Money is the modern equivalent of the long-sought "philosopher's stone." For centuries, alchemists vainly sought the stone that could transform one type of metal into another. Now we have that capacity, indirectly. With money as the medium of exchange, we can convert one type of resource into other types easily and rapidly, but not always wisely. The worthiness of this transformation is a subtle aspect of the mission of engineering economists. Telltale analyses of alternatives reveal the innermost workings of a project and burden the analyst with ethical responsibilities atop fiscal obligations. A prerequisite to bearing the burden is a thorough knowledge of accepted economic principles and practices. This knowledge facilitates putting a legitimate monetary value on the transformation of each resource and allows an accurate and conscientious appraisal of worthiness when combined with technical expertise about the subject. Resource commitments monetized as cash flows set a quantitative framework for ensuing qualitative value considerations. This book is dedicated to the economic analysts who contribute to resource-allocation decisions. May you do so wisely.

It can be said that those who manage people manage people who manage works, but those who manage money manage all. We hope that you accept the challenge and enjoy a satisfying and profitable experience from *Engineering Economics.*

Great is the art of beginning,
but greater the art of ending.

Henry Wadsworth Longfellow
Elegiac Verse

David D. Bedworth
Sabah U. Randhawa

CHAPTER 1

INTRODUCTION TO ENGINEERING ECONOMICS

If thou wouldst keep money, save money; If thou wouldst reap money, sow money.

Thomas Fuller
Gnomology, 1732

Engineers are planners and builders. They are also problem solvers, managers, and decision makers. Engineering economics touches each of these activities. Plans and production must be financed. Problems are eventually defined by dollar dimensions, and decisions are evaluated by their monetary consequences. Much of the management function is directed toward economic objectives and is monitored by economic measures.

Engineering economics is closely aligned with conventional microeconomics, but it has a history and a special flavor of its own. It is devoted to problem solving and decision making at the operations level. It can lead to *suboptimization*—a condition in which a solution satisfies tactical objectives at the expense of strategic effectiveness—but careful attention to the collection and analysis of data minimizes the danger.

An engineering economist draws upon the accumulated knowledge of engineering and economics to identify alternative uses of limited resources and to select the preferred course of action. Evaluations rely mainly on mathematical models and cost data, but judgment and experience are pivotal inputs. Many accepted models are available for analyses of short-range projects when the time value of money is not relevant, and of long-range proposals when discounting is required for input data assumed to be known or subject to risk. Familiarity with these models, gained from studying subsequent chapters, should guide your passage through the engineering economic decision maze (such a maze will be summarized at the end of this chapter).

1.1 ENGINEERING DECISION MAKERS

The following general questions are representative of those that an engineer might encounter:

- Which one of several competing engineering designs should be selected?
- Should the machine now in use be replaced with a new one?
- With limited capital available, which investment alternative should be funded?
- Would it be preferable to pursue a safer conservative course of action or to follow a riskier one that offers higher potential returns?
- How many units of production have to be sold before a profit can be made? This area is commonly called *break-even analysis.*
- Among several proposals for funding that yield substantially equivalent worthwhile results but have different cash flow patterns, which is preferable?
- Are the benefits expected from a public service project large enough to make its implementation costs acceptable?

Two characteristics of the questions above should be apparent. First, each deals with a choice among alternatives; second, all involve economic considerations. Less obvious are the requirements of adequate data and an awareness of technological constraints to define the problem and to identify legitimate solutions. These considerations are embodied in the decision-making role of engineering economists to

1. Identify alternative uses for limited resources and obtain appropriate data
2. Analyze the data to determine the preferred alternative

The breadth of problems, depth of analysis, and scope of application that a practicing engineer encounters vary widely. Newly graduated engineers are regularly assigned to cost reduction projects and are expected to be cost-conscious in all their operations. As they gain more experience, they may become specialists in certain application areas or may undertake more general responsibilities as managers. Beginners are usually restricted to short-range decisions for low-budget operations, whereas engineering managers are confronted with policy decisions that involve large sums and are influenced by many factors with long-range consequences. Both situations are served by the principles and practices of engineering economics.

Now let's be a little more specific with engineering economic problems than we were with the general questions just discussed. In the following typical situations, economic decisions are required.

