipe size for economic pipe diameter, number of effects in evaporator systems, etc.
4. Ascertain if the optimum size must be one of a number of discrete sizes that are commercially available or whether it can be any size. For example, pipe insulation as shown in Figure 13.1 can only be purchased in standard thickness. Distillation towers, heat exchangers, rotary driers, etc. may be fabricated in any size specified by the design engineer.
5. Solve the total expense equation by either an analytical or graphical method. These two methods have certain advantages and disadvantages.

13.4.1 Analytical Method

Common mathematical techniques are used to locate the optimum. For problems concerned with equipment size, the minimum size is sought; however, in cases where optimum yield is sought, the objective is to find the maximum. For the simple case in which all expenses are expressed as functions of a single variable, the total expense equation can be differentiated with respect to the single variable, the result set equal to zero and the equation solved for the optimum. Unless it is obvious from the nature of the expense curves that there is a true optimum, mathematical tests must be performed as a check.

$$\text{Total annual expenses} = \text{fixed expenses} + \text{variable expenses}$$

where the fixed expenses are depreciation and plant indirect expenses. By convention, the return on investment term is included with the fixed expenses. The variable or recurring expenses are utilities, maintenance, etc. Therefore,

$$\text{TAE} = \text{FE} + \text{VE} \tag{13.1}$$

where

$$\text{TAE} = \text{total annual expenses}$$
$$\text{FE} = \text{fixed expenses}$$
$$\text{VE} = \text{variable expenses}$$

If the derivative of Eq. (13.1) is taken with respect to the controllable variable x, then

$$\frac{d(\text{TAE})}{d\text{x}} = \frac{d(\text{FE})}{d\text{x}} + \frac{d(\text{VE})}{d\text{x}} \tag{13.2}$$

Equation (13.2) is set equal to zero and solved for x,

$$\frac{d(\text{FE})}{d\text{x}} + \frac{d(\text{VE})}{d\text{x}} = 0 \tag{13.3}$$

The value of x is either a maximum or minimum, depending on the problem objective.

Advantage of method: It is a quick method.

Disadvantages of method:

1. Does not afford ready comprehension of how different cost elements vary with size.
2. Final answer does not yield standard sizes.
3. Does not indicate how sharp the maximum or minimum curve is at the optimum.
4. May result in an equation that is difficult to solve mathematically.

13.4.2 Graphical Method

For a reasonable range of sizes, the fixed and variable expenses in the total expense equation are calculated and tabulated. For piping and insulation, discrete commercial sizes are selected. The graphical method is shown in Figure 13.1. For equipment that is not fabricated in discrete sizes, the selection is dictated by the design engineer or by common engineering practice. The optimum is found by plotting the fixed expenses, variable expenses, and the total expense curves as a function of the controllable variable. From the plot, one may observe the nature of the optimum and provide a basis for judgment. If the curve has a sharp minimum, the indicated size is correct; however, if the total expense curve is relatively flat, there is some latitude in the choice. For instance, if the proposed investment is to be a minimum, the smaller equipment size is selected, whereas, if a margin for increased capacity is desirable, then a larger size might be selected provided that there is not a significant increase in the total annual expenses.

Advantages:

1. Yields an answer for available or approximate sizes that will provide the desired service at minimum cost or will provide maximum yield.
2. Produces a solution where the analytical method may be difficult or impossible to solve.
3. Indicates pictorially how the fixed, variable and total annual expenses vary with size.

Disadvantage: Takes more time to solve:

Example 13.1 is an illustration of the analytical and graphical techniques.

Example 13.1

A food company is concerned is about the conservation of energy in their baking ovens. New insulation needs to be installed and the information for this economic analysis is:

Temperature at surface of the inside oven wall	550 F
Ambient air temperature	70 F
Combined ambient air film coefficient	4 Btu/hr ft^2 F
Thermal conductivity of insulation	0.30 Btu/hr ft F
Insulation cost, installed	\$3.50/board ft
(A board foot is 1 ft^2 of area, 1 in. thick or 144 in.^{3})	
The value of heat	\$3.00/MM Btu
Estimated oven life	10 yr
Depreciation	7 years straight-line
Maintenance	3% FCI/yr
Insurance and property taxes	1.5% FCI/yr
Combined federal and state taxes	42%
Stream time	8700 hr/yr
Cost of capital	10%

Determine the optimum insulation thickness.

Only the expenses that appear to vary with insulation thickness will be considered:

- Installed cost of the insulation
- Cost of heat lost through the oven wall
- Maintenance on the insulation
- Depreciation

- Insurance and property taxes
- Return on investment

Analytical Solution:

Basis: 1 year of operation and 100 ft^2 of oven wall surface. Let

$$\begin{aligned} t &= \text{thickness of insulation, in} \\ \text{TAE} &= \text{total annual expense, \$} \\ q &= \text{heat loss through insulation, Btu/hr} \\ U &= \text{overall heat transfer coefficient, Btu/hr ft}^2/^\circ\text{F} \\ \text{FCI} &= \text{fixed capital investment, \$} \\ A &= \text{area of oven wall, ft}^2 \\ \Delta T &= \text{driving force temperature difference, }^\circ\text{F} \end{aligned}$$

$$\text{Total fixed expenses} = \text{depreciation} + \text{return on investment} \tag{13.4}$$

$$\text{Total fixed expenses} = \frac{1}{7}\,\text{FCI} + \left[\frac{0.10}{1-0.42}\right]\text{FCI} \tag{13.5}$$

$$\text{Total fixed expenses} = 0.143\,\text{FCI} + 0.172\,\text{FCI} = 0.315\,\text{FCI} \tag{13.6}$$

On the basis of 100 ft^2

$$\text{FCI} = (100)(3.50)t = 350t \tag{13.7}$$

Therefore,

$$\text{Total fixed expense term} = (0.315)(350)t = 110t \tag{13.8}$$

$$\begin{aligned} \text{Variable expenses} = {} & \text{Cost of heat lost} + \text{maintenance} \\ & + \text{insurance} + \text{property taxes} \end{aligned} \tag{13.9}$$

$$\text{Heat loss expense} = (Q)(8700)\left(\frac{\$3.00}{10^6}\right) \tag{13.10}$$

but

$$q = UA\Delta T = U(100)(500-70) = 43{,}000U \tag{13.11}$$

and

$$U = \frac{(1)}{1/[0.25 + (t)(0.30)/(12)]} \tag{13.12}$$

$$\text{Heat loss} = \left[\frac{(43{,}000)(8700)(\$3.00)}{10^6}\right]\left[\frac{1}{0.25+0.278t}\right] \tag{13.13}$$

$$\text{Maintenance} = 0.03\,\text{FCI} = (0.03)(350)t = 10.5t \tag{13.14}$$

$$\text{Insurance} + \text{property taxes} = 0.015\,\text{FCI} = 5.25t \tag{13.15}$$

$$\text{Total variable expenses} = 10.5t + 5.25t + \frac{1122}{0.25 + 0.278t} \tag{13.16}$$

$$\text{Total annual expenses} = 1100t + 10.5t + 5.25t + \frac{1122}{0.25 + 0.278t} \tag{13.17}$$

$$\text{Total annual expenses} = 125.8t + \left[\frac{1122}{0.25 + 0.278t}\right] \tag{13.18}$$

$$d(\text{TAE})/dt = 125.8 - \left[\frac{1122}{(0.25 + 0.278t)^2}\right] \tag{13.19}$$

$$t = 4.75\,\text{in}$$

This solution does not indicate how sharp the minimum is, nor does it indicate which of the nearest sizes of insulation will be more economical, 4 or 5 in thickness. This decision must be resolved by calculating the total annual expense for both sizes, viz. 4 and 5 in, or by preparing a graphical solution. Probably the 5-in insulation will be selected.

Graphical Solution:

The graphical solution is performed using the same expense equations as in the analytical solution. The terms for each expense item are calculated and presented in Table 13.4. In order to complete this solution, the fixed expenses [Eq. (13.8)], the variable expenses [Eq. (13.9)] and the total annual expenses [Eq. (1.17)] are plotted as a function of t, the thickness of the insulation. The resulting total minimum expense is found to be 4.75, as shown in Figure 13.2.

13.5 PROCEDURE WITH MORE THAN ONE CONTROLLABLE VARIABLE

In some economic analysis problems, more than one controllable variable affects the optimum cost or maximum yield. The general approach, analytical or graphical, for solving this type problem is the same; however, determining the optimum is rather tedious. This situation occurs when technical relations between design, batch size, or other economic conditions produce a basis equation such as in Eq. (3.20):

$$C_T = g(x, y) \tag{13.20}$$

TABLE 13.4 Tabulated Results of Graphical Solution for Example 13.1

Thickness	3 in	4 in	4.75 in	5 in	6 in	7 in	8 in
Fixed expenses	$330.00	$440.00	$522.50	$550.00	$660.00	$770.00	$880.00
Variable expenses							
Heat loss	$1,035.06	$823.79	$714.42	$684.15	$584.98	$511.07	$454.42
Maintenance	31.50	42.00	49.88	52.50	63.00	73.50	84.00
Taxes & insurance	15.75	21.00	24.94	26.25	31.50	36.75	42.00
Total variable expenses	$1,082.31	$886.79	$789.24	$762.90	$679.98	$621.32	$580.42
Total annual expenses	$1,412.31	$1,326.79	$1,311.74	$1,312.90	$1,339.48	$1,391.32	$1,460.42

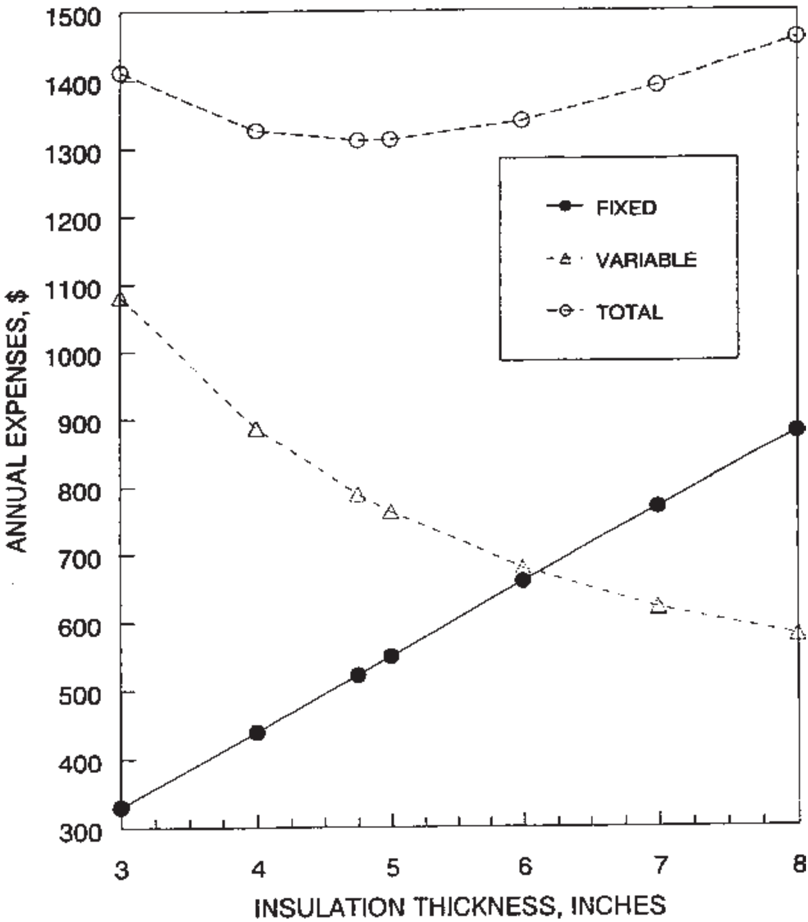

FIGURE 13.2 Optimum insulation thickness—Example 13.1.

For example, in a manufacturing process, the production capacity may vary with the speed of the equipment and its size. Since both variables are controlled by management or design personnel, perhaps the best policy is a combination of optimum speed and optimum size. The mathematical relationships for a case of two (or more) variables may be:

$$C_T = ax + \frac{b}{xy} + cy + d \tag{13.21}$$

where

$$C_T = \text{annual dollars}$$
$$x, y = \text{controllable variables}$$
$$a, b, c, d = \text{constants}$$

The annual cost will pass through a minimum when either x or y is held constant as found by partial differentiation.

$$\frac{\partial c}{\partial x} = a - \frac{b}{yx^2} \tag{13.22}$$

and

$$\frac{\partial c_T}{\partial y} = \frac{-b}{xy^2} \tag{13.23}$$

If c_T is plotted as the ordinate with x as the abscissa and y as the third coordinate, a curved surface results as shown in Figure 13.3. The minimum cost c_T is found by plotting Eq. (13.21) for assumed constant values of x. The line made where one constant x plane intersects the surface will give a minimum cost c_T and an optimum value. The same result may be found analytically by setting Eq. (13.23) equal to zero and solving for y at a constant assumed value of x.

Example 13.2 is an illustration of finding the optimum when two controllable variables are present. This problem is adapted from Schweyer [7].

Example 13.2

A plastics plant is producing a variable number of blended specialty products per year that sell at a fixed price. The final product is composed of two materials,

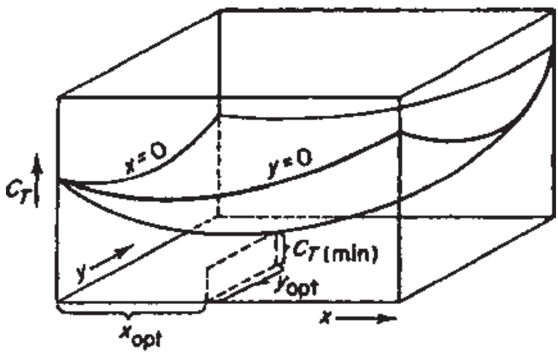

FIGURE 13.3 Economic balance with two variables.

A and B, with some of each being required. The costs will vary depending upon the amount of each component required to meet production.

Expenses for the process employing component A vary as $2A/10^2$ dollars per unit of product. Expenses for component B are $(36\,B/A) + 720/B$ with B being the number of required annually. The total cost per unit of finished product is

$$c_T = 36\left(\frac{B}{A}\right) + \frac{720}{B} + \frac{2A}{10^6} \text{ dollars per unit} \tag{13.24}$$

All other costs are constant and may be neglected. Find the optimum amounts of A and B required to meet the minimum total cost.

Solution:

If the amount of A components is fixed (held constant), the optimum amount of B components can be determined by differentiating the annual cost equation at constant A to give

$$\frac{dC_1}{dB} = \frac{36}{A} - \frac{720}{B^2} = 0 \tag{13.25}$$

$$B^2 = \frac{720A}{36} \tag{13.26}$$

$$B_{\text{OPT}} = 4.48A^{0.5} \tag{13.27}$$

For an annual usage of A, the corresponding amount of B is

A annual units	B_{OPT} annual units
50,000	1010
100,000	1420
150,000	1740
200,000	2010
250,000	2240

To find A_{OPT}, direct substitution of B_{OPT} into the total cost equation yields

$$C_T = \frac{36(4.48A^{0.5})}{A} + \frac{720}{4.48A^{0.5}} + \frac{2A}{10^6} \tag{13.28}$$

Absolute annual costs per item are expressed in terms of A. A can be computed and the results are shown in Table 13.5.

From the graphical solution, the minimum unit costs occurs at an average annual amount of 192,000 units of A. The same results could also be

Table 13.5 Tabulated Results for Minimum Unit Costs in Multivariable Problem

A	50,000	100,000	150,000	200,000	250,000
$324/A^{0.5}$	1.45	1.04	0.83	0.72	0.65
$2A \times 10^{-6}$	0.10	0.20	0.30	0.40	0.50
$C_{T\text{min}}$	1.55	1.24	1.13	1.12	1.15

obtained by mathematical solution of optimum A, using the preceding unit cost equation.

Using partial differentiation of the annual unit cost equation for C_T, the result is

$$\frac{\partial C_T}{\partial B} = \frac{36}{A} - 720B^{-2} = 0 \tag{13.29}$$

At constant B, the result would be

$$\frac{\partial C_T}{\partial B} = \frac{36B}{A^2} + \frac{2}{10^6} = 0 \tag{13.30}$$

These two equations can be solved simultaneofusly for A_{OPT} and B_{OPT} starting with the second equation as follows:

$$\frac{36B}{A^2} = 2 \times 10^6 \tag{13.31}$$

$$A_{\text{OPT}} = \sqrt{\frac{36B \times 10^6}{2}} = 4250\sqrt{B} \tag{13.32}$$

This value of A is substituted in Equation 13.31 to give

$$\frac{36}{4250B^{0.5}} - \frac{720}{B^2} = 0 \tag{13.33}$$

Multiplying through by B^2 yields

$$0.00846B^{1.5} = 720$$

$$B_{\text{OPT}} = 1940 \text{ units per year}$$

From the A_{OPT} equation,

$$A_{\text{OPT}} = 4250\sqrt{1940} = 192,000 \text{ units per year}$$

which is the same result obtained from the graphical solution. See Figure 13.4.

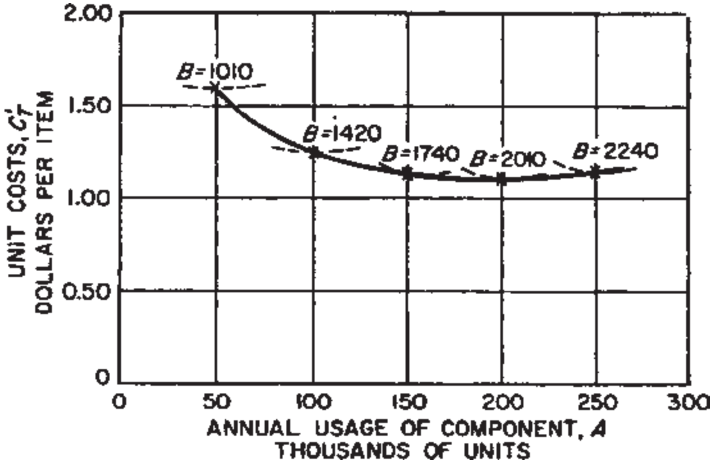

FIGURE 13.4 Solution to multivariable problem—Example 13.2.

13.6 INTERACTIVE SYSTEMS

Frequently more than one item of equipment influences the controllable variable(s) and the optimum solution. In this case, when solving a problem graphically, if only one item of equipment is selected, the total annual expense curve does not pass through a minimum but continues to decrease with increasing size or it may increase with increasing equipment size. If this phenomenon occurs, then more than one equipment item is affecting the optimization. The next step is to inspect the flowsheet for equipment directly upstream or downstream from the selected item. It may be necessary to group two or more items together and treat them as a single equipment item. Such a system is said to be interactive since more than one item of equipment affects the optimum conditions. Example 13.3 is an illustration of such a system.