- Should a manufacturing plant produce a part in its own production facility, knowing that major investment will be needed in new equipment and that expensive training procedures will have to be implemented, or should the plant subcontract to an outside vendor?
- Should an arid southwestern city immediately implement a manually controlled irrigation system with a planned update to an automated system in 3 years, or should a more expensive automated control system be immediately implemented? Bond issues will be required to assist in financing either alternative.
- A university is planning a new football stadium. Should the stadium be constructed now with a planned seating capacity of 80,000, or should it first be constructed with 65,000 seats with a planned end-zone enclosure to bring it to 80,000 seats in 5 years? Projected attendance revenues, expected increases in labor costs in 5 years, and potential stadium use problems during expansion are all factors that need to be considered.
- An electric utility is considering updating its computer networking capability. Should the utility upgrade its existing minicomputer file servers, or should it consider scrapping them for new IBM AS/400 minicomputer systems? If it takes the latter, should the utility buy or lease?
- An oil refinery needs to enlarge its port facilities to allow more tankers to be serviced per week. What are the potential gains associated with a dock expansion? Doing nothing is always one possible alternative.
- A manufacturing engineer is planning a high-speed production line that will use automated transfer mechanisms to move and position products from one automated workstation to the next. More complex workstations will allow more operations to be completed at a workstation at the expense of lower production rates per hour. However, such a situation could have the advantage of allowing fewer expensive transfer mechanisms. Given forecasts of product demand for the next 5 years, should the engineer plan for a one-shift operation with a certain number of transfer mechanisms or for a two-shift operation with fewer transfer mechanisms?

Lest these problems seem overly simple, which they are not (especially when we consider that the value of money changes over time), consider the following problem which was given to one of this text's authors when he worked at an oil refinery in the late 1950s. He was asked to weigh the benefits of polyvinyl chloride (PVC) piping, which was then being experimented with to transport corrosive acids, against those of the then-conventional piping systems. Unfortunately, there was no known life for PVC at the time since it had been just recently developed during World War II. Now we have a situation where we have incomplete data that might be evaluated under a variety of scenarios to give ranges of possible outcomes for the engineer's analysis. Another problem tackled at the refinery related to heat exchangers that periodically needed to be "wash-welded" to relieve lining deterioration. At what point is it more economical to replace the exchanger than to continue with the expensive wash-welding? In later chapters, after first being thoroughly schooled in the fundamentals of economic alternative evaluation, we will look at ways to evaluate situations with incomplete data, inexact data, and data that are probabilistic (uncertain).

A decision is simply the selection from two or more courses of action, whether it takes place in construction or production operations, service or manufacturing industries, private or public agencies. Some choices are trivial or largely automatic, but, as we have seen, other decisions can be challenging and exciting experiences. Most major decisions, even personal ones, have economic overtones. This consistent usage makes the subject of engineering economics especially challenging and rewarding.

1.2 ENGINEERING AND ECONOMICS

Before 1940, engineers were mainly concerned with the design, construction, and operation of machines, structures, and processes. They gave less attention to the resources, human and physical, that produced the final products. Many factors have since contributed to an expansion of engineering responsibilities and concerns.

Besides the traditional work with scientists to develop discoveries about nature into useful products, engineers are now expected not only to generate novel technological solutions but also to make skillful financial analyses of the effects of implementation. In today's close and tangled relations among industry, the public, and government, cost and value analyses are expected to be more detailed and inclusive (e.g., worker safety, environmental effects, consumer protection, resource conservation) than ever before. Without these analyses, an entire project can easily become more of a burden than a benefit.

Most definitions of engineering suggest that the mission of engineers is to transform the resources of nature for the benefit of the human race. The types of resources susceptible to engineering enrichment include everything from ores and crops to information and energy. A growing awareness of the finite limits of the earth's resources has added a pressing dimension to engineering evaluations. The focus on scarce resources welds engineering to economics.

Paul A. Samuelson, Nobel laureate in economics, and William D. Nordhaus suggest that

> Economists today agree on a general definition something like the following: Economics is the study of how people and society choose to employ scarce resources that could have alternative uses in order to produce various commodities and to distribute them for consumption, now or in the future, among various persons and groups in society.[†]

[†]Paul A. Samuelson and William D. Nordhaus, *Economics*, 12th ed., McGraw-Hill, New York, 1985.

The relation of engineering to economics can be likened to that of engineering to physics. Scientists are devoted to the discovery and explanation of nature's laws. Engineers work with scientists and translate the revelations to practical applications. The "laws" of economics are not as precise as those of physics, but their obvious application to the production and utilization of scarce resources ensures increasing attention from engineers.

1.3 ECONOMICS: A CAPSULE VIEW

Economics, like engineering, has informal roots deep in history. The construction of the pyramids is considered an engineering marvel. It was also a significant economic accomplishment in that it funneled all the necessary resources into monuments rather than consuming them in commerce. The formal roots of economics stretch back two centuries to the publication (in 1776) of Adam Smith's *The Wealth of Nations*.

Early writings deplored government intervention in commerce and promoted a laissez faire policy. In *An Essay on the Principles of Population* (1798), Thomas Malthus conjectured about the causes of economic crises, saying that population tends to increase geometrically and the means of subsistence only arithmetically; his forecasts of misery for most of the population predisposed the "dismal science" nickname for economics. Later John Stuart Mill, in his *Treatise on Political Economy* (1800), argued against Malthus' pessimism by suggesting that the laws of distribution are not as immutable as are the laws of production. Modern doomsday scenarios indicate that the issue is still in doubt.

In *Das Kapital* (1867), Karl Marx argued that capitalism would be superseded by socialism, which would then develop into communism. According to his view, workers produce more value than they receive in wages. The surplus takes the form of profit and allows capital accumulation. He argued that the capitalist system will eventually fail, owing to cyclic depressions and other inherent weaknesses. Recent dramatic changes in the political and geographical structure of eastern Europe show that the percentage of the world's population that agrees with Marx is dwindling.

"New economics" evolved from the work of John Maynard Keynes in the 1930s. In *The General Theory of Employment, Interest, and Money*, Keynes[‡] clashed with classical economic theory by proclaiming, e.g., that interest rates and price-wage adjustments are not adequate mechanisms for controlling unemployment in capitalistic economies. Refinements and extensions of the original work are collectively called *keynesian economics*, which is one of many current schools of economic thought.

[‡]J. M. Keynes, *The General Theory of Employment, Interest, and Money*, Harcourt, Brace and Co., New York, 1936.

Keynes' and Marx' theories deal with the entire economic system with respect to national income, flow of money, consumption, investment, wages, and general prices. This level of analysis concerned with the economy as a whole is called *macroeconomics.* It produces economywide statistical measures such as the national cost-of-living index and total employment figures.

Microeconomics is the study of economic behavior in very small segments of the economy, such as a particular firm or household. It is generally assumed that the objective of a firm is to maximize profit and the objective of a household is to maximize satisfaction. Measurement statistics for a small economic unit might be the number of workers employed by a firm and income or expenditures of a given firm or family.

Engineering economics, with its focus on economic decision making in an individual organizational unit, is closely aligned with microeconomics.

1.4 ENGINEERING ECONOMY: A SHORT HISTORY

The Economic Theory of the Location of Railways, written by Arthur M. Wellington in 1887, pioneered an engineering interest in economic evaluations. Wellington, a civil engineer, reasoned that the capitalized cost method of analysis should be utilized in selecting the preferred lengths of rail lines or curvatures of the lines. He delightfully captured the thrust of engineering economy:

> It would be well if engineering were less generally thought of, and even defined, as the art of constructing. In a certain important sense it is rather the art of not constructing; or, to define it rudely but not ineptly, it is the art of doing that well with one dollar which any bungler can do with two after a fashion.[†]

In the 1920s, C. L. Fish and O. B. Goldman looked at investments in engineered structures from the perspective of actuarial mathematics. Fish[‡] formulated an investment model related to the bond market. In *Financial Engineering,* Goldman proposed a compound-interest procedure for determining comparative values and said that

> It seems peculiar and is indeed very unfortunate that so many authors in their engineering books give no, or very little, consideration to costs, in spite of the fact that the primary duty of the engineer is to consider costs in order to obtain real economy—to get the most possible number of dollars and cents: to get the best financial efficiency.[§]

[†]A. M. Wellington, *The Economic Theory of the Location of Railways,* John Wiley & Sons, New York, 1887.
[‡]C. L. Fish, *Engineering Economics,* 2d ed., McGraw-Hill, New York, 1923.
[§]O. B. Goldman, *Financial Planning,* John Wiley & Sons, Inc., New York, 1920.