Example 13.3

A pharmaceutical product is prepared as a 15% by weight aqueous solution. The moisture is removed partly by evaporation and then almost completely removed in a vacuum drier. Figure 13.5 is a flowsheet of the process. The annual fixed expenses for the evaporator–drier system are related to the weight fraction of solids S of the slurry fed to the drier. The equation for the fixed expenses of the system per year, FE, is

$$\text{Fixed expenses} = \text{FE} = \underbrace{(18000)\,(S - 0.15)^{0.5}}_{\text{Evaporator}} + \underbrace{(8895)\,(1 - S)}_{\text{Drier}} \qquad (13.34)$$

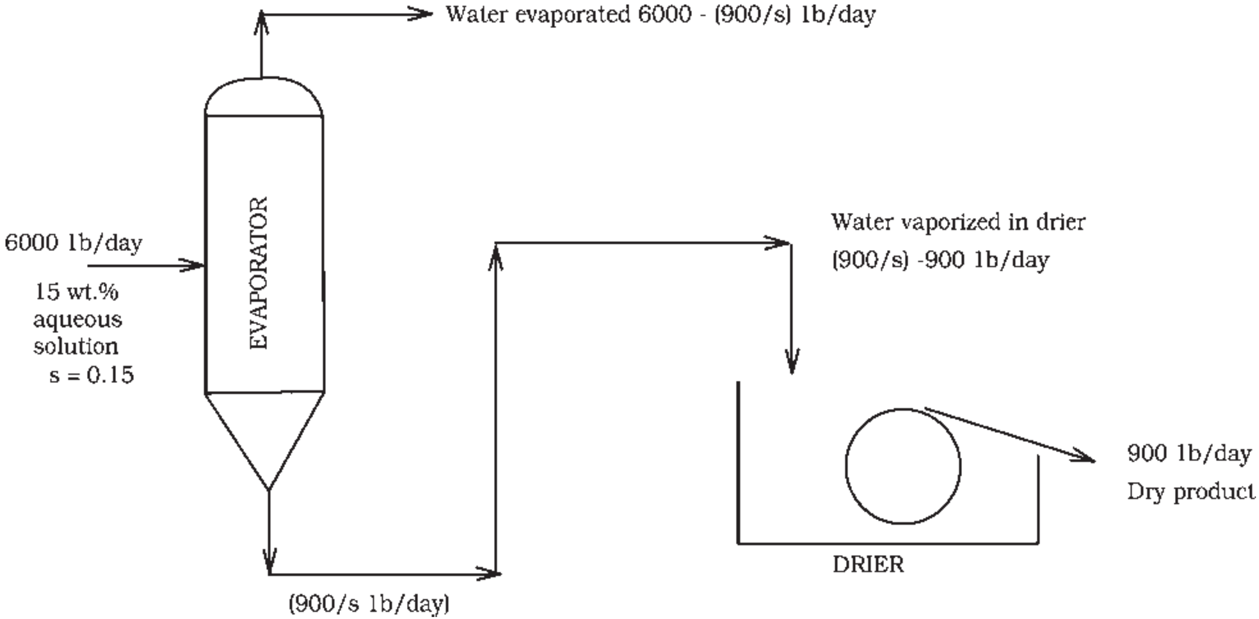

FIGURE 13.5 Flowsheet of evaporator–drier process—Example 13.3.

The variable expenses, VE, for the evaporator are \$0.003/lb water evaporated and for the drier are \$0.009/lb water removed. Develop an equation for the variable expenses in terms of the weight fraction solids fed to the drier for a production of 3 tons/day of solution fed to the evaporator. Also, determine the optimum concentration of the slurry from the evaporator.

Solution:

Basis: 1 year (300 operating days)
Duty: 3 tons/day fed to evaporator
Controllable variable: S, weight fraction of solids fed to the drier

Figure 13.5 is a flowsheet of the process. The variable expense of evaporating water is

$$\mathrm{VE} = (300)\left(6000 - \frac{900}{S}\right)(0.003) = 5400 - \frac{810}{S} \tag{13.35}$$

The variable expense of removing the remaining moisture in the drier on an annual basis is

$$\mathrm{VE} = (300)\left(\frac{900}{S} - 900\right)(0.009) = \frac{2430}{S} - 2430 \tag{13.36}$$

Then, the total annual expense (TAE) is

$$\mathrm{TAE} = (18,000)(S - 0.15)^{0.5} + (8895)(1 - S) + 5400 - \frac{810}{S} + \frac{2430}{S} + 2430 \tag{13.37}$$

or

$$\mathrm{TAE} = (18,000)(S - 0.15)^{0.5} - (8895)(S) + \frac{1620}{S} + 11865 \tag{13.38}$$

If this equation is differentiated with respect to S, the result is

$$d(\mathrm{TAE})/dS = (9000)\left[\frac{1}{(S - 0.15)^{0.5}} - 8895 - \frac{1620}{S^2}\right] \tag{13.39}$$

If Eq. (13.39) is set equal to zero, S is found by trial and error to be between 0.55 and 0.65. A plot of the total annual expenses as a function of S reveals that the TAE gradually decreases to a minimum value at about 0.55, then passes through an inflection point at $S = 0.604$. After that, the TAE increases slightly to a maximum at about 0.65. Beyond this the value of the total annual expense decreases further as S approaches 1.0. Such behavior can be also detected by mathematical tests. The results of the solution to Example 13.3 are found in Figure 13.6 and Table 13.6.

This solution indicates that most of the water should be removed in the evaporator and S should be increased to the maximum practical value. The overriding decision would be the behavior of the slurry in the concentration range of 0.65. There is the potential problem that the slurry might be too thick to pump. In this case based upon a real plant problem, the slurry was too thick to pump but by lowering S to between 0.5 and 0.55, it could be pumped. From Table 13.6, it is apparent that the total annual expenses in the range of 0.50–0.55 are essentially the same as at 0.65. Therefore, by operating at 0.50, the criteria of operability and economics are satisfied.

The purpose of this problem was to demonstrate how equipment items interact, and when such systems are encountered, more than one item must be included in the optimization of the system. The designer should be aware of process limitations when the total annual expense expression is developed. Judgment based upon the engineer's experience with respect to equipment and process limitations exclusive of the mathematical results affect the final selection of the optimum.

Another example of an interactive system is a natural gas pipeline in which the distance between compressor stations, pipe diameter, and compressor discharge pressure of the fluid are the operating variables. The total annual expense equation for this case can be solved by the simple approach of differentiating the equation with respect to each independent variable, equating the resulting equations equal to zero and solving as a set of simultaneous equations. The alternative is to solve the equations by a sophisticated computer optimization method. There is the possibility that several minima exist and they need to be considered individually to obtain the best expense result.

Another example is a direct-fired heater with convection and radiation sections. In this case, the variables might be the heat transfer areas for both sections of the furnace or the furnace gas temperatures leaving both sections. As demonstrated in this section, a system consisting of several equipment items or parts of the system must be considered as a unit to find the optimum.

13.7 SUMMARY

This chapter was concerned with the development of an economic balance to determine a minimum total expense or a maximum process yield. Methodologies were developed and checklists were provided for the solution of simple optimization problems. Analytical and graphical methods of solution were demonstrated for single or multiple controllable variable cases. In some instances, the analytical solution may be simpler to use but in other cases, the graphical solution is more direct and less cumbersome mathematically but may be more time consuming.

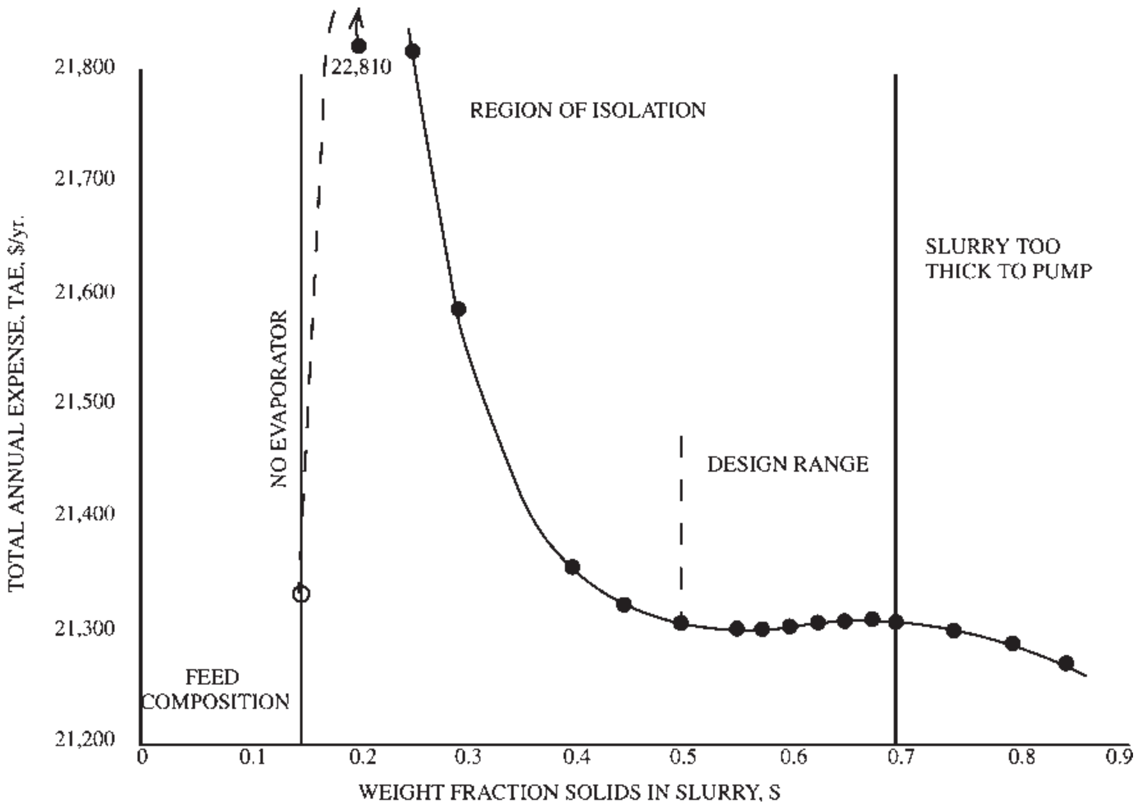

FIGURE 13.6 Solution to Example 13.3.

Table 13.6 Solution of Illustrative Example 13.3

S	$(S-0.15)^{0.5}$	$18000\ (S-0.15)^{0.5}$	$-8895S$	$+1620/S$	$+11865$	TAE
0.15	0	0	−1334	10800	+11865	21331
0.175	0.1581	2846	−1557	9257	+11865	22411
0.20	0.2236	4025	−1179	8100	+11865	22811
0.25	0.3162	5692	−2224	6480	+11865	21813
0.30	0.3873	6971	−2668	5400	+11865	21568
0.35	0.4472	8050	−3113	4629	+11865	21431
0.40	0.5000	9000	−3558	4050	+11865	21357
0.45	0.5477	9859	−4003	3600	+11865	21321
0.50	0.5916	10649	−4448	3240	+11865	21306
0.55	0.6325	11385	−4892	2945	+11865	21303
0.575	0.6519	11734	−5115	2817	+11865	21301
0.60	0.6708	12074	−5337	2700	+11865	21302
0.625	0.6892	12406	−5559	2592	+11865	21304
0.65	0.7071	12728	−5782	2492	+11865	21303
0.675	0.7246	13043	−6004	2400	+11865	21304
0.70	0.7416	13349	−6226	2314	+11865	21302
0.75						21296
0.80						21286
0.85						21270

Interactive systems were introduced wherein more than one equipment item affects the controllable variable and the resulting optimum. A solution to such a problem was presented. Judgment based upon an engineer's experience is necessary in this case because there may be equipment or process limitations beyond the mathematical solution that affect the final decision.

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PROBLEMS

13.1 Calculate the number of effects for the minimum total annual operating expense of a small evaporator system to concentrate a colloidal suspension. Steam costs \$3.00/M Btu and each pound of steam will evaporate $0.8N$ lb of water, N being the number of effects. The capital cost of each effect is \$40,000 and has an estimated life of 10 years. The annual maintenance expense is 10% of the capital cost. Labor and other expenses not mentioned may be considered as independent of the number of effects. The system will operate 300 days/yr with 100 M Btu/day evaporator duty. Depreciation may be taken as 7-year straight-line and the federal income tax rate is 35%. Annual net profit after taxes on the investment must be 15% for the installed equipment.

13.2 A furnace wall is at a temperature of 1000 F. This wall is to be insulated with a material whose installed cost is \$12t/ft^2 where t is the thickness in feet. Thermal conductivity of the insulation is 0.03 Btu/hr ft F. The film heat transfer coefficient is 4 Btu/hr ft^2 F. Depreciation is 20% per year and the company return on investment is 15% after taxes. Energy is valued at \$5/million Btu and the furnace operates around the clock 330 days/yr. Determine the optimum thickness of the insulation.

13.3 Air (600 SCFM) at 80 F and 15 psia is to be compressed to 350 psia. This can be accomplished in a single-stage or multistage compressor. Compressor power requirement, CP, for 600 SCFM are given by

$$CP = 125\left[\left(\frac{P_b}{P_a}\right)^{0.285} - 1\right]$$

where

$$\begin{aligned} P_b &= \text{discharge pressure from a given stage} \\ P_a &= \text{suction pressure of a given stage} \\ P_b/P_a &= \text{compression ratio (CR)} \\ \text{CR} &= (350/15)^{1/N} \\ \text{N} &= \text{number of stages} \end{aligned}$$

Compressor fixed capital investment is \$60,000N. Depreciation is 7-year straight-line and the desired return is 10% after a 50% tax rate. Electricity costs \$0.06/kWh and the compressor will operate 8000 hr/yr. Recommend the number of stages based on a minimum total annual expense.

13.4 A paper mill plans to use a combination settling basin and rotary filter to remove insoluble solids from their wastewater stream as a first step in treatment and recycle. Figure 13.7 is a sketch of the system. Solids settled in the basin are given by

$$M = 4000L^{0.5}\ \text{lb/day}$$

where L is the length of the settling basin in feet. The capital cost of the basin is \$500 per foot of length. Solids not removed in the basin are removed in the filter, with the filter area given by

$$A = 10 + 0.001M_f\ \text{ft}^2$$

where

M_f = solids removed in the filter, lb/day.

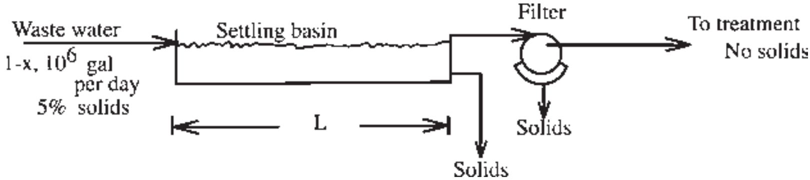

FIGURE 13.7 Schematic diagram for Problem 13.4.

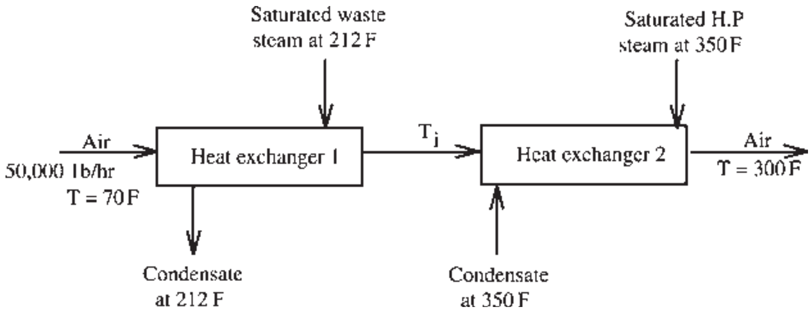

FIGURE 13.8 Schematic diagram for Problem 13.5.

The capital cost of the filter is $2000/ft^2 of filter area. The annual operating cost of the filter is $0.80/lb day of solids removed in the filter. There are no significant operating costs associated with the settling basin. Depreciation is 20% per year and the return on investment is 20%. Determine the optimum length of the settling basin.

13.5 You are in charge of the design of a process that requires 50,000 lb/hr of air to be heated as shown in Figure 13.8. Other pertinent data are:

$$
\begin{aligned}
c_p \text{ for air} &= 0.24\,\text{Btu/lb F} \\
U &= 8\,\text{Btu/hr ft}^2\,\text{F} \\
\text{Operation} &= 8000\,\text{hr/yr} \\
\text{Waste steam value} &= \$0 \\
\text{High pressure steam value} &= \$4/\text{M Btu} \\
\text{Annual capital cost for exchangers} &= \$10/\text{ft}^2 \text{ per year}
\end{aligned}
$$

Determine the temperature of the exit air from the first heat exchanger T_i for the minimum total annual expense. Discuss what happens to the various expenses as T_i changes.

13.6 You are a process engineer in a paper mill that has six boilers producing high-pressure steam. Each of these boilers is fired by 10,000 SCFH of natural gas. The heating value of the gas is 1000 Btu/SCF and its cost under the present contract is $5.00/SCF.

Because there are large amounts of wood waste both within the mill and also in nearby forest product industries, you suggest to the plant manager the possibility of utilizing these wastes as a fuel for the boilers. You are immediately assigned this project and within a couple of weeks have collected the following information:

- Each boiler operates at 8000 hr/yr.
- It will cost $1 million per boiler to retrofit for wood waste. This cost can be depreciated over 5 years. On projects of this type, the company requires a 20% return on the investment.
- The average heating value for the wood waste is 8000 Btu/lb.
- Boiler efficiency is roughly the same on the wood waste as on natural gas.
- Wood waste within our mill amounts to 30 tons/day. This waste is currently hauled from the mill by a private company at no cost to either party.
- Your company can contract with other forest product companies in the area to buy their wood waste. Collection and hauling costs will increase with distance from the mill. You have estimated these amounts and the respective expenses are

Radius from mill, mi	Available waste, tons/day	Purchase, collection and hauling costs, $/ton
10	15	20
10–20	15	30
20–30	15	40
>30	90	50

a. Under the existing economic conditions, how many boilers should be retrofitted?
b. What is your recommendation to management?

13.7 Twenty-five thousand pounds per hour of a heat-sensitive salt are to be dried from 5.0 to 0.10% water. The amount of water to be removed per hour is calculated to be 1226 lb and the estimated heat duty is 1.226 million Btu/hr. The salt temperature remains constant at 150 F during the drying process using air that has a maximum allowable inlet temperature of 430 F. The maximum allowable mass velocity of air in the drier because of dusting conditions is 1000 lb/hr $\cdot$ ft^2 of surface area. The flow of the salt is countercurrent to the flue gas.

The FOB purchased cost of rotary driers can be calculated by the following equation:

$$\text{FOB cost} = 3.00(\text{peripheral area})^{0.91}$$
$$\text{Peripheral area} = \pi DL$$

The FOB cost includes an induced-draft fan, stack, cyclone dust collector, oil burner, feeder and instrumentation. For a rough estimate of the installed cost, multiply the FOB cost by 1.75. A fixed charge of 40% covering depreciation, indirect expenses, and the profit on the investment is to be applied to the installation cost of the drier and auxiliary equipment. The expense of heating the air to 430 F from 70 F is \$3.20 per M Btu. The operating time is 8500 hr/yr. The specific heat of the air is 0.25. For U_a use

$$U_a = \frac{10G^{0.16}}{D}$$

and $$q = U_a \Delta T \left(\frac{\pi}{4}\right) D^2 L$$

Determine the following:

a. Diameter and length of the optimum drier for this service
b. Total capital investment for the drier installation
c. Annual expense of heating air for the optimum design

13.8 It is necessary to design a water-cooled condenser to remove 8,000,000 Btu/hr liberated by an organic condensing vapor at 200 F. The overall heat transfer coefficient for the condensing vapor is 150 Btu/hr · ft^2 · F. Condensing heat transfer surface can be bought and installed for \$40/ft^2. It has been decided by management to charge off 40% of the purchased price annually to cover the return on the investment, property taxes, repairs and depreciation. Cooling water is available at 90 F and costs 4 cents per 1,000 gal. The condenser is to operate 7200 hr/yr.

a. What is the optimum heat transfer area for the condenser?
b. What is the corresponding cooling-water rate, expressed as lb mass/hr and the temperature at which the water leaves the condenser?
c. What is the annual fixed expenses and the annual water expense?
d. Are there any process limitations? If there are, discuss them, indicating what remedies are available.

13.9 You are employed as a chemical engineer in the production department of Excalibar Chemicals, a company that produces large-volume inorganic chemicals. One of our processes produces 100 tons stream day of 50% caustic via the electrolytic decomposition of a water solution of NaCl. Since you have only recently been placed in charge of the caustic unit, you are checking for optimum operation of the unit. See Figure 13.9 for schematic sketch of system. The evaporator is obsolete and needs to be replaced at this time. The cell and filter are in good shape. You have gathered the following information:

1. Caustic is produced via the following reaction:

$$2\,NaCl + 2\,H_2O = 2\,NaOH + Cl_2 + H_2$$

2. The process flow diagram is found in Figure 13.9.

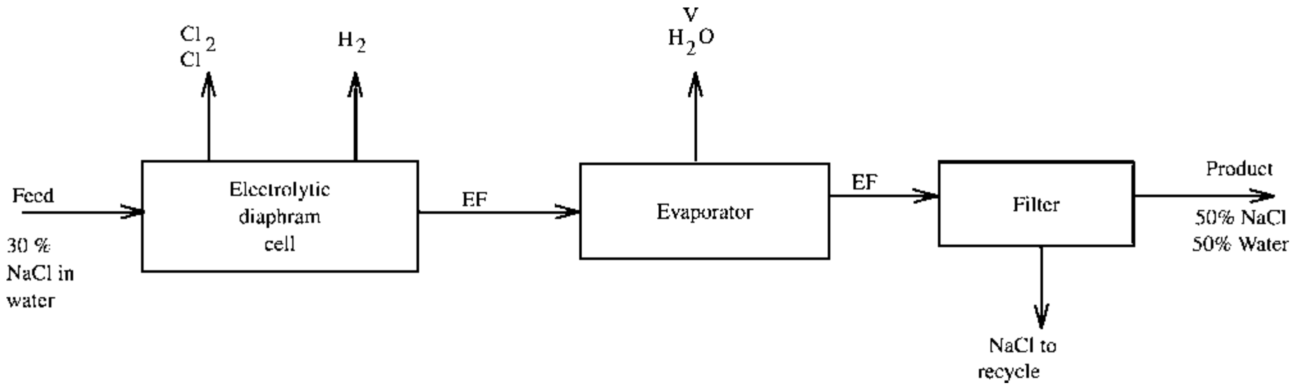

FIGURE 13.9 Schematic diagram for Problem 13.9.

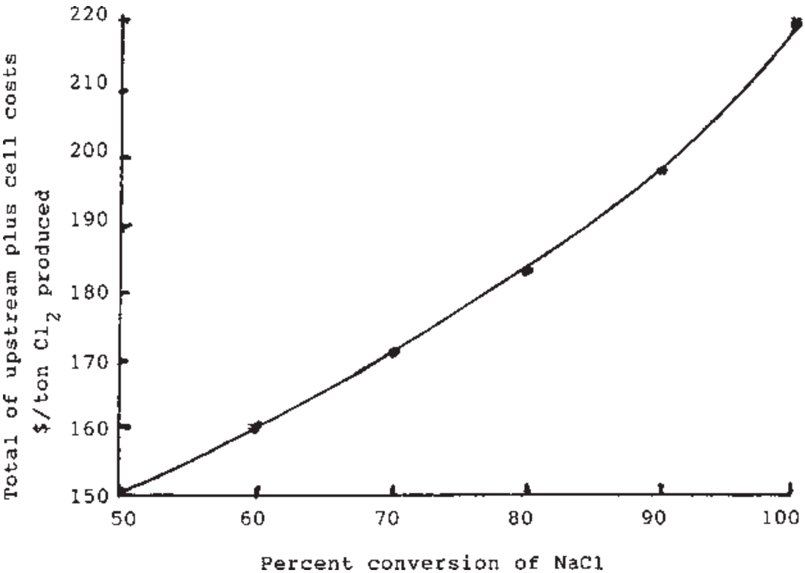

FIGURE 13.10 Operating expenses as a function of NaCl concentration.

3. The operating expense for the electrolytic cell plus all other upstream expenses is given in Figure 13.10, in dollars per ton of Cl_2, produced as a function of the percent conversion of the NaCl in the feed.
4. Your material balance calculations have shown that 100 tons stream day (4167 lb/hr of NaOH and 4167 lb/hr of H_2O) of 50% caustic is equivalent to 104 lb moles/hr of NaOH. The mole balance is

$$104\,\mathrm{NaCl} + 104\,\mathrm{H_2O} = 104\,\mathrm{NaOH} + 52\,\mathrm{Cl_2} + 52\,\mathrm{H_2}$$

5. The filter feed (FF) must have 4167 lb/hr of NaOH and 4167 lb/hr of H_2O since only NaCl is removed in the filter. Filter cost is independent of the NaCl concentration in FF.
6. Evaporator capital cost is given by

$$200{,}000\left(\frac{Aft^2}{100}\right)^{0.8}$$

Evaporator operating expense is steam only at \$5.00/1000 lb.
Evaporator economy is 0.8 lb evaporated/lb steam.
Evaporator heat transfer coefficient is 200 Btu/hr $\cdot$ ft^2 $\cdot$ F.
Steam is available at 350 F and the evaporator pressure is such that the caustic solution boils at 230 F.

7. The unit will operate 330 days/yr.
8. Depreciation is 20%/yr and the return is 30%/yr.

Determine the percent conversion of NaCl in the cells, and the evaporator size, ft^2, for minimum total annual expense. Perform additional mass balance calculations in lb/hr.

13.10 It is desired to size a heat exchanger and pump system to process a dilute aqueous solution as shown in Figure 13.11. The physical properties of the solution may be taken as those for water. The solution is heated in the tubes of the exchanger using 50 psig steam. The saturation temperature of 50 psig steam is 298 F. The pressure in the distillation column is 1 atmosphere and here the solution boils at 212 F. The heat exchanger tubes in this design are 1 in. O.D., 16 BWG, 8 ft long with an I.D. of 0.870 in. The heat exchanger is single pass. No boiling takes place in the reboiler. Because of the tendency of the tubes to foul, the solution is heated from 212 F to some higher temperature that depends on the pumping rate. Therefore, the pressure on the inlet side of the valve must be controlled to be at least high enough that no boiling takes place in the tubes. For design purposes, this pressure is found by determining the saturation pressure

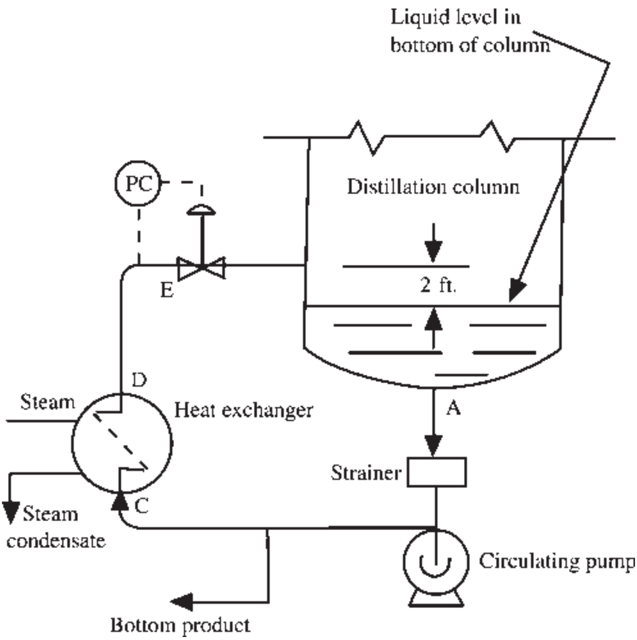

FIGURE 13.11 High-velocity forced convection reboiler layout.

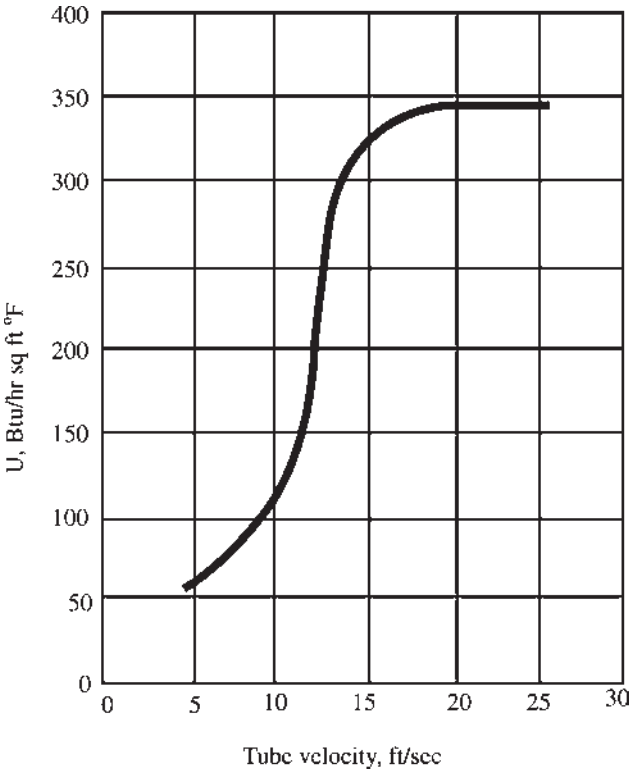

FIGURE 13.12 Variation of fouled heat transfer coefficient with velocity.

from the steam tables for the outlet temperature from the exchanger and adding 2 psi for safety.

Pilot plant data on the variation of the overall heat transfer coefficient U with the tube side velocity is found in Figure 13.12. These values of U are those that become constant after the unit is in operation for a short time at a given tube side velocity. The shape of the curve is determining by the fouling characteristics of the solution.

The total equivalent length of pipe from A to C is 30 ft and from D to E is 18 ft. The pipe is 8 in Schedule 40. The pressure drop through the strainer is four velocity heads, i.e, $4v^2/2g_c$. The pressure drop at the inlet and outlet headers of the exchanger may be assumed to be two velocity heads.

Assume the head developed by the pump must overcome the friction in the system and the pressure drop across the valve. Values for ΔH_f have been determined in terms of velocities in the heat exchanger tubes as follows:

u, ft/sec	5	8	10	13	15	17	20
ΔH_f/ft tube	0.86	2.2	3.4	5.8	7.7	9.9	13.7

Data:

$$\text{Delivered pump cost} = \$1300(H_{\text{actual}})^{0.5}$$

$$\text{Reboiler cost delivered} = \$400\,A^{0.62}$$

where

$$
\begin{aligned}
A &= \text{the outside heat transfer are of the tubes}\\
\text{Pump efficiency} &= 70\%\\
\text{Maintenance charges on reboiler} &= \$1500/\text{yr}\\
\text{Maintenance charges on the pump} &= \$2500/\text{yr}\\
\text{Cost of steam} &= \$3.00/1000\,\text{lb}\\
\text{Cost of electricity} &= \$0.04/\text{kWh}\\
\text{Stream time} &= 8000\,\text{hr/yr}\\
\text{Insurance and property taxes} &= 2\%\ \text{per year of the installed cost}\\
\text{Federal income taxes} &= 35\%\\
\text{Depreciation} &= 7\text{-year straight-line}\\
\text{Annual net profit after taxes} &= 15\%\ \text{based on the installed cost}
\end{aligned}
$$

The solution should specify the velocity in the tubes and the outside heat transfer area of the exchanger as well as the actual horsepower of the pump for the optimum operating conditions and costs.

14

Concluding Comments

The intent of this book as stated in the Preface was to present a fundamental, practical approach to financial and economic analysis used in industry. The text is primarily directed to undergraduate chemical engineering students in a process economics or design course. This text may also be used for a continuing education course in process economics for experienced engineers who feel the need to refresh their use of the principles of economic and financial analysis. The book may also serve as a self-study text.

A chemical engineering graduate upon entering industry is confronted with financial terminology unfamiliar to this person. Further, each company has jargon used by the company to add to the confusion. These terms and associated concepts are new to the engineer who has been engrossed in scientific and technological terminology. When the young engineer comes in contact with middle- or upper-level management, they often use financial terminology in discussions or meetings.

The focus of this chapter is to show how the topics presented in this book, in Chapters 4 through 13, ultimately appear in financial reports. The reader is lead through information in these chapters in an orderly, logical manner.

The backbone of any economic analysis is the capital cost estimate. Methods for preparing an estimate were presented based upon the quality of information and data available to the engineer. Although most corporations use sophisticated computer programs for obtaining a capital cost estimate, the young engineer must understand the principles used in preparing an estimate and especially know the limitations. This is particularly true today since many companies outsource the capital cost estimate. It is often the responsibility of the young engineer to review such estimates however generated, using handheld calculators or desktop computers to check the reasonableness of the estimate. Just because an estimate was computer generated does not mean that it is correct. If the project is approved, the capital cost ultimately appears in balance sheet as fixed assets and in the income statement since certain operating expenses are capital dependent.

Although there are numerous methods for obtaining a capital cost estimate extant in the literature, the same cannot be said for estimating operating expenses. There is a dearth of operating expense estimation, because such information is often of a proprietary nature. The information on the preparation of an operating expense is based upon the author's experience and information available in the literature. The operating expenses will appear along with operating expenses from other segments of a company under the cost of goods sold in the income statement.

Time value of money, that is, interest, is a business fact of life. Interest is charged no matter the source of funding, be it from external sources such as loans, bonds, or stock, or from internal sources such as retained earnings, or a combination of both. Interest is an item in the income statement and the balance sheet of a firm.

Depreciation and taxes are irrevocably tied together, as noted in Chapter 7. Depreciation appears on the balance sheet and both depreciation and taxes are found in the income statement as operating expenses. One important item in financial reporting is cash flow. By definition it is the net income after taxes plus depreciation. It is the amount of money available for the day-to-day operating expenses. In financial reports, there is a table showing the changes in cash flow generated by the company from year to year. The net income after taxes is found in the firm's income statement and depreciation, the other component of cash flow ultimately appears in the balance sheets.

After these foregoing items are estimated, the next step is to determine the profitability of a venture. Current methods for quantitatively determining this information were presented in Chapter 9. In today's economy, qualitative factors affect the decision to invest in a venture even though the quantitative numbers appear attractive.

No economic study would be complete without sensitivity and/or uncertainty analyses being performed, wherein various scenarios are examined to determine the affect on profitability of changes in sales price, sales volume, capital requirements, and operating expenses. These studies permit management to consider what might happen should such changes occur.

A discussion of the requirements for the preparation of a feasibility analysis is appropriate since it includes items from estimating the capital requirements (Chap. 4) through sensitivity and uncertainty analyses (Chap. 10). A sample feasibility study is presented to illustrate how one is prepared.

The last two topics, choice between alternatives and economic balance, are directed toward plant-scale problems and their methods for solution. The results of these studies ultimately affect the income statement through operating expenses and the attendant capital investment requirements in both the balance sheet and the income statement.

This chapter then is a recapitulation of the material presented in the text with indications of how the contents of each chapter affect the financial reporting of an enterprise.

An engineer seeking upward mobility as a technical manager in a firm must not only be technically capable but also have a clear understanding of process economics and know financial terminology. The contents of this text should assist the reader in understanding process economics and its relationship with financial terminology.

APPENDIX A

Glossary

Accounts payable: The value of purchased services and materials that are being used but have not been paid.

Accounts receivable: Credit extended to customers usually on a 30-day basis. Cash is set aside to account for the fact that some customers may not pay their bills.

Administrative expense: Includes administrative and offices salaries, rent, auditing, legal, engineering, etc. expenses.

Amortization: Often used interchangeably with depreciation but there is a slight technical difference depending on whether or not the life of an asset is known. If the period of time is definitively known, the annual expense is called *amortization*. If the life is estimated, it is called *depreciation*.

Annual net sales: Pounds of product sold times the net selling price.

Annual report: The report of management to stockholders and other interested parties at the end of a year of operation showing the status of the company, its funds, profits, income, expenses, and other information.

Assets: The list of money on hand, marketable securities, monies due, investments, plants, properties, patents, inventory, etc. at cost or market value whichever is smaller. These are the items a company or a person owns.

Balance sheet: This is a tabulation of the assets, liabilities, and stockholders' equity for a company. The assets must equal the liabilities plus the stockholders' equity.

Bonds: When one purchases a bond, this person acquires an interest in debt and becomes a creditor of a company. The purchaser receives the right to receive regular interest payments and the subsequent repayment of the principal.

Book value of common stock: This is the net worth of a firm divided by the number of shares of common stock issued at the time of a report.

Book value: The original investment minus the accumulated depreciation.

Break-even chart: This is an economic production chart depicting the point at which the total revenue equals the total cost of production.

By-product: A production item made as a consequence of the production of a main product. The by-product may have value in itself or as a raw material for another use.

Capital ratio: The ratio of capital investment to sales dollars; it is the reciprocal of capital turnover.

Capital turnover: The ratio of sales dollars to capital investment; it is the reciprocal of the capital ratio.

Cash: Money that must be on hand to pay for monthly operating expenses, e.g., wages, salaries, raw materials, etc.

Cash flow: Net income after taxes plus depreciation (and depletion) is the cash flow into a company's treasury.

Common stock: Money paid into a corporation for the purchase of shares of common stock that becomes the permanent capital of the firm. Common stockholders have the right to transfer ownership and may sell the stock to individuals or firms. Common stockholders have the right to vote at annual meetings or by proxy.

Compound interest: The interest charges under the condition that interest is charged on previous interest plus the principal in any time period.

Continuous compounding: A mathematical procedure based upon a continuous interest function rather than a discrete interest period.

Conversion cost: The cost of converting raw materials into a finished product.

Corporation: In 1819, Chief Justice Marshall of the Supreme Court defined a corporation as "and artificial being, invisible, intangible and existing only in contemplation of law." It exists by the grace of the state and the laws of a state govern the procedure for its formation.

Cost of capital: This is what it costs a company to borrow money from all sources, namely, loans, bonds, preferred and common stocks. It is expressed as an interest rate.

Cost of sales: The sum of the fixed and variable (direct and indirect) expenses for producing a product and delivering it to the customer.

Decision or decision making: A program of action undertaken as the result of (a) an established policy or (b) an analysis of variables.

Design to cost: A management technique to achieve system designs that meet stated cost parameters. Cost as a design parameter is considered on a continuous basis as part of a system's development and production processes.

Depreciation: A reasonable allowance by the Internal Revenue Service for exhaustion, wear and tear, and normal obsolescence of equipment used the trade or business. Such property must have a useful life of more than 1 year. It is a noncash expense deductible from the income for tax purposes.

Direct expense: The expense directly associated with the production of a product like utilities, labor, maintenance, etc.

Direct labor expense: The expense of labor involved in the actual production of a product or a service.

Direct material expense: The expense of materials consumed in or incorporated into a product or service.

Distribution expense: This expense includes advertising, samples, travel, entertainment, freight, warehousing, etc. to distribute a product.

Dollar volume: Dollar worth of a product manufactured per unit of time.

Earnings: The difference between income and operating expenses.

Economic value added (EVA): It is the period dollar profit above the cost of capital. It is a means to measure an organization's value and as a way to determine how management's decisions contribute to the value of a company.

Effective interest: The true value of interest computed by equations for the compound interest rate for a 1-year period.

Equity: The owner's actual capital held by a company for its operations.

External funds: Capital obtained by selling stock, bonds or by borrowing.

FIFO (first in, first out): This term refers to the valuation of raw material and supplies inventory, meaning the first into a company or process is the first used or out.

Financial expense: The charges for use of borrowed funds.

Fixed assets: These are the real or material facilities that represent part of the capital in an economic venture.

Fixed capital: This item includes the buildings and equipment.

Fixed expense: An expense that is independent of the rate of output, for example, depreciation, plant indirect expenses, etc.

Full cost accounting: It describes how goods and services can be priced to reflect their true costs, including production, use, recycling, and disposal.

Future growth value (FGV): It is a measure that represents where company performance is relative to the business cycle—above or below the average long-term performance.

Future worth: The future worth is an expected value of capital in the future according to some predetermined method of computation.

Goods-in-process inventory: The hold-up of product in a partially finished state.

Goods manufactured, cost of: This is the total expense, direct and indirect expenses, including overhead charges.

Goods sold, cost of: The total of all expenses before income taxes that is deducted from revenue.

Gross domestic product: An indicator of a country's economic activity. It is the sum of the goods and services produced by a nation within its borders.