The confines of classical engineering economy were staked out in 1930 by Eugene L. Grant in *Principles of Engineering Economy.*[†] Grant discussed the importance of judgment factors and short-term investment evaluation as well as conventional comparisons of long-run investments in capital goods based on compound-interest calculations. His many contributions resulted in the recognition that "Eugene L. Grant can truthfully be called the father of engineering economy."[‡]

Modern approaches to discounted cash flow and capital rationing were influenced by the work of Joel Dean.[§] He incorporated the theories of Keynes and other economists to develop ways to analyze the effects of supply and demand for investment funds in allocating resources.

Current developments are pushing the frontiers of engineering economics to encompass new methods of risk, sensitivity, and intangible analysis. Traditional methods are being refined to reflect today's concerns for resource conservation and effective utilization of public funds.

EXAMPLE 1.1 Economics of Energy

The divergent missions of classical economics and engineering economics are apparent when a specific application is examined. Consider the energy problem. How serious is it? What are its dimensions? What can be done about it?

Energy supply and demand relations fit familiar economic concepts. Collection of data about who uses how much energy falls into the province of economic demographics, a growing branch of economics that deals with the consequence of changes in the characteristics of the nation's population. An optimal energy mix that best utilizes the national energy supply can be determined according to market prices and market risks, economic principles that give priority to energy sources that are cheapest and carry the least risk, other things being equal.

From an understanding of supply-demand relations, engineering effort can be unleashed to overcome technological constraints. If solar or geothermal energy appears to be the most promising source, engineers must provide the means to convert the promise to reality. Engineering economics can be applied to evaluate alternative solutions.

A proposal from the National Academy of Sciences is to ease the energy crisis by reducing waste. Amazing advances have been made since the first oil shortage in 1972, but more are needed. Federal regulations that mandate progressively more efficient fuel consumption by automobiles have had dramatic effects on consumption per automobile as well as emissions generated. Other actions to plug energy leaks in the national economic

[†]E. L. Grant, *Principles of Engineering Economy,* The Ronald Press, New York, 1930.
[‡]A. Lesser, Jr., "Engineering Economy in the United States in Retrospect—An Analysis," *The Engineering Economist,* vol. 14, no. 2, pp. 109–115, 1969.
[§]J. Dean, *Capital Budgeting,* Columbia, New York, 1951.

machine include correcting heat losses in offices and homes, creating better building designs, building more energy-efficient machines and automobiles, and developing cogeneration of electricity and steam. Effects of a broad-based Btu energy tax, proposed by the Clinton administration in 1993 (not passed), as contrasted to dramatic increases in federal gasoline taxes (passed), have to be quantified with reliable data to predict the outcomes and determine the better alternative. Estimating gas flows, comparing investment proposals, and testing the sensitivity of specific energy conservation actions are tasks for engineering economists.

1.5 PROBLEM SOLVING AND DECISION MAKING

An engineering economist draws upon the accumulated knowledge of engineering and economics to fashion and employ tools to identify a preferred course of action. The tools developed so far are not perfect. There is still considerable debate about their theoretical bases and how they should be used. This concern is wholesome because it promises improved procedures, but the variety of analysis techniques can frustrate practitioners, especially inexperienced ones: There are many aspects to consider and many ways to consider them.

The fundamental approach to economic problem solving is to elaborate on the time-honored *scientific method*. The method is anchored in two worlds: the real, everyday working world and the abstract, scientifically

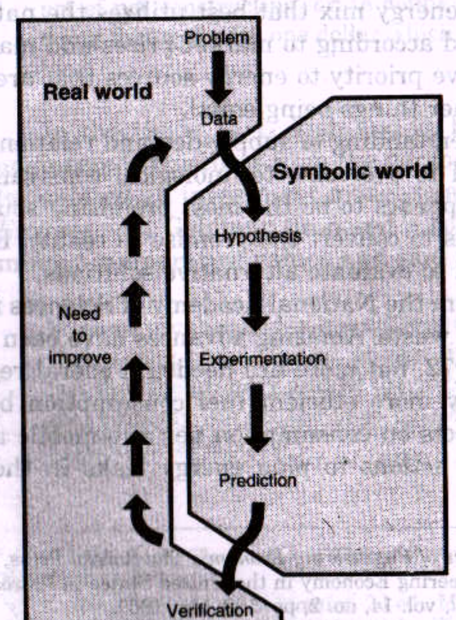

FIGURE 1.1 Problem-solving process.