Gross national product: Another indicator of a country's economic activity. It is the sum of all the goods and services produced by a nation including domestic and foreign activities attributable to that nation.

Gross margin (profit): The total revenue minus the cost of goods sold.

Income tax: This is the tax imposed on corporation profits by the federal and/or the state governments.

Indirect expenses: These expenses are part of the manufacturing expense of a product but are not directly related to the amount of that product manufactured. Examples are depreciation, local taxes, insurance, etc.

Internal funds: This is the capital available from depreciation and accumulated retained earnings.

Inventory: This is the quantity of raw materials and/or supplies held in a process or in storage.

Last in, first out (LIFO): This term refers to the valuation of raw material and supplies inventory, meaning the last material into a process or storage is the first used or out.

Leverage: The influence of debt on the earning rate of a company.

Liabilities: This is the amount of capital owed by a company.

Life-cycle cost: It is the cost of development, acquisition, support, and disposal of a system over its full life.

Manufacturing expense: This is the sum of the raw materials, utilities, labor, maintenance, depreciation, local taxes, etc. It is the sum of the direct and indirect (variable and fixed) manufacturing expenses.

Marginal costs: This is the rate of change of costs with production or output.

Market capitalization: It is the product of the number of common stock shares outstanding times the share price.

Market value added: The market has a certain future economic value added for a company. It is the present value of the future economic value added (EVA) generated by a company. It is a good measure of how much value a firm has created.

Minimum acceptable rate of return (MARR): This is the minimum interest rate that management selects as acceptable for a financial investment.

Net sales price: Gross sales price minus freight adjustments.

Net worth: This is the sum of the stockholders' investment plus surplus, or total assets minus total liabilities.

Nominal interest: The number applied loosely to describe the annual interest rate.

Operating expense: This is the sum of the expenses for the manufacturing of a product plus general, administrative, and selling expenses.

Operating margin: The gross margin minus the general, administrative, and selling expenses.

Opportunity cost: This is the return that would have been realized had the funds been invested in an alternative opportunity. Therefore, any time an amount of capital is invested in an investment, an opportunity to invest that amount elsewhere at the MARR has been foregone. The MARR can be defined at the cost of the opportunity foregone.

Payout time (payback period): Fixed capital investment divided by the after-tax cash flow.

Preferred stock: This stock has claims that it commands over the common stock and the preference is related to dividends. The holders of such stock receive dividends before any distribution is made to the common stockholders. Preferred stockholders usually do not have voting rights.

Present worth: The value at some datum time (present time) of expenditures, costs, profits, etc. according to a predetermined method of computation.

Production rate: The amount of product manufactured in a given time period.

Profitability: A term applied in a broad sense to the economic feasibility of a proposed venture or an ongoing operation.

Revenues: The net sales received for selling a product to a customer.

Sales, administration, research, and engineering expenses (SARE): Overhead item for expenses incurred as a result of maintaining sales offices, administration offices, and the expenses of maintaining research and engineering departments. Usually expressed as a percentage of annual net sales.

Sales volume: The amount of sales expressed in pounds, gallons, tons, cubic feet, etc. per unit of time.

Selling expenses: Salaries and commissions paid to sales personnel.

Simple interest: The interest charges under the condition that interest in any time period is only charged on the principal.

Sinking fund: An accounting procedure computed according to a specified procedure to provide capital to replace an asset.

Surplus: The excess of earnings over expenses that is not distributed to stockholders.

Tax credit: The amount available to a firm as part of its annual return because of deductible expenses for tax purposes. Examples have been research and development expenses, energy tax credits, etc.

Time value of money: The expected interest rate that capital should or would earn. Money has a value with respect to time.

Total operating investment: This includes the fixed capital, backup capital, utilities and services capital, and working capital.

Utilities and services capital: Includes electrical substations, plant sewers, water facilities, etc.

Value added: The value added to a product is the difference between the raw material expenses and the selling price of that product.

Variable expense: Any expense that varies directly with output.

Working capital: In the accounting sense, it is the current assets minus the current liabilities. It consists of the total amount of money invested in raw materials, supplies, goods-in-process and product inventories, accounts receivable, and cash minus the those liabilities due within 1 year.

APPENDIX B

Rules of Thumb[1]

Although experienced engineers know where to find information and how to make accurate computations, they also keep a minimum body of information in mind on the ready, made up largely of shortcuts and rules of thumb. The present compilation may fit into such a minimum body of information, as a boost to the memory or extension in some instances into less often encountered areas. It is derived from the material in this book and is, in a sense, a digest of the book.

An Engineering Rule of Thumb is an outright statement regarding suitable sizes or performance of equipment that obviates all need for extended calculations. Because any brief statements are subject to varying degrees of qualification, they are most safely applied by engineers who are substantially familiar with the topics. Nevertheless, such rules should be of value for

[1]These Rules of Thumb were obtained from Stanley M. Walas' book *Chemical Process Equipment: Selection and Design* (Woburn, MA: Butterworth, 1986). Permission was granted to reproduce this material. Butterworth is now part of Elsevier Science and Technical Publications.

The following are additional references for Rules of Thumb

1. CR Branan. Rules of Thumb for Chemical Engineers. Houston, TX: Gulf Publishing Company, 1994.
2. D Woods. Process Design and Engineering Practice, Englewood Cliffs, NJ: Prentice Hall, 1995.
3. GD Ulrich, A Guide to Chemical Engineering Process Design and Economics, New York: Wiley, 1984.
4. WJ Korchinski, LE Turpin. Hydrocarbon Processing. January 1996: 129–133.

approximate design and cost estimation, and should provide even the inexperienced engineer with perspective and a foundation whereby the reasonableness of detailed and computer-aided results can be appraised quickly, particularly on short notice such as in conference.

Everyday activities also are governed to a large extent by rules of thumb. They serve us when we wish to take a course of action but are not in a position to find the best course of action. Of interest along this line is an amusing and often useful list of some 900 such digests of everyday experience that has been compiled by Parker (*Rules of Thumb*, Houghton Mifflin, Boston, 1983).

Much more can be stated in adequate summary fashion about some topics than about others, which accounts in part for the spottiness of the present coverage, but the spottiness also is due to ignorance and oversights on the part of the author. Accordingly, every engineer undoubtedly will supplement or modify this material in his own way.

COMPRESSORS AND VACUUM PUMPS

1. *Fans* are used to raise the pressure about 3% (12 in. water), *blowers* raise to less than 40 psig, and *compressors* to higher pressures, although the blower range commonly is included in the compressor range.
2. Vacuum pumps: reciprocating piston type decrease the pressure to 1 Torr; rotary piston down to 0.001 Torr, two-lobe rotary down to 0.0001 Torr; steam jet ejectors, one stage down to 100 Torr, three stage down to 1 Torr, five stage down to 0.05 Torr.
3. A three-stage ejector needs 100 lb steam/lb air to maintain a pressure of 1 Torr.
4. In-leakage of air to evacuated equipment depends on the absolute pressure, Torr, and the volume of the equipment, V cuft, according to $w = kV^{2/3}$ lb/hr, with $k = 0.2$ when P is more than 90 Torr, 0.08 between 3 and 20 Torr, and 0.025 at less than 1 Torr.
5. Theoretical adiabatic horsepower (THP) $= [(\text{SCFM})T_1/8130a] \times [(P_2/P_1)^a - 1]$, where T_1 is inlet temperature in F + 460 and $a = (k-1)/k$, $k = C_p/C_v$.
6. Outlet temperature $T_2 = T_1(P_2/P_1)^a$.
7. To compress air from 100 F, $k = 1.4$, compression ratio = 3, theoretical power required = 62 HP/million cuft/day, outlet temperature 306 F.
8. Exit temperature should not exceed 350–400 F; for diatomic gases ($C_p/C_v = 1.4$) this corresponds to a compression ratio of about 4.

9. Compression ratio should be about the same in each stage of a multistage unit, ratio $= (P_n/P_1)^{1/n}$, with n stages.
10. Efficiencies of reciprocating compressors: 65% at compression ratio of 1.5, 75% at 2.0, and 80–85% at 3–6.
11. Efficiencies of large centrifugal compressors, 6000–100,000 ACFM at suction, are 76–78%.
12. Rotary compressors have efficiencies of 70%, except liquid liner type which have 50%.

CONVEYORS FOR PARTICULATE SOLIDS

1. *Screw conveyors* are suited to transport of even sticky and abrasive solids up inclines of 20° or so. They are limited to distances of 150 ft or so because of shaft torque strength. A 12 in. dia conveyor can handle 1000–3000 cuft/hr, at speeds ranging from 40 to 60 rpm.
2. *Belt conveyors* are for high capacity and long distances (a mile or more, but only several hundred feet in a plant), up inclines of 30° maximum. A 24 in. wide belt can carry 3000 cuft/hr at a speed of 100 ft/min, but speeds up to 600 ft/min are suited to some materials. Power consumption is relatively low.
3. *Bucket elevators* are suited to vertical transport of sticky and abrasive materials. With buckets 20 × 20 in. capacity can reach 1000 cuft/hr at a speed of 100 ft/min, but speeds to 300 ft/min are used.
4. *Drag-type conveyors* (Redler) are suited to short distances in any direction and are completely enclosed. Units range in size from 3 in. square to 19 in. square and may travel from 30 ft/min (fly ash) to 250 ft/min (grains). Power requirements are high.
5. *Pneumatic conveyors* are for high capacity, short distance (400 ft) transport simultaneously from several sources to several destinations. Either vacuum or low pressure (6–12 psig) is employed with a range of air velocities from 35 to 120 ft/sec depending on the material and pressure, air requirements from 1 to 7 cuft/cuft of solid transferred.

COOLING TOWERS

1. Water in contact with air under adiabatic conditions eventually cools to the wet bulb temperature.
2. In commercial units, 90% of saturation of the air is feasible.

3. Relative cooling tower size is sensitive to the difference between the exit and wet bulb temperatures:

ΔT(F)	5	15	25
Relative volume	2.4	1.0	0.55

4. Tower fill is of a highly open structure so as to minimize pressure drop, which is in standard practice a maximum of 2 in. of water.
5. Water circulation rate is 1–4 gpm/sqft and air rates are 1300–1800 lb/(hr)(sqft) or 300–400 ft/min.
6. Chimney-assisted natural draft towers are of hyperbolical shapes because they have greater strength for a given thickness; a tower 250 ft high has concrete walls 5–6 in. thick. The enlarged cross section at the top aids in dispersion of exit humid air into the atmosphere.
7. Countercurrent induced draft towers are the most common in process industries. They are able to cool water within 2 F of the wet bulb.
8. Evaporation losses are 1% of the circulation for every 10 F of cooling range. Windage or drift losses of mechanical draft towers are 0.1–0.3%. Blowdown of 2.5–3.0% of the circulation is necessary to prevent excessive salt buildup.

CRYSTALLIZATION FROM SOLUTION

1. Complete recovery of dissolved solids is obtainable by evaporation, but only to the eutectic composition by chilling. Recovery by melt crystallization also is limited by the eutectic composition.
2. Growth rates and ultimate sizes of crystals are controlled by limiting the extent of supersaturation at any time.
3. The ratio $S = C/C_{sat}$ of prevailing concentration to saturation concentration is kept near the range of 1.02–1.05.
4. In crystallization by chilling, the temperature of the solution is kept at most 1–2 F below the saturation temperature at the prevailing concentration.
5. Growth rates of crystals under satisfactory conditions are in the range of 0.1–0.8 mm/hr. The growth rates are approximately the same in all directions.
6. Growth rates are influenced greatly by the presence of impurities and of certain specific additives that vary from case to case.

DISINTEGRATION

1. Percentages of material greater than 50% of the maximum size are about 50% from rolls, 15% from tumbling mills, and 5% from closed circuit ball mills.
2. Closed circuit grinding employs external size classification and return of oversize for regrinding. The rules of pneumatic conveying are applied to design of air classifiers. Closed circuit is most common with ball and roller mills.
3. Jaw crushers take lumps of several feet in diameter down to 4 in. Stroke rates are 100–300/min. The average feed is subjected to 8–10 strokes before it becomes small enough to escape. Gyratory crushers are suited to slabby feeds and make a more rounded product.
4. Roll crushers are made either smooth or with teeth. A 24 in. toothed roll can accept lumps 14 in. dia. Smooth rolls effect reduction ratios up to about 4. Speeds are 50–900 rpm. Capacity is about 25% of the maximum corresponding to a continuous ribbon of material passing through the rolls.
5. Hammer mills beat the material until it is small enough to pass through the screen at the bottom of the casing. Reduction ratios of 40 are feasible. Large units operate at 900 rpm, smaller ones up to 16,000 rpm. For fibrous materials the screen is provided with cutting edges.
6. Rod mills are capable of taking feed as large as 50 mm and reducing it to 300 mesh, but normally the product range is 8–65 mesh. Rods are 25–150 mm dia. Ratio of rod length to mill diameter is about 1.5. About 45% of the mill volume is occupied by rods. Rotation is at 50–65% of critical.
7. Ball mills are better suited than rod mills to fine grinding. The charge is of equal weights of 1.5, 2, and 3 in. balls for the finest grinding. Volume occupied by the balls is 50% of the mill volume. Rotation speed is 70–80% of critical. Ball mills have a length to diameter ratio in the range 1–1.5. Tube mills have a ratio of 4–5 and are capable of very fine grinding. Pebble mills have ceramic grinding elements, used when contamination with metal is to be avoided.
8. Roller mills employ cylindrical or tapered surfaces that roll along flatter surfaces and crush nipped particles. Products of 20–200 mesh are made.

DISTILLATION AND GAS ABSORPTION

1. Distillation usually is the most economical method of separating liquids, superior to extraction, adsorption, crystallization, or others.

2. For ideal mixtures, relative volatility is the ratio of vapor pressures $\alpha_{12} = P_2/P_1$.
3. Tower operating pressure is determined most often by the temperature of the available condensing medium, 100–120 F if cooling water; or by the maximum allowable reboiler temperature, 150 psig steam, 366 F.
4. Sequencing of columns for separating multicomponent mixtures: (a) perform the easiest separation first, that is, the one least demanding of trays and reflux, and leave the most difficult to the last; (b) when neither relative volatility nor feed concentration vary widely, remove the components one by one as overhead products; (c) when the adjacent ordered components in the feed vary widely in relative volatility, sequence the splits in the order of decreasing volatility; (d) when the concentrations in the feed vary widely but the relative volatilities do not, remove the components in the order of decreasing concentration in the feed.
5. Economically optimum reflux ratio is about 1.2 times the minimum reflux ratio R_m.
6. The economically optimum number of trays is near twice the minimum value N_m.
7. The minimum number of trays is found with the Fenske-Underwood equation

$$N_m = \log\{[x/(1-x)]_{\text{ovhd}}/[x/(1-x)]_{\text{btms}}\}/\log \alpha.$$

8. Minimum reflux for binary or pseudobinary mixtures is given by the following when separation is essentially complete ($x_D \simeq 1$) and D/F is the ratio of overhead product and feed rates:

$$R_m D/F = 1/(\alpha - 1), \qquad \text{when feed is at the bubblepoint,}$$

$$(R_m + 1)D/F = \alpha/(\alpha - 1), \qquad \text{when feed is at the dewpoint.}$$

9. A safety factor of 10% of the number of trays calculated by the best means is advisable.
10. Reflux pumps are made at least 25% oversize.
11. For reasons of accessibility, tray spacings are made 20–24 in.
12. Peak efficiency of trays is at values of the vapor factor $F_s = u\sqrt{\rho_v}$ in the range 1.0–1.2 (ft/sec) $\sqrt{\text{lb/cuft}}$. This range of F_s establishes the diameter of the tower. Roughly, linear velocities are 2 ft/sec at moderate pressures and 6 ft/sec in vacuum.

13. The optimum value of the Kremser–Brown absorption factor $A = K(V/L)$ is in the range 1.25–2.0.
14. Pressure drop per tray is of the order of 3 in. of water or 0.1 psi.
15. Tray efficiencies for distillation of light hydrocarbons and aqueous solutions are 60–90%; for gas absorption and stripping, 10–20%.
16. Sieve trays have holes 0.25–0.50 in. dia, hole area being 10% of the active cross section.
17. Valve trays have holes 1.5 in. dia each provided with a liftable cap, 12–14 caps/sqft of active cross section. Valve trays usually are cheaper than sieve trays.
18. Bubblecap trays are used only when a liquid level must be maintained at low turndown ratio; they can be designed for lower pressure drop than either sieve or valve trays.
19. Weir heights are 2 in., weir lengths about 75% of tray diameter, liquid rate a maximum of about 8 gpm/in. of weir; multipass arrangements are used at high liquid rates.
20. Packings of random and structured character are suited especially to towers under 3 ft dia and where low pressure drop is desirable. With proper initial distribution and periodic redistribution, volumetric efficiencies can be made greater than those of tray towers. Packed internals are used as replacements for achieving greater throughput or separation in existing tower shells.
21. For gas rates of 500 cfm, use 1 in. packing; for gas rates of 2000 cfm or more, use 2 in.
22. The ratio of diameters of tower and packing should be at least 15.
23. Because of deformability, plastic packing is limited to a 10–15 ft depth unsupported, metal to 20–25 ft.
24. Liquid redistributors are needed every 5–10 tower diameters with pall rings but at least every 20 ft. The number of liquid streams should be 3–5/sqft in towers larger than 3 ft dia (some experts say 9–12/sqft), and more numerous in smaller towers.
25. Height equivalent to a theoretical plate (HETP) for vapor–liquid contacting is 1.3–1.8 ft for 1 in. pall rings, 2.5–3.0 ft for 2 in. pall rings.
26. Packed towers should operate near 70% of the flooding rate given by the correlation of Sherwood, Lobo, et al.
27. Reflux drums usually are horizontal, with a liquid holdup of 5 min half full. A takeoff pot for a second liquid phase, such as water in hydrocarbon systems, is sized for a linear velocity of that phase of 0.5 ft/sec, minimum diameter of 16 in.
28. For towers about 3 ft dia, add 4 ft at the top for vapor disengagement and 6 ft at the bottom for liquid level and reboiler return.

29. Limit the tower height to about 175 ft max because of wind load and foundation considerations. An additional criterion is that L/D be less than 30.

DRIVERS AND POWER RECOVERY EQUIPMENT

1. Efficiency is greater for larger machines. Motors are 85–95%; steam turbines are 42–78%; gas engines and turbines are 28–38%.
2. For under 100 HP, electric motors are used almost exclusively. They are made up to 20,000 HP.
3. Induction motors are most popular. Synchronous motors are made for speeds as low as 150 rpm and are thus suited for example for low speed reciprocating compressors, but are not made smaller than 50 HP. A variety of enclosures is available, from weather-proof to explosion-proof.
4. Steam turbines are competitive above 100 HP. They are speed controllable. Frequently they are employed as spares in case of power failure.
5. Combustion engines and turbines are restricted to mobile and remote locations.
6. Gas expanders for power recovery may be justified at capacities of several hundred HP; otherwise any needed pressure reduction in process is effected with throttling valves.

DRYING OF SOLIDS

1. Drying times range from a few seconds in spray dryers to 1 hr or less in rotary dryers and up to several hours or even several days in tunnel shelf or belt dryers.
2. Continuous tray and belt dryers for granular material of natural size or pelleted to 3–15 mm have drying times in the range of 10–200 min.
3. Rotary cylindrical dryers operate with superficial air velocities of 5–10 ft/sec, sometimes up to 35 ft/sec when the material is coarse. Residence times are 5–90 min. Holdup of solid is 7–8%. An 85% free cross section is taken for design purposes. In countercurrent flow, the exit gas is 10–20 C above the solid; in parallel flow, the temperature of the exit solid is 100 C. Rotation speeds of about 4 rpm are used, but the product of rpm and diameter in feet is typically between 15 and 25.
4. Drum dryers for pastes and slurries operate with contact times of 3–12 sec, produce flakes 1–3 mm thick with evaporation rates of 15–30 kg/m^2 hr. Diameters are 1.5–5.0 ft; the rotation rate is

2–10 rpm. The greatest evaporative capacity is of the order of 3000 lb/hr in commercial units.