oriented world, as depicted in Fig. 1.1. Problems in engineering and managerial economy originate in the real world of economic planning, management, and control. The problem is confined and clarified by *data* from the real world. This information is combined with scientific principles supplied by the analyst to formulate a *hypothesis* in symbolic terms. The symbolic language aids the digestion of data. By manipulating and *experimenting* with the abstractions of the real world, the analyst can simulate multiple configurations of reality that otherwise would be too costly or too inconvenient to investigate. From this activity a *prediction* usually emerges.

The predicted behavior is converted back to reality for testing in the form of hardware, designs, or commands. If it is valid, the problem is solved. If not, the cycle is repeated with the added information that the previous approach was unsuccessful. Fortunately, a host of successful approaches have been discovered and validated for economic analyses; the challenge now is to use them wisely.

1.5.1 Intuition and Analysis

Because engineers generally attack practical problems with solution deadlines instead of engaging in esoteric issues for long-term enlightenment, their mission might appear relatively simple. Engineering economic evaluations could even seem mundane, since they usually rely on data from the marketplace and technology from the shelf—simply grab prices from a catalog, plug them into a handy formula, and grind out an answer. Occasionally, such a routine works. Spectacular workbench discoveries and overnight fortunes attest to the fact that plungers sometimes win. There are also innumerable instances where rule-of-thumb, skin-deep evaluations are absolutely unsatisfactory.

As represented in Fig. 1.2, a decision made now is based on data from past performances and establishes a course of action that will result in some future outcome. When the decision is shallow and the outcomes are not of much consequence, a reflex response based upon intuition is feasible. Instinctive judgments are often formalized by *standard operating procedures (SOPs)*. In economic analyses, SOPs often take the form of worksheets for the justification of investments. Such short-form justifications are typically limited to smaller investments, say, less than $10,000, that can be recaptured from savings generated by the investment within 6 months or 1 year. These SOP forms represent collective intuition derived from experience. They have a secure place in economic evaluations, but their use should be tempered by economic principles and a continuing audit to verify that previous judgments are appropriate for current decisions.

Most significant problems require both analysis and personal judgment. Initially the analyst settles on which evaluation technique to utilize and how to apply it. As the solution procedures progress, factors that are

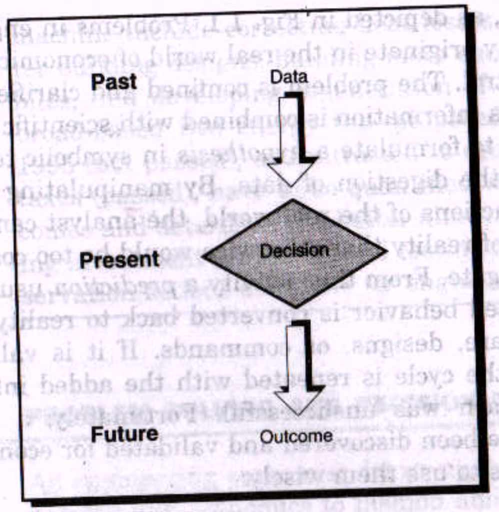

FIGURE 1.2
Decision-making process.

difficult to quantify often arise. These are called *intangibles;* they represent aspects of a problem that cannot be translated readily to monetary values. Intuitive ratings are frequently assigned to intangibles to allow them to be included in the decision process. Judgment also enters the process in determining whether a solution is well enough founded to be accepted. Thus intuition and judgment complement analysis methods by contributing to better decisions.

EXAMPLE 1.2 **To Intuit or to Analyze**

Most decision makers informally set boundaries for routine responses to noncritical problems of a personal and professional nature. Three possible parameters to identify routine responses are shown in Fig. 1.3. The level that separates an automatic decision from a problem that requires more investigation varies among decision makers.