5. Pneumatic conveying dryers normally take particles 1–3 mm dia but up to 10 mm when the moisture is mostly on the surface. Air velocities are 10–30 m/sec. Single pass residence times are 0.5–3.0 sec but with normal recycling the average residence time is brought up to 60 sec. Units in use range from 0.2 m dia by 1 m high to 0.3 m dia by 38 m long. Air requirement is several SCFM/lb of dry product/hr.
6. Fluidized bed dryers work best on particles of a few tenths of a mm dia, but up to 4 mm dia have been processed. Gas velocities of twice the minimum fluidization velocity are a safe prescription. In continuous operation, drying times of 1–2 min are enough, but batch drying of some pharmaceutical products employs drying times of 2–3 hr.
7. Spray dryers: Surface moisture is removed in about 5 sec, and most drying is completed in less than 60 sec. Parallel flow of air and stock is most common. Atomizing nozzles have openings 0.012–0.15 in. and operate at pressures of 300–4000 psi. Atomizing spray wheels rotate at speeds to 20,000 rpm with peripheral speeds of 250–600 ft/sec. With nozzles, the length to diameter ratio of the dryer is 4–5; with spray wheels, the ratio is 0.5–1.0. For the final design, the experts say, pilot tests in a unit of 2 m dia should be made.

EVAPORATORS

1. Long tube vertical evaporators with either natural or forced circulation are most popular. Tubes are 19–63 mm dia and 12–30 ft long.
2. In forced circulation, linear velocities in the tubes are 15–20 ft/sec.
3. Elevation of boiling point by dissolved solids results in differences of 3–10 F between solution and saturated vapor.
4. When the boiling point rise is appreciable, the economic number of effects in series with forward feed is 4–6.
5. When the boiling point rise is small, minimum cost is obtained with 8–10 effects in series.
6. In backward feed the more concentrated solution is heated with the highest temperature steam so that heating surface is lessened, but the solution must be pumped between stages.
7. The steam economy of an *N*-stage battery is approximately 0.8*N* lb evaporation/lb of outside steam.
8. Interstage steam pressures can be boosted with steam jet compressors of 20–30% efficiency or with mechanical compressors of 70–75% efficiency.

EXTRACTION, LIQUID–LIQUID

1. The dispersed phase should be the one that has the higher volumetric rate except in equipment subject to backmixing where it should be the one with the smaller volumetric rate. It should be the phase that wets the material of construction less well. Since the holdup of continuous phase usually is greater, that phase should be made up of the less expensive or less hazardous material.
2. There are no known commercial applications of reflux to extraction processes, although the theory is favorable (Treybal).
3. Mixer-settler arrangements are limited to at most five stages. Mixing is accomplished with rotating impellers or circulating pumps. Settlers are designed on the assumption that droplet sizes are about 150 μm dia. In open vessels, residence times of 30–60 min or superficial velocities of 0.5–1.5 ft/min are provided in settlers. Extraction stage efficiencies commonly are taken as 80%.
4. Spray towers even 20–40 ft high cannot be depended on to function as more than a single stage.
5. Packed towers are employed when 5–10 stages suffice. Pall rings of 1–1.5 in. size are best. Dispersed phase loadings should not exceed 25 gal/(min) (sqft). HETS of 5–10 ft may be realizable. The dispersed phase must be redistributed every 5–7 ft. Packed towers are not satisfactory when the surface tension is more than 10 dyn/cm.
6. Sieve tray towers have holes of only 3–8 mm dia. Velocities through the holes are kept below 0.8 ft/sec to avoid formation of small drops. Redispersion of either phase at each tray can be designed for. Tray spacings are 6–24 in. Tray efficiencies are in the range of 20–30%.
7. Pulsed packed and sieve tray towers may operate at frequencies of 90 cycles/min and amplitudes of 6–25 mm. In large diameter towers, HETS of about 1 m has been observed. Surface tensions as high as 30–40 dyn/cm have no adverse effect.
8. Reciprocating tray towers can have holes 9/16 in. dia, 50–60% open area, stroke length 0.75 in., 100–150 strokes/min, plate spacing normally 2 in. but in the range 1–6 in. In a 30 in. dia tower, HETS is 20–25 in. and throughput is 2000 gal/(hr)(sqft). Power requirements are much less than of pulsed towers.
9. Rotating disk contactors or other rotary agitated towers realize HETS in the range 0.1–0.5 m. The especially efficient Kuhni with perforated disks of 40% free cross section has HETS 0.2 m and a capacity of 50 m^3/m^2 hr.

FILTRATION

1. Processes are classified by their rate of cake buildup in a laboratory vacuum leaf filter: rapid, 0.1–10.0 cm/sec; medium, 0.1–10.0 cm/min; slow, 0.1–10.0 cm/hr.
2. Continuous filtration should not be attempted if 1/8 in. cake thickness cannot be formed in less than 5 min.
3. Rapid filtering is accomplished with belts, top feed drums, or pusher-type centrifuges.
4. Medium rate filtering is accomplished with vacuum drums or disks or peeler-type centrifuges.
5. Slow filtering slurries are handled in pressure filters or sedimenting centrifuges.
6. Clarification with negligible cake buildup is accomplished with cartridges, precoat drums, or sand filters.
7. Laboratory tests are advisable when the filtering surface is expected to be more than a few square meters, when cake washing is critical, when cake drying may be a problem, or when precoating may be needed.
8. For finely ground ores and minerals, rotary drum filtration rates may be 1500 lb/(day)(sqft), at 20 rev/hr and 18–25 in. Hg vacuum.
9. Coarse solids and crystals may be filtered at rates of 6000 lb/(day)(sqft) at 20 rev/hr, 2–6 in. Hg vacuum.

FLUIDIZATION OF PARTICLES WITH GASES

1. Properties of particles that are conducive to smooth fluidization include: rounded or smooth shape, enough toughness to resist attrition, sizes in the range 50–500 μm dia, a spectrum of sizes with ratio of largest to smallest in the range of 10–25.
2. Cracking catalysts are members of a broad class characterized by diameters of 30–150 μm, density of 1.5 g/mL or so, appreciable expansion of the bed before fluidization sets in, minimum bubbling velocity greater than minimum fluidizing velocity, and rapid disengagement of bubbles.
3. The other extreme of smoothly fluidizing particles is typified by coarse sand and glass beads both of which have been the subject of much laboratory investigation. Their sizes are in the range 150–500 μm, densities 1.5–4.0 g/mL, small bed expansion, about the same magnitudes of minimum bubbling and minimum fluidizing velocities, and also have rapidly disengaging bubbles.
4. Cohesive particles and large particles of 1 mm or more do not fluidize well and usually are processed in other ways.

5. Rough correlations have been made of minimum fluidization velocity, minimum bubbling velocity, bed expansion, bed level fluctuation, and disengaging height. Experts recommend, however, that any real design be based on pilot plant work.
6. Practical operations are conducted at two or more multiples of the minimum fluidizing velocity. In reactors, the entrained material is recovered with cyclones and returned to process. In dryers, the fine particles dry most quickly so the entrained material need not be recycled.

HEAT EXCHANGERS

1. Take true countercurrent flow in a shell-and-tube exchanger as a basis.
2. Standard tubes are 3/4 in. OD, 1 in. triangular spacing, 16 ft long; a shell 1 ft dia accommodates 100 sqft; 2 ft dia, 400 sqft, 3 ft dia, 1100 sqft.
3. Tube side is for corrosive, fouling, scaling, and high pressure fluids.
4. Shell side is for viscous and condensing fluids.
5. Pressure drops are 1.5 psi for boiling and 3–9 psi for other services.
6. Minimum temperature approach is 20 F with normal coolants, 10 F or less with refrigerants.
7. Water inlet temperature is 90 F, maximum outlet 120 F.
8. Heat transfer coefficients for estimating purposes, Btu/(hr)(sqft)(F): water to liquid, 150; condensers, 150; liquid to liquid, 50; liquid to gas, 5; gas to gas, 5; reboiler, 200. Max flux in reboilers, 10,000 Btu/(hr)(sqft).
9. Double-pipe exchanger is competitive at duties requiring 100–200 sqft.
10. Compact (plate and fin) exchangers have 350 sqft/cuft, and about 4 times the heat transfer per cuft to shell-and-tube units.
11. Plate and frame exchangers are suited to high sanitation services, and are 25–50% cheaper in stainless construction than shell-and-tube units.
12. Air coolers: Tubes are 0.75–1.00 in. OD, total finned surface 15–20 sqft/sqft bare surface, $U = 80 - 100\,\text{Btu}/(\text{hr})$ (sqft bare surface)(F), fan power input 2–5 HP (MBtu/hr), approach 50 F or more.
13. Fired heaters: radiant rate, 12,000 Btu/(hr)(sqft); convection rate, 4000; cold oil tube velocity, 6 ft/sec; approx equal transfers of heat in the two sections; thermal efficiency 70–75%; flue gas temperature 250–350 F above feed inlet; stack gas temperature 650–950 F.

INSULATION

1. Up to 650 F, 85% magnesia is most used.
2. Up to 1600–1900 F, a mixture of asbestos and diatomaceous earth is used.
3. Ceramic refractories at higher temperatures.
4. Cyrogenic equipment (−200 F) employs insulants with fine pores in which air is trapped.
5. Optimum thickness varies with temperature: 0.5 in. at 200 F, 1.0 in. at 400 F, 1.25 in. at 600 F.
6. Under windy conditions (7.5 miles/hr), 10–20% greater thickness of insulation is justified.

MIXING AND AGITATION

1. Mild agitation is obtained by circulating the liquid with an impeller at superficial velocities of 0.1–0.2 ft/sec, and intense agitation at 0.7–1.0 ft/sec.
2. Intensities of agitation with impellers in baffled tanks are measured by power input, HP/1000 gal, and impeller tip speeds:

Operation	HP/1000 gal	Tip speed (ft/min)
Blending	0.2–0.5	
Homogeneous reaction	0.5–1.5	7.5–10
Reaction with heat transfer	1.5–5.0	10–15
Liquid–liquid mixtures	5	15–20
Liquid–gas mixtures	5–10	15–20
Slurries	10	

3. Proportions of a stirred tank relative to the diameter *D*: liquid level = *D*; turbine impeller diameter = *D*/3; impeller level above bottom = *D*/3; impeller blade width = *D*/15; four vertical baffles with width = *D*/10.
4. Propellers are made a maximum of 18 in., turbine impellers to 9 ft.
5. Gas bubbles sparged at the bottom of the vessel will result in mild agitation at a superficial gas velocity of 1 ft/min, severe agitation at 4 ft/min.
6. Suspension of solids with a settling velocity of 0.03 ft/sec is accomplished with either turbine or propeller impellers, but when the settling

velocity is above 0.15 ft/sec intense agitation with a propeller is needed.

7. Power to drive a mixture of a gas and a liquid can be 25–50% less than the power to drive the liquid alone.
8. In-line blenders are adequate when a second or two contact time is sufficient, with power inputs of 0.1–0.2 HP/gal.

PARTICLE SIZE ENLARGEMENT

1. The chief methods of particle size enlargement are: compression into a mold, extrusion through a die followed by cutting or breaking to size, globulation of molten material followed by solidification, agglomeration under tumbling or otherwise agitated conditions with or without binding agents.
2. Rotating drum granulators have length to diameter ratios of 2–3, speeds of 10–20 rpm, pitch as much as 10°. Size is controlled by speed, residence time, and amount of binder; 2–5 mm dia is common.
3. Rotary disk granulators produce a more nearly uniform product than drum granulators. Fertilizer is made 1.5–3.5 mm; iron ore 10–25 mm dia.
4. Roll compacting and briquetting is done with rolls ranging from 130 mm dia by 50 mm wide to 910 mm dia by 550 mm wide. Extrudates are made 1–10 mm thick and are broken down to size for any needed processing such as feed to tabletting machines or to dryers.
5. Tablets are made in rotary compression machines that convert powders and granules into uniform sizes. Usual maximum diameter is about 1.5 in., but special sizes up to 4 in. dia are possible. Machines operate at 100 rpm or so and make up to 10,000 tablets/min.
6. Extruders make pellets by forcing powders, pastes, and melts through a die followed by cutting. An 8 in. screw has a capacity of 2000 lb/hr of molten plastic and is able to extrude tubing at 150–300 ft/min and to cut it into sizes as small as washers at 8000/min. Ring pellet extrusion mills have hole diameters of 1.6–32 mm. Production rates cover a range of 30–200 lb/(hr)(HP).
7. Prilling towers convert molten materials into droplets and allow them to solidify in contact with in air stream. Towers as high as 60 m are used. Economically the process becomes competitive with other granulation processes when a capacity of 200–400 tons/day is reached. Ammonium nitrate prills, for example, are 1.6–3.5 mm dia in the 5–95% range.

8. Fluidized bed granulation is conducted in shallow beds 12–24 in. deep at air velocities of 0.1–2.5 m/s or 3–10 times the minimum fluidizing velocity, with evaporation rates of 0.005–1.0 kg/m^2 sec. One product has a size range 0.7–2.4 mm dia.

PIPING

1. Line velocities and pressure drops, with line diameter D in inches: liquid pump discharge, $(5 + D/3)$ ft/sec, 2.0 psi/100 ft; liquid pump suction, $(1.3 + D/6)$ ft/sec, 0.4 psi/100 ft; steam or gas, $20D$ ft/sec, 0.5 psi/100 ft.
2. Control valves require at least 10 psi drop for good control.
3. Globe valves are used for gases, for control and wherever tight shutoff is required. Gate valves are for most other services.
4. Screwed fittings are used only on sizes 1.5 in, and smaller, flanges or welding otherwise.
5. Flanges and fittings are rated for 150, 300, 600, 900, 1500, or 2500 psig.
6. Pipe schedule number $= 1000P/S$, approximately, where P is the internal pressure psig and S is the allowable working stress (about 10,000 psi for A120 carbon steel at 500 F). Schedule 40 is most common.

PUMPS

1. Power for pumping liquids: HP = (gpm) (psi difference)/(1714) (fractional efficiency).
2. Normal pump suction head (NPSH) of a pump must be in excess of a certain number, depending on the kind of pumps and the conditions, if damage is to be avoided. NPSH = (pressure at the eye of the impeller − vapor pressure)/(density). Common range is 4–20 ft.
3. Specific speed $N_s = (\text{rpm})(\text{gpm})^{0.5}/(\text{head in ft})^{0.75}$. Pump may be damaged it certain limits of N_s are exceeded, and efficiency is best in some ranges.
4. Centrifugal pumps: Single stage for 15–5000 gpm, 500 ft max head; multistage for 20–11,000 gpm, 5500 ft max head. Efficiency 45% at 100 gpm, 70% at 500 gpm, 80% at 10,000 gpm.
5. Axial pumps for 20–100,000 gpm, 40 ft head, 65–85% efficiency.
6. Rotary pumps of 1–5000 gpm, 50,000 ft head, 50–80% efficiency.
7. Reciprocating pumps for 10–10,000 gpm, 1,000,000 ft head max. Efficiency 70% at 10 HP, 85% at 50 HP, 90% at 500 HP.

REACTORS

1. The rate of reaction in every instance must be established in the laboratory, and the residence time or space velocity and product distribution eventually must be found in a pilot plant.
2. Dimensions of catalyst particles are 0.1 mm in fluidized beds, 1 mm in slurry beds, and 2–5 mm in fixed beds.
3. The optimum proportions of stirred tank reactors are with liquid level equal to the tank diameter, but at high pressures slimmer proportions are economical.
4. Power input to a homogeneous reaction stirred tank is 0.5–1.5 HP/1000 gal, but three times this amount when heat is to be transferred.
5. Ideal CSTR (continuous stirred tank reactor) behavior is approached when the mean residence time is 5–10 times the length of time needed to achieve homogeneity, which is accomplished with 500–2000 revolutions of a properly designed stirrer.
6. Batch reactions are conducted in stirred tanks for small daily production rates or when the reaction times are long or when some condition such as feed rate or temperature must be programmed in some way.
7. Relatively slow reactions of liquids and slurries are conducted in continuous stirred tanks. A battery of four or five in series is most economical.
8. Tubular flow reactors are suited to high production rates at short residence times (sec or min) and when substantial heat transfer is needed. Embedded tubes or shell-and-tube construction then are used.
9. In granular catalyst packed reactors, the residence time distribution often is no better than that of a five-stage CSTR battery.
10. For conversions under about 95% of equilibrium, the performance of a five-stage CSTR battery approaches plug flow.

REFRIGERATION

1. A ton of refrigeration is the removal of 12,000 Btu/hr of heat.
2. At various temperature levels: 0–50 F, chilled brine and glycol solutions; −50–40 F, ammonia, freons, butane; −150– −50 F, ethane or propane.
3. Compression refrigeration with 100 F condenser requires these HP/ton at various temperature levels: 1.24 at 20 F; 1.75 at 0 F; 3.1 at −40 F; 5.2 at −80 F.

4. Below −80 F, cascades of two or three refrigerants are used.
5. In single stage compression, the compression ratio is limited to about 4.
6. In multistage compression, economy is improved with interstage flashing and recycling, so-called economizer operation.
7. Absorption refrigeration (ammonia to −30 F, lithium bromide to +45 F) is economical when waste steam is available at 12 psig or so.

SIZE SEPARATION OF PARTICLES

1. Grizzlies that are constructed of parallel bars at appropriate spacings are used to remove products larger than 5 cm dia.
2. Revolving cylindrical screens rotate at 15–20 rpm and below the critical velocity; they are suitable for wet or dry screening in the range of 10–60 mm.
3. Flat screens are vibrated or shaken or impacted with bouncing balls. Inclined screens vibrate at 600–7000 strokes/min and are used for down to 38 μm although capacity drops off sharply below 200 μm. Reciprocating screens operate in the range 30–1000 strokes/min and handle sizes down to 0.25 mm at the higher speeds.
4. Rotary sifters operate at 500–600 rpm and are suited to a range of 12 mm to 50 μm.
5. Air classification is preferred for fine sizes because screens of 150 mesh and finer are fragile and slow.
6. Wet classifiers mostly are used to make two product size ranges, oversize and undersize, with a break commonly in the range between 28 and 200 mesh. A rake classifier operates at about 9 strokes/min when making separation at 200 mesh, and 32 strokes/min at 28 mesh. Solids content is not critical, and that of the overflow may be 2–20% or more.
7. Hydrocyclones handle up to 600 cuft/min and can remove particles in the range of 300–5 μm from dilute suspensions. In one case, a 20 in. dia unit had a capacity of 1000 gpm with a pressure drop of 5 psi and a cutoff between 50 and 150 μm.

UTILITIES: COMMON SPECIFICATIONS

1. Steam: 15–30 psig, 250–275 F, 150 psig, 366 F, 400 psig, 448 F; 600 psig, 488 F or with 100–150 F superheat.

2. Cooling water: Supply at 80–90 F from cooling tower, return at 115–125 F; return seawater at 110 F, return tempered water or steam condensate above 125 F.
3. Cooling air supply at 85–95 F; temperature approach to process, 40 F.
4. Compressed air at 45, 150, 300, or 450 psig levels.
5. Instrument air at 45 psig, 0 F dewpoint.
6. Fuels: gas of 1000 Btu/SCF at 5–10 psig, or up to 25 psig for some types of burners: liquid at 6 million Btu/barrel.
7. Heat transfer fluids: petroleum oils below 600 F, Dowtherms below 750 F, fused salts below 1100 F, direct fire or electricity above 450 F.
8. Electricity: 1–100 Hp, 220–550 V; 200–2500 Hp, 2300–4000 V.