Since there are limits to a decision maker's time and energy whereas the reservoir of problems often seems infinite, guidelines are necessary to confine involvement. SOPs do save time. An intuitive response is quick. Both draw upon experience to yield a reasonable solution. However, handy answers may mask better solutions than could have been exposed by analysis. What was good for yesterday's operations may not be adequate for tomorrow's.

1.5.2 Tactics and Strategy

About the only thing more frustrating than a wrong decision for an important problem is the right decision for the wrong problem. Some problems

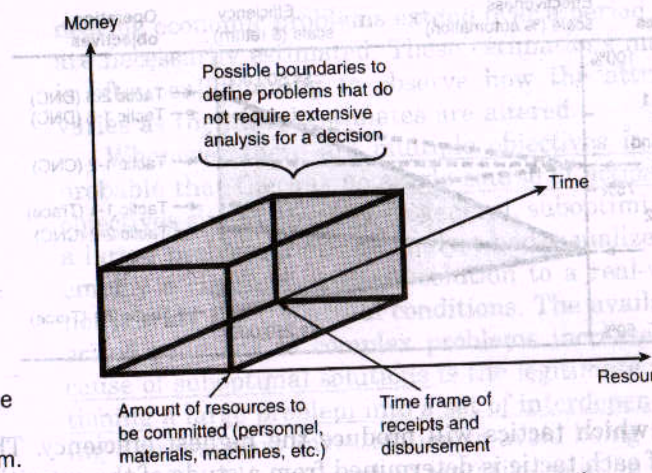

FIGURE 1.3
Criteria for routine responses to an economic problem.

are virtually handed to an analyst on a platter, complete with data trimmings. More commonly, a problem is ill-defined, and the analyst is forced to seek the intent of a solution before applying analytical tools. Recognizing the difference between tactical and strategic considerations may clarify the purpose.

Strategy and *tactics* historically are military terms associated with broad plans from the high command and specific schedules from lower echelons, respectively. Strategy sets ultimate objectives, and the associated tactics define the multiple maneuvers required to achieve the objectives. Strategic and tactical considerations have essentially the same meaning for economic studies.

There are usually several strategies available to an organization. A strategic decision ideally selects the overall plan that makes the best use of the organization's resources in accordance with its long-range objectives. A strategic industrial decision could be a choice from several different product designs to develop or products to promote. In government, strategic evaluations could take the form of benefit-cost analyses to select the preferred method of flood control or development of recreational sites. The measure of merit for strategic alternatives is *effectiveness*—the degree to which a plan meets economic targets.

A strategic plan can normally be implemented in a number of ways. For example, each industrial design or product has tactical alternatives, such as which kind of machine to employ or materials to use; tactics for flood control might involve choices among dams, levees, dredging, etc. The relative values of tactical choices are rated according to their *efficiency*—the degree to which an operation accomplishes a mission within economic expectations.

The relationship between strategies and tactics offers some constructive insights. The effectiveness of each strategy is initially estimated from the effect it will have on system objectives. It thus serves as a guide to the

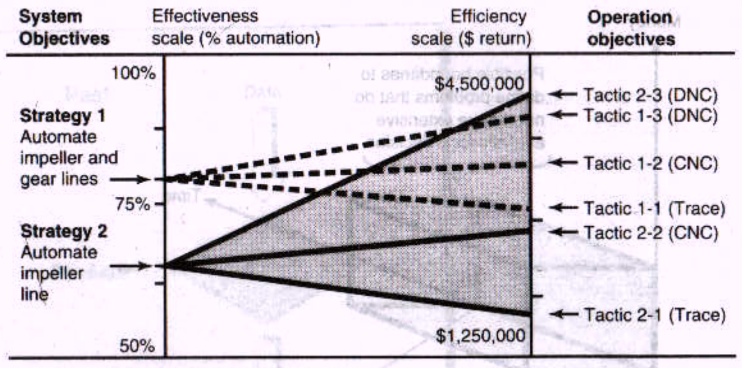

FIGURE 1.4 Relation of strategies and real-world tactics.

area in which tactics will produce the highest efficiency. The actual efficiency of each tactic is determined from a study of the activities required to conduct the tactical operation.

An aerospace engine manufacturer is considering job shop automation. Two strategies, each with three apparent means of accomplishment, are depicted in Fig. 1.4. Strategy 2 is to automate the impeller line, which will automate about 65 percent of the total shop. Strategy 1 is to automate both impeller and gear lines, which will affect about 80 percent of the facility. The company has decided that the effectiveness measure is the percentage of shop automation. The tactics shown in Fig. 1.4 represent approaches to automation. *DNC* refers to centralized, integrated direct numerical control by computer, *CNC* is local *computer numerical control* for each machine, and *trace* refers to template tracing and duplication for multiple-part setups. The efficiency, or means by which each approach is measured, in this case will be the dollar benefits from installing the new equipment. In this case, we have a situation where the best dollar return is not realized by the "most effective" strategy. Possibly, the cost of automating the gear line is relatively higher than for the impeller portion of the shop. The selection of a tactic policy must be evaluated in relation to the strategic objectives and the resources required for implementation.

1.5.3 Sensitivity and Suboptimization

The decision situation related by Fig. 1.4 has high sensitivity; i.e., it is vulnerable to small changes in the controlling conditions. With tactics 1-3 and 2-3 so close on the efficiency scale, a slight change in operating conditions or external influencing factors could switch the positions of the top tactics, or even the strategies. An insensitive situation occurs when all the tactics for a given strategy have a higher efficiency than the best tactic of any other strategy. The consequence of high sensitivity is to force a complete investigation to ensure the validity of the data being evaluated.

A *sensitivity analysis* can be conducted on any problem to explore the effects of deviations from the original problem conditions. Since most engineering economic problems extend over a period of years, future cash flows are necessarily estimated. These estimations may be quite reliable, but it is often enlightening to observe how the attractiveness of alternatives varies as the initial estimates are altered.

Whenever there are multiple objectives in a decision situation, it is probable that there is no single course of action that will optimize all the objectives simultaneously. In general, suboptimization occurs when there is a larger problem than the analyst had visualized. It is always tempting to employ a classical textbook solution to a real-world problem, whether or not it truly fits the actual conditions. The availability of "canned" computerized solutions to complex problems increases the temptation. Another cause of suboptimal solutions is the legitimate analysis technique of partitioning a large problem into a set of interdependant smaller problems during a preliminary investigation to avoid being bogged down in a deluge of details. Trouble enters when tentative solutions to the subproblems are not integrated. Advances in computer science and operations research may eventually allow analysis of an entire complex system in a single evaluation, but until then, it helps to be aware of the areas in which suboptimization is most likely to occur. Three regularly encountered perspectives that lead to suboptimization are described below.

1. *The cross-eyed view.* Both organizations and individuals can be confused by opposing objectives. An example of the danger inherent in focusing on only one parameter while blurring others is what would happen to a company that redeployed its resources to save its ailing flagship product at the expense of the rest of the product line. The rescue could boost sales for the previously eminent product while total sales declined owing to the drain on resources suffered by the rest of the company's products; thus, the battle could be won, but the war lost.

   Individuals seeking "the good life" also get caught by conflicting goals. If "good" is interpreted as "long and full," then unlimited pleasure seeking for a full life would undoubtedly jeopardize the health needed for a long life. Moderation, however, should produce a temperate plan to satisfy both goals, resulting in a life less full but longer. Of course, there are also irreconcilable objectives such as those pictured in Fig. 1.5.

2. *The shortsighted view.* Tactics based on a planning horizon of 1 or 2 years may not have the same efficiency as those based on a longer span of years. Suppose that a manufacturer anticipates using a fixed number of containers each year. The containers can be purchased, or the manufacturer can make them by acquiring new production equipment. Costs for the choices are displayed by the chart in Fig. 1.6. (This is a break-even chart, and a major discussion of such charts ensues later in this book.) A planning horizon under 2 years would indicate that purchasing is the preferable alternative; beyond 2 years it is more attractive to make the containers. Individuals face the same danger of suboptimization in lease-or-buy decisions for housing and transportation.

FIGURE 1.5
Symbolic world strategy and real-world tactics.

3. <u>*Tunnel vision viewpoint.*</u> Organizations are very susceptible to situations in which <u>departments understand the common goal</u> but <u>individually go about working in ways that hurt the goal.</u> A typical example is the goal to reduce material and inventory costs, as viewed by

• Purchasing:	Buy in large quantities to get quantity discounts.
• Comptroller:	Buy in smaller quantities to avoid paying interest on the capital required for purchases.
• Production:	Larger inventories allow longer production runs that reduce manufacturing costs.
• Warehousing:	Larger inventories cost more to store and increase the cost of material handling.