VESSELS (DRUMS)

1. Drums are relatively small vessels to provide surge capacity or separation of entrained phases.
2. Liquid drums usually are horizontal.
3. Gas/liquid separators are vertical.
4. Optimum length/diameter = 3, but a range of 2.5–5.0 is common.
5. Holdup time is 5 min half full for reflux drums, 5–10 min for a product feeding another tower.
6. In drums feeding a furnace, 30 min half full is allowed.
7. Knockout drums ahead of compressors should hold no less than 10 times the liquid volume passing through per minute.
8. Liquid/liquid separators are designed for settling velocity of 2–3 in./min.
9. Gas velocity in gas/liquid separators, $V = k\sqrt{\rho_L/\rho_v - 1}$ ft/sec, with $k = 0.35$ with mesh deentrainer, $k = 0.1$ without mesh deentrainer.
10. Entrainment removal of 99% is attained with mesh pads of 4–12 in. thickness; 6 in. thickness is popular.
11. For vertical pads, the value of the coefficient in Step 9 is reduced by a factor of 2/3.
12. Good performance can be expected at velocities of 30–100% of those calculated with the given k; 75% is popular.
13. Disengaging spaces of 6–18 in. ahead of the pad and 12 in. above the pad are suitable.
14. Cyclone separators can be designed for 95% collection of 5 μm particles, but usually only droplets greater than 50 μm need be removed.

VESSELS (PRESSURE)

1. Design temperature between −20 F and 650 F is 50 F above operating temperature; higher safety margins are used outside the given temperature range.
2. The design pressure is 10% or 10–25 psi over the maximum operating pressure, whichever is greater. The maximum operating pressure, in turn, is taken as 25 psi above the normal operation.
3. Design pressures of vessels operating at 0–10 psig and 600–1000 F are 40 psig.
4. For vacuum operation, design pressures are 15 psig and full vacuum.
5. Minimum wall thicknesses for rigidity: 0.25 in. for 42 in. dia and under, 0.32 in. for 42–60 in. dia, and 0.38 in. for over 60 in. dia.
6. Corrosion allowance 0.35 in. for known corrosive conditions, 0.15 in. for non-corrosive streams, and 0.06 in. for steam drums and air receivers.
7. Allowable working stresses are one-fourth of the ultimate strength of the material.
8. Maximum allowable stress depends sharply on temperature.

Temperature (F)	− 20–650	750	850	1000
Low alloy steel SA203 (psi)	18,750	15,650	9550	2500
Type 302 stainless (psi)	18,750	18,750	15,900	6250

VESSELS (STORAGE TANKS)

1. For less than 1000 gal, use vertical tanks on legs.
2. Between 1000 and 10,000 gal, use horizontal tanks on concrete supports.
3. Beyond 10,000 gal, use vertical tanks on concrete foundations.
4. Liquids subject to breathing losses may be stored in tanks with floating or expansion roofs for conservation.
5. Freeboard is 15% below 500 gal and 10% above 500 gal capacity.
6. Thirty days capacity often is specified for raw materials and products, but depends on connecting transportation equipment schedules.
7. Capacities of storage tanks are at least 1.5 times the size of connecting transportation equipment; for instance, 7500 gal tank trucks, 34,500 gal tank cars, and virtually unlimited barge and tanker capacities.

APPENDIX C

Equipment Cost-Capacity Algorithms[1]

The choice of appropriate equipment often is influenced by considerations of price. A lower efficiency or a shorter life may be compensated for by a lower price. Funds may be low at the time of purchase and expected to be more abundant later, or the economic life of the process is expected to be limited. Alternative kinds of equipment for the same service may need to be considered: water-cooled exchangers vs. air coolers, concrete cooling towers vs. redwood, filters vs. centrifuges, pneumatic conveyors vs. screw or bucket elevators, and so on.

In this chapter, the prices of classes of the most frequently used equipment are collected in the form of correlating equations. The prices are given in terms of appropriate key characteristics of the equipment, such as sqft, gpm, lb/hr, etc. Factors for materials of construction and performance characteristics other than the basic ones also are provided. Although graphs are easily read and can bring out clearly desirable comparisons between related types of equipment, algebraic representation has been adopted here. Equations are capable of consistent

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[1]The cost-capacity algorithms were obtained from Stanley M. Walas' book, Chemical Process Equipment: Selection and Design (Woburn, MA: Butterworth, 1988). Permission was obtained to reproduce the material. Butterworth is now part of Elsevier Science and Technical Publications.

Example 1

Installed Cost of a Distillation Tower

Shell and trays are made of AISI 304 stainless steel. Dimensional data are:

$D = 4$ ft,

$L = 120$ ft,

$N = 58$ sieve trays,

wall thickness $t_p = 0.50$ in. for pressure,

$t_b = 0.75$ in. at the bottom,

flanged and dished heads weigh 325 lb each,

weight $W = (\pi/4)(16)(120(0.5/12)(501) + 2(325) = 32{,}129$ lb

$$C_b = 1.218 \exp[7.123 + 0.1478(10.38) + 0.02488(10.38)^2 + 0.158(120/4) \ln (0.75/0.50)] = 697{,}532,$$

$f_1 = 1.7,$

$f_2 = 1.189 + 0.0577(4) = 1.420,$

$f_3 = 0.85,$

$f_4 = 1,$

$C_t = 457.7 \exp[0.1739(4)] = 917.6,$

$C_{p1} = 249.1(4)^{0.6332}(120)^{0.8016} = 27{,}867,$

$$\text{purchase price } C = 1.7(697{,}532) + 58(1.42)(0.85)(917.6) + 27{,}867 = \$1{,}266{,}414$$

From Table 3, the installation factor is 2.1 so that the installed price is

$$C_{\text{installed}} = 2.1(1{,}266{,}414) = \$2{,}659{,}467.$$

A tower packed with 2 in. pall rings instead of trays:

packing volume $V_p = (\pi/4)(4)^2(120) = 1508$ cuft,

$C_{\text{installed}} = 2.1[1.7(697{,}532) + 1508(28.0) + 27{,}867] = \$2{,}637{,}380.$

reading, particularly in comparison with interpolation on logarithmic scales, and are amenable to incorporation in computer programs.

Unless otherwise indicated, the unit price is \$1000, \$K. Except where indicated, notably for fired heaters, refrigeration systems, and cooling towers

Example 2
Purchased and Installed Prices of Some Equipment

a. A box type fired heater with CrMo tubes for pyrolysis at 1500 psig with a duty of 40 million Btu/hr. From Item No. 10 (Table 1), the installed price is

$$C_{\text{installed}} = (6218)\ 33.8(1.0 + 0.10 + 0.15)(40)^{0.86} = 1{,}228{,}134$$

b. A 225 HP reciprocating compressor with motor drive and belt drive coupling. Items Nos. 2 and 13 (Table 1). The installation factor is 1.3.

$$\text{Compressor } C = 7190(225)^{0.61} = 197{,}572,$$

$$\begin{aligned}\text{motor, 1800 rpm, TEFC, } C &= 1.46 \times \exp[4.5347 + 0.57065(5.42) \\ &\quad + 0.04069(5.42)^2] \\ &= \$11{,}858\end{aligned}$$

$$\text{belt drive coupling, } C = 1.46 \exp[3.689 + 0.8917(5.42)] = \$8{,}772,$$

$$\text{total installed cost, } C_{\text{total}} = 1.3(197{,}572 + 11{,}858 + 8772) = \$283{,}663.$$

c. A two-stage steam ejector with one surface condenser to handle 200 lb/hr of air at 25 Torr, in carbon steel construction. From Table 3 the installation factor is 1.7.

$$X = 200/25 = 8,$$

$$f_1 = 1.6,\ f_2 = 1.8,\ f_3 = 1.0$$

$$\text{purchase } C_p = 13.3(1.6)(1.8(1.0)(8))^{0.41} = \$90{,}510,$$

$$\text{installed } C = 1.7C_p = \$153{,}866.$$

(which are installed prices), the prices are purchase prices, FOB, with delivery charges extra. In the United States delivery charges are of the order of 5% of the purchase price, but, of course, dependent on the unit value, as cost per lb or per cuft. Multipliers have been developed whereby the installed cost of various kinds of equipment may be found. Such multipliers range from 1.2 to 3.0, but details are shown in Table 1.

Data are taken from Walas and were updated to the end of fourth quarter 2002, a selection of which is in Table 2. The equipment prices have been spot checked with vendors.

TABLE 1 Index of Equipment

1. Agitators
2. Compressors, turbines, fans
   - Centrifugal compressors
   - Reciprocating compressors
   - Screw compressors
   - Turbines
     - Pressure discharge
     - Vacuum discharge
   - Fans
3. Conveyors
   - Troughed belt
   - Flat belt
   - Screw, steel
   - Screw, stainless
   - Bucket elevator
   - Pneumatic
4. Cooling towers
   - Concrete
   - Wooden
5. Crushers and grinders
   - Cone crusher
   - Gyratory crusher
   - Jaw crusher
   - Hammer mill
   - Ball mill
   - Pulverizer
6. Crystallizers
   - External forced circulation
   - Internal draft tube
   - Batch vacuum
7. Distillation and absorption towers
   - Distillation tray towers
   - Absorption tray towers
   - Packed towers
8. Dryers
   - Rotary, combustion gas heated
   - Rotary, hot air heated
   - Rotary, steam tube heated
   - Cabinet dryers
   - Spray dryers
   - Multiple hearth furnace
9. Evaporators
   - Forced circulation
   - Long tube
   - Falling film
10. Fired heaters
    - Box types
    - Cylindrical types
11. Heat exchangers
    - Shell-and-tube
    - Double pipe
    - Air coolers
12. Mechanical separators
    - Centrifuges
    - Cyclone separators
      - Heavy duty
      - Standard duty
      - Multiclone
    - Disk separators
    - Filters
      - Rotary vacuum belt discharge
      - Rotary vacuum scraper discharge
      - Rotary vacuum disk
      - Horizontal vacuum belt
      - Pressure leaf
      - Plate-and-frame
    - Vibrating screens
13. Motors and couplings
    - Motors
    - Belt drive coupling
    - Chain drive coupling
    - Variable speed drive coupling
14. Pumps
    - Centrifugal
    - Vertical mixed flow
    - Vertical axial flow
    - Gear pumps
    - Reciprocating pumps
15. Refrigeration
16. Steam ejectors and vacuum pumps
    - Ejectors
    - Vacuum pumps
17. Vessels
    - Horizontal pressure vessels
    - Vertical pressure vessels
    - Storage tanks, shop fabricated
    - Storage tanks, field erected

Table 2 Purchase Prices of Process Equipment Costs 1st Q 2003

1. Agitators

$C = 1.218 \exp[a + b \ln \text{HP} + c(\ln \text{HP})^2]$ K\$, $1 < \text{HP} < 400$

		Single Impeller			Dual Impeller		
		Speed 1	2	3	1	2	3
Carbon steel	a	8.57	8.43	8.31	8.80	8.50	8.43
	b	0.1195	−0.0880	−0.1368	0.1603	0.0257	−0.1981
	c	0.0819	0.1123	0.1015	0.0659	0.0878	0.1239
Type 316	a	8.82	8.55	8.52	9.25	8.82	8.72
	b	0.2474	0.0308	−0.1802	0.2801	0.1235	−0.1225
	c	0.0654	0.0943	0.1158	0.0542	0.0818	0.1075

Speeds 1: 30, 37, and 45 rpm
2: 56, 68, 84, and 100 rpm
3: 125, 155, 190, and 230 rpm

2. Compressors, turbines, and fans (K\$)

Centrifugal compressors, without drivers

$$C = 7.90(\text{HP})^{0.62} \quad \text{K\$}, \quad 200 < \text{HP} < 30{,}000$$

Reciprocating compressors without drivers

$$C = 7.19(\text{HP})^{0.61} \quad \text{K\$}, \quad 100 < \text{HP} < 20{,}000$$

Screw compressors with drivers

$$C = 1.81(\text{HP})^{0.71} \quad \text{K\$}, \quad 10 < \text{HP} < 800$$

Turbines:

Pressure discharge, $C = 0.378(\text{HP})^{0.81}$ K\$, $20 < \text{HP} < 5000$
vacuum discharge, $C = 1.10(\text{HP})^{0.81}$ K\$, $200 < \text{HP} < 8000$

Fans with motors

$C = 1.218\, f_m f_p \exp[a + b \ln Q + c(\ln Q)^2]$ installed cost, K\$, Q in KSCFM

(continued)

TABLE 2 (*continued*)

	a	b	c	Q
Radial blades	0.4692	0.1203	0.0931	2–500
Backward curved	0.0400	0.1821	0.0786	2–900
Propeller	−0.4456	0.2211	0.0820	2–300
Propeller, with guide vanes	−1.0181	0.3332	0.0647	2–500

Installation factor, f_m

Carbon steel	2.2
Fiberglass	4.0
Stainless steel	5.5
Nickel alloy	11.0

Pressure factors, F_p

	Centrifugal		Axial	
Pressure (kPa[gage])	**Radial**	**Backward curved**	**Prop.**	**Vane**
1	1.0	1.0	1.0	1.00
2	1.15	1.15	—	1.15
4	1.30	1.30	—	1.30
8	1.45	1.45	—	—
16	1.60	—	—	—

3. Conveyors K$

Troughed belt: $C = 1.71L^{0.66}$, $10 < L < 1300$ ft

Flat belt: $C = 1.10L^{0.66}$, $10 < L < 1300$ ft

Screw (steel): $C = 0.49L^{0.78}$, $7 < L < 100$ ft

Screw (stainless steel): $C = 0.85L^{0.78}$, $7 < L < 100$ ft

Bucket elevator: $C = 5.14L^{0.63}$, $10 < L < 100$ ft

Pneumatic conveyor 600 ft length

$$C = 1.218 \exp[3.5612 - 0.0048 \ln W + 0.0913(\ln W)^2], 10 < W < 100 \text{ klb/hr}$$

4. Cooling towers, installed K$

Concrete $C = 164fQ^{0.61}$, $1 < Q < 60$ K gal/min:

Δt(°C)	10	12	15
f	1.0	1.5	2.0

Redwood, without basin: $C = 44.3Q^{0.85}$, $1.5 < Q < 20$ K gal/min

Table 2 (*continued*)

5. Crushers and grinders K$

Cone crusher: $C = 1.89W^{1.05}$, $20 < W < 300$ tons/hr
Gyratory crusher: $C = 9.7W^{0.60}$, $25 < W < 200$ tons/hr
Jaw crusher: $C = 7.7W^{0.57}$, $10 < W < 200$ tons/hr
Hammer mill: $C = 2.97W^{0.78}$, $2 < W < 200$ tons/hr
Ball mill: $C = 61.0W^{0.69}$, $1 < W < 30$ tons/hr
Pulverizer: $C = 27.5W^{0.39}$, $1 < W < 5$ tons/hr

6. Crystallizers

External forced circulation:

$$C = 1.218\, f \exp\{4.868 + 0.3092 \ln W + 0.0548(\ln W)^2\},$$
$10 < W < 100$ klb/hr of crystals

Internal draft tube: $C = 217fW^{0.58}$, $15 < W < 100$ klb/hr of crystals
Batch vacuum: $C = 9.94fV^{0.47}$, $50 < V < 1000$ cuft of vessel

Type	Material	f
Forced circulation	Mild steel	1.0
	Stainless type 304	2.5
Vacuum batch	Mild steel	1.0
	Rubber-lined	1.3
	Stainless type 304	2.0

7. Distillation and absorption towers, tray and packed prices in $

Tray towers:

$$C_t = 1.218\,[f_1 C_b + N f_2 f_3 f_4 C_t + C_{pl}]$$

Distillation:

$$C_b = 1.218 \exp[7.123 + 0.1478 (\ln W) + 0.02488(\ln W)^2 + 0.01580(L/D) \ln (T_b/T_p)],$$
$9020 < W < 2{,}470{,}000$ lbs of shell exclusive of nozzles and skirt
$C_t = 457.7 \exp(0.1739D)$, $2 < D < 16$ ft tray diameter
N = number of trays
$C_{p1} = 249.6D^{0.6332}L^{0.8016}$, $2 < D < 24$, $57 < L < 170$ ft (platforms and ladders)

Material	f_1	f_2
Stainless steel, 304	1.7	$1.189 + 0.0577D$
Stainless steel, 316	2.1	$1.401 + 0.0724D$
Carpenter 20CB-3	3.2	$1.525 + 0.0788D$
Nickel-200	5.4	
Monel-400	3.6	$2.306 + 0.1120D$
Inconel-600	3.9	
Incoloy-825	3.7	
Titanium	7.7	

TABLE 2 (*continued*)

Tray Types	f_3
Valve	1.00
Grid	0.80
Bubble cap	1.59
Sieve (with downcorner)	0.95

$f_4 = 2.25/(1.0414)^N$, when the number of trays N is less than 20

T_b is the thickness of the shell at the bottom, T_p is thickness required for the operating pressure, D is the diameter of the shell and tray, L is tangent-to-tangent length of the shell

Absorption:

$$C_b = 1.218\exp[6.629 + 0.1826(\ln W) + 0.02297(\ln W)^2],$$
$$4250 < W < 980{,}000 \text{ lb shell}$$
$$C_{p1} = 300D^{0.7396}L^{0.7068},\quad 3 < D < 21,$$
$$27 < L < 40 \text{ ft (platforms and ladders)},$$

f_1, f_2, f_3, and f_4 as for distillation

Packed towers:

$$C = 1.218\,[f_1 C_b + V_p C_p + C_{p1}]$$

V_p is volume of packing, C_p is cost of packing $/cuft

Packing Type	C_p ($/cuft)
Ceramic Raschig rings, 1 in.	23.9
Metal Raschig rings, 1 in.	39.3
Intalox saddles, 1 in.	23.9
Ceramic Raschig rings, 2 in.	76.6
Metal Raschig rings, 2 in.	28.0
Metal Pall rings, 1 in.	39.3
Intalox saddles, 2 in.	17.4
Metal Pall rings, 2 in.	28.0

8. Dryers

Rotary combustion gas heated: $C = 1.218(1 + f_g + f_m)\exp[4.9504 - 0.5827(\ln A) + 0.0925(\ln A)^2]$, $200 < A < 30{,}000$ sqft lateral surface

Table 2 *(continued)*

Rotary hot air heated: $C = 2.90(1 + f_g + f_m)A^{0.63}$, $200 < A < 4000$ sqft lateral surface

Rotary steam tube: $C = 2.23FA_t^{0.60}$, $500 < A_t < 18{,}000$ sqft tube surface, $F = 1$ for carbon steel, $F = 1.75$ for 304 stainless

Cabinet dryer: $C = 1.40f_pA^{0.77}$, $10 < A < 50$ sqft tray surface

Pressure	f_p
Atmospheric pressure	1.0
Vacuum	2.0

Material	f_m
Mild steel	1.0
Stainless type 304	1.4

Drying Gas	f_g
Hot air	0.00
Combustion gas (direct contact)	0.12
Combustion gas (indirect contact)	0.35

Materials	f_m
Mild steel	0.00
Lined with stainless 304–20%	0.25
Lined with stainless 316–20%	0.50

Spray dryers:

$$C = 1.218\ F\exp(0.8403 + 0.8526(\ln x) - 0.0229(\ln x)^2,$$
$$30 < x < 3000 \text{ lb/hr evaporation}$$

Material	F
Carbon steel	0.33
304, 321	1.00
316	1.13
Monel	3.0
Inconel	3.67

Multiple hearth furnaces (Hall, 1984)

$$C = 1.218\exp(a + 0.88N), \quad 4 < N < 14 \text{ number of hearths}$$

TABLE 2 (*continued*)

Diameter (ft)	6.0	10.0	14.25	16.75	18.75	22.25	26.75
Sqft/hearth, approx	12	36	89	119	172	244	342
a	5.071	5.295	5.521	5.719	5.853	6.014	6.094

9. Evaporators (IFP)

Forced circulation: $C = 1.218\, f_m \exp[5.9785 - 0.6056(\ln A) + 0.08514(\ln A)^2]$, $150 < A < 8000$ sqft heat transfer surface

Long tube: $C = 0.44 f_m A^{0.85}$, $300 < A < 20{,}000$ sqft

Falling film (316 internals, carbon steel shell)

$$C = 1.218 \exp[3.2362 - 0.0126(\ln A) + 0.0244(\ln A)^2], \quad 150 < A < 4000 \text{ sqft}$$

Forced-Circulation Evaporators

Construction Material: Shell/Tube	f_m
Steel/copper	1.00
Monel/cupronickel	1.35
Nickel/nickel	1.80

Long-Tube Evaporators

Construction Material: Shell/Tube	f_m
Steel/copper	1.0
Steel/steel	0.6
Steel/aluminum	0.7
Nickel/nickel	3.3

10. Fired heaters, installed

Box type: $C = 1.218\, k(1 + f_d + f_p)Q^{0.86}$, $20 < Q < 200$ M Btu/hr

Tube Material	k
Carbon steel	25.5
CrMo steel	33.8
Stainless	45.0

Design Type	f_d
Process heater	0
Pyrolysis	0.10
Reformer (without catalyst)	0.35

Table 2 *(continued)*

Design Pressure, (psi)	f_p
Up to 500	0
1,000	0.10
1,500	0.15
2,000	0.25
2,500	0.40
3,000	0.60

Cylindrical type: $C = 1.218k(1 + f_d + f_p)Q^{0.82}$, $2 < Q < 30$ M Btu/hr

Tube Material	k
Carbon steel	27.3
CrMo steel	40.2
Stainless	42.0

Design Type	f_d
Cylindrical	0
Dowtherm	0.33

Design Pressure (psi)	f_p
Up to 500	0
1,000	0.15
1,500	0.20

11. Heat exchangers

Shell-and-tube: $C = 1.218\ f_d f_m f_p C_b$, price in \$

$$C_b = \exp[8.821 - 0.30863(\ln A) + 0.0681(\ln A)^2],\ 150 < A < 12{,}000 \text{ sqft}$$

Type	f_d
Fixed-head	$\exp[-1.1156 + 0.0906(\ln A)]$
Kettle reboiler	1.35
U-tube	$\exp[-0.9816 + 0.0830(\ln A)]$

Pressure Range (psig)	f_p
100–300	$0.7771 + 0.04981(\ln A)$
300–600	$1.0305 + 0.07140(\ln A)$
600–900	$1.1400 + 0.12088(\ln A)$

$f_m = g_1 + g_2(\ln A)$

Table 2 (*continued*)

Material	g_1	g_2
Stainless steel 316	0.8603	0.23296
Stainless steel 304	0.8193	0.15984
Stainless steel 347	0.6116	0.22186
Nickel 200	1.5092	0.60859
Monel 400	1.2989	0.43377
Inconel 600	1.2040	0.50764
Incoloy 825	1.1854	0.49706
Titanium	1.5420	0.42913
Hastelloy	0.1549	0.51774

Double pipe: $C = 1096\, f_m f_p A^{0.18}$, $2 < A < 60$ sqft, price in \$

Material: Shell/Tube	f_m
cs/cs	1.0
cs/304L stainless	1.9
cs/316 stainless	2.2

Pressure (bar)	f_p
<4	1.00
4–6	1.10
6–7	1.25

Air coolers: $C = 30.0A^{0.40}$, $0.05 < A < 200$ K sqft, price in K\$

12. Mechanical separators

Centrifuges: solid bowl, screen bowl or pusher types

$$C = 1.218\,[a + bW],\ \text{K\$}$$

	Inorganic Process		Organic Process	
Material	a	b	a	b
Carbon steel	42	1.63	—	—
316	65	3.50	98	5.06
Monel	70	5.50	114	7.14
Nickel	84.4	6.56	143	9.43
Hastelloy	—	—	300	10.0
	$10 < W < 90$		$5 < W < 40$ tons/hr	

Table 2 *(continued)*

Disk separators, 316 stainless:

$C = 9.74\ Q^{0.52}$, $15 < Q < 150$ gpm, K\$

Cyclone separators: K\$

Heavy duty: $C = 1.69Q^{0.98}$, $2 < Q < 40$ K SCFM

Standard duty: $C = 0.79Q^{0.91}$, $2 < Q < 40$ K SCFM

Multiclone: $C = 1.90Q^{0.68}$, $9 < Q < 180$ K SCFM

Filters, prices in \$/sqft:

rotary vacuum belt discharge: $C = 1.218\exp[11.20 - 1.2252(\ln A) + 0.0587(\ln A)^2]$, $10 < A < 800$ sqft

rotary vacuum drum scraper discharge: $C = 1.218\exp[11.27 - 1.3408(\ln A) + 0.0709(\ln A)^2]$ \$/sqft, $10 < A < 1500$ sqft

rotary vacuum disk: $C = 1.218\exp[10.50 - 1.008(\ln A) + 0.0344(\ln A)^2]$ \$/sqft, $100 < A < 4000$ sqft

horizontal vacuum belt: $C = 34469/A^{0.5}$ \$/sqft, $10 < A < 1200$ sqft

pressure leaf: $C = 847/A^{0.29}$ \$/sqft, $30 < A < 2500$ sqft

plate-and-frame: $C = 560/A^{0.45}$ \$/sqft, $10 < A < 1000$ sqft

vibrating screen: $C = 3.8A^{0.59}$ K\$, $0.5 < A < 35$ sqft

13. Motors and couplings, prices in \$

Motors: $C = 1.46\exp[a_1 + a_2(\ln \text{HP}) + a_3(\ln \text{HP})^2]$

Belt drive coupling: $C = 1.46\exp[3.689 + 0.8917(\ln \text{HP})]$

Chain drive coupling: $C = 1.46\exp[5.329 + 0.5048(\ln \text{HP})]$

Variable speed drive coupling: $C = 14616/(1.562 + 7.877/\text{HP})$, $\text{HP} < 75$

	Coefficients			
Type	a_1	a_2	a_3	**HP limit**
Open, drip-proof				
3600 rpm	4.8314	0.09666	0.10960	1–7.5
	4.1514	0.53470	0.05252	7.5–250
	4.2432	1.03251	−0.03595	250–700
1800 rpm	4.7075	−0.01511	0.22888	1–7.5
	4.5212	0.47242	0.04820	7.5–250
	7.4044	−0.06464	0.05448	250–600
1200 rpm	4.9298	0.30118	0.12630	1–7.5
	5.0999	0.35861	0.06052	7.5–250
	4.6163	0.88531	−0.02188	250–500

Table 2 (*continued*)

Totally enclosed, fan-cooled				
3600 rpm	5.1058	0.03316	0.15374	1–7.5
	3.8544	0.83311	0.02399	7.5–250
	5.3182	1.08470	−0.05695	250–400
1800 rpm	4.9687	−0.00930	0.22616	7.5–250
	4.5347	0.57065	0.04609	250–400
1200 rpm	5.1532	0.28931	0.14357	1–7.5
	5.3858	0.31004	0.07406	7.5–350
Explosion-proof				
3600 rpm	5.3934	−0.00333	0.15475	1–7.5
	4.4442	0.60820	0.05202	7.5–200
1800 rpm	5.2851	0.00048	0.19949	1–7.5
	4.8178	0.51086	0.05293	7.5–250
1200 rpm	5.4166	0.31216	0.10573	1–7.5
	5.5655	0.31284	0.07212	7.5–200

14. Pumps

Centrifugal prices in \$: $C = F_M F_T C_b$, base cast-iron, 3550 rpm

VSC

$$C_b = 1.39\exp[8.833-0.6019(\ln Q\sqrt{H}) +0.0519(\ln Q\sqrt{H})^2],\ Q \text{ in gpm, } H \text{ in ft head}$$

Material	Cost Factor F_M
Cast steel	1.35
304 or 316 fittings	1.15
Stainless steel, 304 or 316	2.00
Cast Gould's alloy no. 20	2.00
Nickel	3.50
Monel	3.30
ISO B	4.95
ISO C	4.60
Titanium	9.70
Hastelloy C	2.95
Ductile iron	1.15
Bronze	1.90

$$F_T = \exp[b_1+b_2+(\ln Q\sqrt{H}) + b_3(\ln Q\sqrt{H})^2]$$

Table 2 (*continued*)

Type	b_1	b_2	b_3
One-stage, 1750 rpm, VSC	5.1029	−1.2217	0.0771
One-stage, 3550 rpm, HSC	0.0632	0.2744	−0.0253
One-stage, 1750 rpm, HSC	2.0290	−0.2371	0.0102
Two-stage, 3550 rpm, HSC	13.7321	−2.8304	0.1542
Multistage, 3550 rpm, HSC	9.8849	−1.6164	0.0834

Type	Flow Range (gpm)	Head Range (ft)	HP (max)
One-stage, 3550 rpm, VSC	50–900	50–400	75
One-stage, 1750 rpm, VSC	50–3500	50–200	200
One-stage, 3550 rpm, HSC	100–1500	100–450	150
One-stage, 1750 rpm, HSC	250–5000	50–500	250
Two-stage, 3550 rpm, HSC	50–1100	300–1100	250
Two-stage, 3550 rpm, HSC	100–1500	650–3200	1450

Vertical mixed flow: $C = 0.044(\text{gpm})^{0.82}$K\$, $500 < \text{gpm} < 130{,}000$

Vertical axial flow: $C = 0.024(\text{gpm})^{0.78}$K\$, $1000 < \text{gpm} < 130{,}000$

Gear pumps: $C = 1.218\exp[-0.0881 + 0.1986(\ln Q) + 0.0291(\ln Q)^2]$K\$, $10 < Q < 900$ gpm

Reciprocating:

Cast iron: $C = 76.9Q^{0.81}$K\$, $15 < Q < 400$ gpm

Others: $C = 795FQ^{0.52}$K\$, $1 < Q < 400$ gpm

316 stainless	$F = 1.00$
Al bronze	1.40
Nickel	1.86
Monel	2.20

15. Refrigeration: $C = 178FQ^{0.65}$K\$, $0.5 < Q < 400$ M Btu/hr, installed prices

Temperature Level (°C)	F
0	1.00
−10	1.55
−20	2.10
−30	2.65
−40	3.20
−50	4.00

TABLE 2 (*continued*)

16. Steam ejectors and vacuum pumps

Ejectors: $C = 13.3 f_1 f_2 f_3 X^{0.41}$ K\$, $0.1 < X < 100$

X = (fb air/hr)/(suction pressure in Torr)

Type	f_1	No. Stages	f_2	Material	f_3
No condenser	1.0	1	1.0	carbon steel	1.0
1 surface condenser	1.6	2	1.8	stainless steel	2.0
1 barometric condenser	1.7	3	2.1	astelloy	3.0
2 surface condensers	2.3	4	2.6		
2 barometric condensers	1.9	5	4.0		

Vacuum pumps: $C = 9.93X^{1.03}$K\$,

$0.3 < X < 15$(lbs air/hr)/(suction Torr).

17. Vessels prices in \$

Horizontal pressure vessels: $C = F_M C_b + C_a$

$C_b = 1.218 \exp[8.571 - 0.2330(\ln W) + 0.04333(\ln W)^2]$,
$800 < W < 914{,}000$ lb shell weight
$C_a = 1669D^{0.2029}$, $3 < D < 12$ ft diameter (platforms and ladders)

Vertical vessels: $C = F_M C_b + C_a$

$C_b = 1.218 \exp[9.100 - 0.2889(\ln W) + 0.04576(\ln W)^2]$,

$5000 < W < 226{,}000$ lb

$C_a = 300D^{0.7396}L^{0.7068}$, $6 < D < 10$,

$12 < L < 20$ ft tangent-to-tangent

Material	Cost Factor F_M
Stainless steel, 304	1.7
Stainless steel, 316	2.1
Carpenter 20CB-3	3.2
Nickel-200	5.4
Monel-400	3.6
Inconel-600	3.9
Incoloy-825	3.7
Titanium	7.7

Table 2 *(continued)*

Storage tanks, shop fabricated: $C = 1.218F_M \exp[2.631 + 1.3673(\ln V) - 0.06309(\ln V)^2]$, $1300 < V < 21{,}000$ gal

Storage tanks, field erected: $C = 1.218F_M \exp[11.662 - 0.6104(\ln V) + 0.04536(\ln V)^2]$, $21{,}000 < V < 11{,}000{,}000$ gal

Material of Construction	Cost Factor F_M
Stainless steel 316	2.7
Stainless steel 304	2.4
Stainless steel 347	3.0
Nickel	3.5
Monel	3.3
Inconel	3.8
Zirconium	11.0
Titanium	11.0
Brick-and-rubber-or brick-and-polyester-lined steel	2.75
Rubber- or lead-lined steel	1.9
Polyster, fiberglass-reinforced	0.32
Aluminium	2.7
Copper	2.3
Concrete	0.55

Material of construction is a major factor in the price of equipment so that multipliers for prices relative to carbon steel or other standard materials are given for many for many of the items covered here. Usually only the parts in contact with process substances need be of special construction, so that, in general, the multipliers are not always as great as they are for vessels that are made entirely of special materials. Thus, when the tube side of an exchanger is special and the shell is carbon steel, the multiplier will vary with the amount of tube surface, as shown in that section. For multipliers see Table 3.

As with most collections of data, the price data correlated here exhibit a certain amount of scatter. This is due in part to the incomplete characterizations in terms of which the correlations are made, but also to variations among manufacturers, qualities of construction, design differences, market situations, and other factors. Accordingly, the accuracy of the correlations cannot be claimed to be better than $\pm 25\%$ or so.

TABLE 3 Multipliers for Installed Costs of Process Equipment[a]

Equipment	Multiplier	Equipment	Multiplier
Agitators, carbon steel	1.3	Evaporators, calandria	1.5
stainless steel	1.2	thin film, carbon steel	2.5
Air heaters, all types	1.5	thin film, stainless steel	1.9
Beaters	1.4	Extruders, compounding	1.5
Blenders	1.3	Fans	1.4
Blowers	1.4	Filters, all types	1.4
Boilers	1.5	Furnaces, direct fired	1.3
Centrifuges, carbon steel	1.3	Gas holders	1.3
stainless steel	1.2	Granulators for plastic	1.5
Chimneys and stacks	1.2	Heat exchangers, air cooled, carbon steel	2.5
Columns, distillation, carbon steel	3.0	coil in shell, stainless steel	1.7
distillation, stainless steel	2.1	Glass	2.2
Compressors, motor driven	1.3	Graphite	2.0
steam on gas driven	1.5	plate, stainless steel	1.5
Conveyors and elevators	1.4	plate, carbon steel	1.7
Cooling tower, concrete	1.2	shell and tube, stainless/stainless steel	1.9
Crushers, classifiers and mills	1.3	shell and tube, carbon/stainless steel	2.1
Crystallizers	1.9	Heat exchangers, shell and tube, carbon/steel/aluminum	2.2
Cyclones	1.4	shell and tube, carbon steel/copper	2.0
Dryers, spray and air	1.6	shell and tube, carbon steel/Monal	1.8
other	1.4	shell and tube, Monel/Monel	1.6
Ejectors	1.7	shell and tube, carbon steel/Hastelloy	1.4

Instruments, all types	2.5
Miscellaneous, carbon steel	2.0
stainless steel	1.5
Pumps, centrifugal, carbon steel	2.8
centrifugal, stainless steel	2.0
centrifugal, Hastelloy trim	1.4
centrifugal, nickel trim	1.7
centrifugal, Monel trim	1.7
centrifugal, titanium trim	1.4
all others, stainless steel	1.4
all others, carbon steel	1.6
Reactor kettles, carbon steel	1.9
kettles, glass lined	2.1
kettles, carbon steel	1.9
Reactors, multitubular, stainless steel	1.6
multitubular, copper	1.8
multitubular, carbon steel	2.2
Refrigeration plant	1.5
Steam drums	2.0
Sum of equipment costs, stainless steel	1.8
Sum of equipment costs, carbon steel	2.0
Tanks, process, stainless steel	1.8
Tanks, process, copper	1.9
process, aluminum	2.0
storage, stainless steel	1.5
storage, aluminum	1.7
storage, carbon steel	2.3
field erected, stainless steel	1.2
field erected, carbon steel	1.4
Turbines	1.5
Vessels, pressure, stainless steel	1.7
pressure, carbon steel	2.8

[a] [J. Gran, *Chem. Eng.*, (6 Apr. 1981)].
Installed Cost = (purchase price)(multiplier).
Note: The multipliers have remained essentially the same through late 2002.

REFERENCE

1. SM Walas. Chemical Process Equipment: Selection and Design. Woburn, MA: Butterworth, 1988.

APPENDIX D

Condensed Continuous Interest Tables

CONDENSED CONTINUOUS INTEREST TABLES*

(Factors for determining zero-time values for cash flows which occur at other than zero time.)

	1%	5%	10%	15%	20%	25%	30%	35%	40%	50%	60%	70%	80%	90%	100%
Compounding of Cash Flows which Occur:															
A. In an Instant															
½ year before	1.005	1.025	1.051	1.078	1.105	1.133	1.162	1.191	1.221	1.284	1.350	1.419	1.492	1.568	1.649
1	1.010	1.051	1.105	1.162	1.221	1.284	1.350	1.419	1.492	1.649	1.822	2.014	2.226	2.460	2.718
1½	1.015	1.078	1.162	1.252	1.350	1.455	1.568	1.690	1.822	2.117	2.460	2.858	3.320	3.857	4.402
2	1.020	1.105	1.221	1.350	1.492	1.649	1.822	2.014	2.226	2.718	3.320	4.055	4.953	6.050	7.309
3	1.030	1.162	1.350	1.568	1.822	2.117	2.460	2.858	3.320	4.482	6.050	8.166	11.023	14.880	20.086
B. Uniformly until Zero Time															
From ½ year before to 0 time	1.002	1.013	1.025	1.038	1.052	1.065	1.079	1.093	1.107	1.135	1.166	1.197	1.230	1.263	1.297
1	1.005	1.025	1.052	1.079	1.107	1.136	1.166	1.197	1.230	1.297	1.370	1.448	1.532	1.622	1.718
1½	1.008	1.038	1.079	1.121	1.166	1.213	1.263	1.315	1.370	1.489	1.622	1.769	1.933	2.117	2.321
2	1.010	1.052	1.107	1.166	1.230	1.297	1.370	1.448	1.532	1.718	1.933	2.182	2.471	2.805	3.194
3	1.015	1.079	1.166	1.263	1.370	1.489	1.622	1.769	1.933	2.321	2.805	3.412	4.176	5.141	6.362
Discounting of Cash Flows which Occur:															
C. In an Instant															
1 year later	.990	.951	.905	.861	.819	.779	.741	.705	.670	.606	.549	.497	.449	.407	.368
2	.980	.905	.819	.741	.670	.606	.549	.497	.449	.368	.301	.247	.202	.165	.135
3	.970	.861	.741	.638	.549	.472	.407	.350	.301	.223	.165	.122	.091	.067	.050
4	.961	.819	.670	.549	.449	.368	.301	.247	.202	.135	.091	.061	.041	.027	.018
5	.951	.779	.606	.472	.368	.286	.223	.174	.135	.082	.050	.030	.018	.011	.007
10 year later	.905	.606	.368	.223	.135	.082	.050	.030	.018	.007	.002	.001	--	--	--
15	.861	.472	.223	.105	.050	.024	.011	.005	.002	.001	--	--	--	--	--
20	.819	.368	.135	.050	.018	.007	.002	.001	--	--	--	--	--	--	--
25	.779	.286	.082	.024	.007	.002	.001	--	--	--	--	--	--	--	--
D. Uniformly over Individual Years															
1st year	.995	.975	.952	.929	.906	.885	.864	.844	.824	.787	.752	.719	.688	.659	.632
2nd	.985	.928	.861	.799	.742	.689	.640	.595	.552	.477	.413	.357	.309	.268	.232
3rd	.975	.883	.779	.688	.608	.537	.474	.419	.370	.290	.226	.177	.139	.109	.086
4th	.966	.840	.705	.592	.497	.418	.351	.295	.248	.176	.124	.088	.062	.044	.032
5th	.956	.799	.638	.510	.407	.326	.260	.208	.166	.106	.068	.044	.028	.018	.012
6th	.946	.760	.577	.439	.333	.254	.193	.147	.112	.065	.037	.022	.013	.007	.004
7th	.937	.723	.522	.378	.273	.197	.143	.103	.075	.039	.020	.011	.006	.003	.002
8th	.928	.687	.473	.325	.224	.154	.106	.073	.050	.024	.011	.005	.002	.001	.001
9th	.918	.654	.428	.280	.183	.120	.078	.051	.034	.014	.006	.003	.001	--	--
10th	.909	.622	.387	.241	.150	.093	.058	.036	.022	.009	.003	.001	--	--	--
E. Uniformly over 5 Year Periods															
1st–5 year	.975	.885	.787	.704	.632	.571	.518	.472	.432	.367	.317	.277	.245	.220	.199
6th–10th year	.928	.689	.477	.332	.232	.164	.116	.082	.058	.030	.016	.008	.004	.002	.001
11th–15th year	.883	.537	.290	.157	.086	.047	.026	.014	.008	.002	.001	--	--	--	--
16th–20th year	.840	.410	.176	.074	.032	.013	.006	.002	.001	--	--	--	--	--	--
21st–25th year	.799	.326	.106	.035	.012	.004	.001	--	--	--	--	--	--	--	--
F. Declining to Nothing at Constant Rate															
1st 5 years	.983	.922	.852	.791	.736	.687	.643	.603	.568	.506	.456	.413	.377	.347	.320
10	.968	.852	.736	.643	.560	.506	.456	.413	.377	.320	.278	.245	.219	.198	.180
15	.952	.791	.643	.536	.456	.394	.347	.309	.278	.231	.198	.172	.153	.137	.124
20	.936	.736	.568	.456	.377	.320	.278	.245	.219	.180	.153	.133	.117	.105	.095
25	.922	.687	.506	.394	.320	.269	.231	.203	.180	.147	.124	.108	.095	.085	.077

*From tables compiled by J. C. Gregory, The Atlantic Refining Co.

APPENDIX E

Hirschmann-Brauweiler Tables

The Hirschmann-Brauweiler Tables may be used for discounting or compounding cash flows, although the tables indicate discounting. These tables are divided into three sections depending upon how the cash flows: instantaneously, uniformly, or years digits. The last section was originally developed when sum-of-years depreciation was allowable. It is still used for cash flows declining to zero uniformly over a time period.

The factors are used to discount cash flows back to time zero continuously. To enter the tables, an argument $R \times T$ must first be calculated, where R is the interest rate expressed as a whole number and T is the time in years. For example, if a cash flow of \$1000 occurs uniformly over a 2-year period at 15% interest, the discounted cash flow is calculated as follows:

Enter the uniform table with the argument of $R \times T = 15 \times 2 = 3$ and the factor is 0.8639. Therefore the discounted cash flow is $\$1000 \times 0.8639 = \$863.90$.

These tables may also be used for compounding as mentioned previously. In this case, the factor used is the reciprocal of $R \times T$ from the compounding table. For example, the factor for a cash flow that occurs instantaneously 2 years prior to time zero at 20% interest is $R \times T$ from the instantaneous table, or $20 \times 2 = 40$. From that table, the factor is 0.6703. But since the cash flow occurs 2 years prior to time zero, the reciprocal of the factor is $1/0.6703 = 1.4919$. For example, a cash flow of \$5000 that occurs instantaneously 2 years prior to time zero at 20% interest is $\$5000 \times (1/0.6703) = \$7459.35$, which is the compound amount of that cash flow.

In using the table, one must select the correct cash flow model.

FACTORS FOR CONTINUOUS DISCOUNTING: UNIFORM

R × T	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9950	.9901	.9851	.9803	.9754	.9706	.9658	.9610	.9563
10	.9516	.9470	.9423	.9377	.9332	.9286	.9241	.9196	.9152	.9107
20	.9063	.9020	.8976	.8933	.8891	.8848	.8806	.8764	.8722	.8681
30	.8639	.8598	.8558	.8517	.8477	.8437	.8398	.8359	.8319	.8281
40	.8242	.8204	.8166	.8128	.8090	.8053	.8016	.7979	.7942	.7906
50	.7869	.7833	.7798	.7762	.7727	.7692	.7657	.7622	.7588	.7554
60	.7520	.7486	.7453	.7419	.7386	.7353	.7320	.7288	.7256	.7224
70	.7192	.7160	.7128	.7097	.7066	.7035	.7004	.6974	.6944	.6913
80	.6883	.6854	.6824	.6795	.6765	.6736	.6707	.6679	.6650	.6622
90	.6594	.6566	.6538	.6510	.6483	.6455	.6428	.6401	.6374	.6348
100	.6321	.6295	.6269	.6243	.6217	.6191	.6166	.6140	.6115	.6090
110	.6065	.6040	.6015	.5991	.5967	.5942	.5918	.5894	.5871	.5847
120	.5823	.5800	.5777	.5754	.5731	.5708	.5685	.5663	.5640	.5618
130	.5596	.5574	.5552	.5530	.5509	.5487	.5466	.5444	.5423	.5402
140	.5381	.5361	.5340	.5320	.5299	.5279	.5259	.5239	.5219	.5199
150	.5179	.5160	.5140	.5121	.5101	.5082	.5063	.5044	.5025	.5007
160	.4988	.4970	.4951	.4933	.4915	.4897	.4879	.4861	.4843	.4825
170	.4808	.4790	.4773	.4756	.4738	.4721	.4704	.4687	.4671	.4654
180	.4637	.4621	.4604	.4588	.4572	.4555	.4539	.4523	.4507	.4492
190	.4476	.4460	.4445	.4429	.4414	.4399	.4383	.4368	.4353	.4338
200	.4323	.4309	.4294	.4279	.4265	.4250	.4236	.4221	.4207	.4193
210	.4179	.4165	.4151	.4137	.4123	.4109	.4096	.4082	.4069	.4055
220	.4042	.4029	.4015	.4002	.3989	.3976	.3963	.3950	.3937	.3925
230	.3912	.3899	.3887	.3874	.3862	.3849	.3837	.3825	.3813	.3801
240	.3789	.3777	.3765	.3753	.3741	.3729	.3718	.3706	.3695	.3683
250	.3672	.3660	.3649	.3638	.3627	.3615	.3604	.3593	.3582	.3571
260	.3560	.3550	.3539	.3528	.3518	.3507	.3496	.3486	.3476	.3465
270	.3455	.3445	.3434	.3424	.3414	.3404	.3394	.3384	.3374	.3364
280	.3354	.3344	.3335	.3325	.3315	.3306	.3296	.3287	.3277	.3268
290	.3259	.3249	.3240	.3231	.3222	.3212	.3203	.3194	.3185	.3176
300	.3167	.3158	.3150	.3141	.3132	.3123	.3115	.3106	.3098	.3089
310	.3080	.3072	.3064	.3055	.3047	.3039	.3030	.3022	.3014	.3006
320	.2998	.2990	.2982	.2974	.2966	.2958	.2950	.2942	.2934	.2926
330	.2919	.2911	.2903	.2896	.2888	.2880	.2873	.2865	.2858	.2850
340	.2843	.2836	.2828	.2821	.2814	.2807	.2799	.2792	.2785	.2778
350	.2771	.2764	.2757	.2750	.2743	.2736	.2729	.2722	.2715	.2709
360	.2702	.2695	.2688	.2682	.2675	.2669	.2662	.2655	.2649	.2642
370	.2636	.2629	.2623	.2617	.2610	.2604	.2598	.2591	.2585	.2579
380	.2573	.2567	.2560	.2554	.2548	.2542	.2536	.2530	.2524	.2518
390	.2512	.2506	.2500	.2495	.2489	.2483	.2477	.2471	.2466	.2460
400	.2454	.2449	.2443	.2437	.2432	.2426	.2421	.2415	.2410	.2404
410	.2399	.2393	.2388	.2382	.2377	.2372	.2366	.2361	.2356	.2350
420	.2345	.2340	.2335	.2330	.2325	.2319	.2314	.2309	.2304	.2299
430	.2294	.2289	.2284	.2279	.2274	.2269	.2264	.2259	.2255	.2250
440	.2245	.2240	.2235	.2230	.2226	.2221	.2216	.2212	.2207	.2202
450	.2198	.2193	.2188	.2184	.2179	.2175	.2170	.2166	.2161	.2157
460	.2152	.2148	.2143	.2139	.2134	.2130	.2126	.2121	.2117	.2113
470	.2108	.2104	.2100	.2096	.2091	.2087	.2083	.2079	.2074	.2070
480	.2066	.2062	.2058	.2054	.2050	.2046	.2042	.2038	.2034	.2030
490	.2026	.2022	.2018	.2014	.2010	.2006	.2002	.1998	.1994	.1990
500	.1987	.1949	.1912	.1877	.1843	.1811	.1779	.1749	.1719	.1690

FACTORS FOR CONTINUOUS DISCOUNTING: INSTANTANEOUS

R × T	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9900	.9802	.9704	.9608	.9512	.9418	.9324	.9231	.9139
10	.9048	.8958	.8869	.8781	.8694	.8607	.8521	.8437	.8353	.8270
20	.8187	.8106	.8025	.7945	.7866	.7788	.7711	.7634	.7558	.7483
30	.7408	.7334	.7261	.7189	.7118	.7047	.6977	.6907	.6839	.6771
40	.6703	.6637	.6570	.6505	.6440	.6376	.6313	.6250	.6188	.6126
50	.6065	.6005	.5945	.5886	.5827	.5769	.5712	.5655	.5599	.5543
60	.5488	.5434	.5379	.5326	.5273	.5220	.5169	.5117	.5066	.5016
70	.4966	.4916	.4868	.4819	.4771	.4724	.4677	.4630	.4584	.4538
80	.4493	.4449	.4404	.4360	.4317	.4274	.4232	.4190	.4148	.4107
90	.4066	.4025	.3985	.3946	.3906	.3867	.3829	.3791	.3753	.3716
100	.3679	.3642	.3606	.3570	.3535	.3499	.3465	.3430	.3396	.3362
110	.3329	.3296	.3263	.3230	.3198	.3166	.3135	.3104	.3073	.3042
120	.3012	.2982	.2952	.2923	.2894	.2865	.2837	.2808	.2780	.2753
130	.2725	.2698	.2671	.2645	.2618	.2592	.2567	.2541	.2516	.2491
140	.2466	.2441	.2417	.2393	.2369	.2346	.2322	.2299	.2276	.2254
150	.2231	.2209	.2187	.2165	.2144	.2122	.2101	.2080	.2060	.2039
160	.2019	.1999	.1979	.1959	.1940	.1920	.1901	.1882	.1864	.1845
170	.1827	.1809	.1791	.1773	.1755	.1738	.1720	.1703	.1686	.1670
180	.1653	.1637	.1620	.1604	.1588	.1572	.1557	.1541	.1526	.1511
190	.1496	.1481	.1466	.1451	.1437	.1423	.1409	.1395	.1381	.1367
200	.1353	.1340	.1327	.1313	.1300	.1287	.1275	.1262	.1249	.1237
210	.1225	.1212	.1200	.1188	.1177	.1165	.1153	.1142	.1130	.1119
220	.1108	.1097	.1086	.1075	.1065	.1054	.1044	.1033	.1023	.1013
230	.1003	.0993	.0983	.0973	.0963	.0954	.0944	.0935	.0926	.0916
240	.0907	.0898	.0889	.0880	.0872	.0863	.0854	.0846	.0837	.0829
250	.0821	.0813	.0805	.0797	.0789	.0781	.0773	.0765	.0758	.0750
260	.0743	.0735	.0728	.0721	.0714	.0707	.0699	.0693	.0686	.0679
270	.0672	.0665	.0659	.0652	.0646	.0639	.0633	.0627	.0620	.0614
280	.0608	.0602	.0596	.0590	.0584	.0578	.0573	.0567	.0561	.0556
290	.0550	.0545	.0539	.0534	.0529	.0523	.0518	.0513	.0508	.0503
300	.0498	.0493	.0488	.0483	.0478	.0474	.0469	.0464	.0460	.0455
310	.0450	.0446	.0442	.0437	.0433	.0429	.0424	.0420	.0416	.0412
320	.0408	.0404	.0400	.0396	.0392	.0388	.0384	.0380	.0376	.0373
330	.0369	.0365	.0362	.0358	.0354	.0351	.0347	.0344	.0340	.0337
340	.0334	.0330	.0327	.0324	.0321	.0317	.0314	.0311	.0308	.0305
350	.0302	.0299	.0296	.0293	.0290	.0287	.0284	.0282	.0279	.0276
360	.0273	.0271	.0268	.0265	.0263	.0260	.0257	.0255	.0252	.0250
370	.0247	.0245	.0242	.0240	.0238	.0235	.0233	.0231	.0228	.0226
380	.0224	.0221	.0219	.0217	.0215	.0213	.0211	.0209	.0207	.0204
390	.0202	.0200	.0198	.0196	.0194	.0193	.0191	.0189	.0187	.0185
400	.0183	.0181	.0180	.0178	.0176	.0174	.0172	.0171	.0169	.0167
410	.0166	.0164	.0162	.0161	.0159	.0158	.0156	.0155	.0153	.0151
420	.0150	.0148	.0147	.0146	.0144	.0143	.0141	.0140	.0138	.0137
430	.0136	.0134	.0133	.0132	.0130	.0129	.0128	.0127	.0125	.0124
440	.0123	.0122	.0120	.0119	.0118	.0117	.0116	.0114	.0113	.0112
450	.0111	.0110	.0109	.0108	.0107	.0106	.0105	.0104	.0103	.0102
460	.0101	.0100	.0099	.0098	.0097	.0096	.0095	.0094	.0093	.0092
470	.0091	.0090	.0089	.0088	.0087	.0087	.0086	.0085	.0084	.0083
480	.0082	.0081	.0081	.0080	.0079	.0078	.0078	.0077	.0076	.0075
490	.0074	.0074	.0073	.0072	.0072	.0071	.0070	.0069	.0069	.0068
500	.0067	.0061	.0055	.0050	.0045	.0041	.0037	.0033	.0030	.0027

FACTORS FOR CONTINUOUS DISCOUNTING: YEARS-DIGITS

$R \times T$	0	1	2	3	4	5	6	7	8	9
0	1.0000	.9968	.9934	.9902	.9867	.9836	.9803	.9771	.9739	.9707
10	.9675	.9643	.9612	.9580	.9549	.9518	.9487	.9457	.9426	.9396
20	.9365	.9335	.9305	.9275	.9246	.9216	.9187	.9158	.9129	.9100
30	.9071	.9042	.9013	.8985	.8957	.8929	.8901	.8873	.8845	.8817
40	.8790	.8763	.8735	.8708	.8681	.8655	.8628	.8601	.8575	.8549
50	.8522	.8496	.8470	.8445	.8419	.8393	.8368	.8343	.8317	.8292
60	.8267	.8242	.8218	.8193	.8169	.8144	.8120	.8096	.8072	.8048
70	.8024	.8000	.7977	.7953	.7930	.7906	.7883	.7860	.7837	.7814
80	.7792	.7769	.7746	.7724	.7702	.7679	.7657	.7635	.7613	.7591
90	.7570	.7548	.7526	.7505	.7484	.7462	.7441	.7420	.7399	.7378
100	.7358	.7337	.7316	.7296	.7275	.7255	.7235	.7215	.7195	.7175
110	.7155	.7135	.7115	.7096	.7076	.7057	.7038	.7018	.6999	.6980
120	.6961	.6942	.6923	.6905	.6886	.6867	.6849	.6830	.6812	.6794
130	.6776	.6757	.6739	.6721	.6704	.6686	.6668	.6650	.6633	.6615
140	.6598	.6581	.6563	.6546	.6529	.6512	.6495	.6478	.6461	.6445
150	.6428	.6411	.6395	.6378	.6362	.6345	.6329	.6313	.6297	.6281
160	.6265	.6249	.6233	.6217	.6202	.6186	.6170	.6155	.6139	.6124
170	.6109	.6093	.6078	.6063	.6048	.6033	.6018	.6003	.5988	.5973
180	.5959	.5944	.5929	.5915	.5900	.5886	.5872	.5857	.5843	.5829
190	.5815	.5801	.5787	.5773	.5759	.5745	.5731	.5718	.5704	.5690
200	.5677	.5663	.5650	.5636	.5623	.5610	.5596	.5583	.5570	.5557
210	.5544	.5531	.5518	.5505	.5492	.5480	.5467	.5454	.5442	.5429
220	.5417	.5404	.5392	.5379	.5367	.5355	.5342	.5330	.5318	.5306
230	.5294	.5282	.5270	.5258	.5246	.5234	.5223	.5211	.5199	.5188
240	.5176	.5165	.5153	.5142	.5130	.5119	.5108	.5096	.5085	.5074
250	.5063	.5052	.5041	.5029	.5018	.5008	.4997	.4986	.4975	.4964
260	.4953	.4943	.4932	.4922	.4911	.4900	.4890	.4879	.4869	.4859
270	.4848	.4838	.4828	.4818	.4807	.4797	.4787	.4777	.4767	.4757
280	.4747	.4737	.4727	.4717	.4707	.4698	.4688	.4678	.4669	.4659
290	.4649	.4640	.4630	.4621	.4611	.4602	.4592	.4583	.4574	.4564
300	.4555	.4546	.4537	.4527	.4518	.4509	.4500	.4491	.4482	.4473
310	.4464	.4455	.4446	.4438	.4429	.4420	.4411	.4402	.4394	.4385
320	.4376	.4368	.4359	.4351	.4342	.4334	.4325	.4317	.4308	.4300
330	.4292	.4283	.4275	.4267	.4259	.4251	.4242	.4234	.4226	.4218
340	.4210	.4202	.4194	.4186	.4178	.4170	.4162	.4154	.4147	.4139
350	.4131	.4123	.4115	.4108	.4100	.4092	.4085	.4077	.4070	.4062
360	.4055	.4047	.4040	.4032	.4025	.4017	.4010	.4003	.3995	.3988
370	.3981	.3973	.3966	.3959	.3952	.3945	.3937	.3930	.3923	.3916
380	.3909	.3902	.3895	.3888	.3881	.3874	.3867	.3860	.3854	.3847
390	.3840	.3833	.3826	.3820	.3813	.3806	.3799	.3793	.3786	.3779
400	.3773	.3766	.3760	.3753	.3747	.3740	.3734	.3727	.3721	.3714
410	.3708	.3702	.3695	.3689	.3683	.3676	.3670	.3664	.3658	.3651
420	.3645	.3639	.3633	.3627	.3621	.3614	.3608	.3602	.3596	.3590
430	.3584	.3578	.3572	.3566	.3560	.3554	.3548	.3543	.3537	.3531
440	.3525	.3519	.3513	.3508	.3502	.3496	.3490	.3485	.3479	.3473
450	.3468	.3462	.3457	.3451	.3445	.3440	.3434	.3429	.3423	.3418
460	.3412	.3407	.3401	.3396	.3390	.3385	.3380	.3374	.3369	.3363
470	.3358	.3353	.3348	.3342	.3337	.3332	.3327	.3321	.3316	.3311
480	.3306	.3301	.3295	.3290	.3285	.3280	.3275	.3270	.3265	.3260
490	.3255	.3250	.3245	.3240	.3235	.3230	.3225	.3220	.3215	.3210
500	.3205	.3157	.3111	.3065	.3021	.2978	.2936	.2895	.2856	.2817