If each of the involved departments acts independently, inventory levels will repeatedly go up and down over time like a yo-yo. A workable plan will obviously be a compromise, probably satisfying no one com-

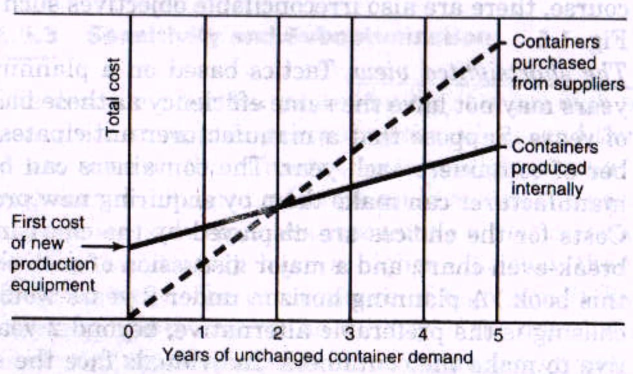

FIGURE 1.6
Pattern for potential suboptimization owing to shortsightedness.

pletely but still producing lower total material costs for the organization as a whole.

EXAMPLE 1.3 **When Optimizing Might Not Be Optimal**

Sheet-metal operations in an aircraft engine manufacturing plant pose some interesting problems, two of which might show that optimizing on a cost basis might not lead to a beneficial solution.

Problem 1. As just mentioned in the discussion of the tunnel vision viewpoint, different people in the organization can have different perspectives on reducing inventory and materials. An aircraft engine requires very complex welding operations to join intricate sheet-metal shapes. Expensive tooling is required to correctly position the parts to be welded. The time to set up parts to be welded can be lengthy, and the setup operation can cost thousands of dollars. Once the fixtures are set up, the parts can be welded in a relatively short time. The value of parts by the time they reach the welding operation can also be in the thousands of dollars. The production quantities required for each of the welded assemblies, on an annual basis, will not utilize a welding station for a very large percentage of the time. A mathematical model can be developed to optimize the total inventory charges, usually called the *lot-sizing model*, which results in the "optimum" number of parts to produce when a welding station has been set up for that part. The time to produce these parts might take, for example, 3 weeks. Then a different fixture is set up for another part. Because of the high costs of conventional tooling, it is possible that 1 or 2 months' worth of inventory for a part might be waiting to go into final assembly, thus creating congestion on the shop floor and tying up capital in the costly parts. Industry today is moving more and more to *just-in-time (JIT) production*, where just the right amount of inventory is available just when needed, relieving congestion and capital tie-up. This is very difficult to do with old, expensive fixturing. One solution is to set up a robotic welding manufacturing cell where up to four welding fixtures can be available to the robot, which can easily alternate between different parts on different fixtures. The economic evaluation for such a cell takes every ounce of skill that the engineering economist has.

Problem 2. Management makes a decision to implement a complex robotic welding manufacturing cell to handle applicable welding assemblies. The manufacturing engineer has determined that the cell can be occupied 95 percent of the time with applicable parts, and the engineering economist has determined that the system should be able to pay for itself within 12 months, much to the satisfaction of manufacturing management. Unfortunately, the people involved did not look at the rest of the system—*the total manufacturing process.* Parts coming to the robotic cell came from traditional manufacturing operations. But to keep the cell busy, management decided to always have inventory waiting to go into the cell so that it would never be idle due to lack of materials. As a result, there was congestion on the work floor around the cell. The productivity level of the cell was so good that subassembled (welded) parts were produced without consideration of when they would be needed in the final assembly line. The final assembly line then became congested with parts that might not be used for a week or so. The moral to this story is that the entire system needs to be considered when one is performing optimization studies. Yes, the robotic cell was optimized, but this turned out to be suboptimization when the entire system was considered, and the entire system was surely not optimized.

1.6 ENGINEERING ECONOMIC DECISION MAZE

Most important decisions in engineering economics entail consideration of future events. A focus on the future has always had a special and irresistible appeal, but it also encumbers the mission of engineering economists. Not only must they search the past to understand the present and survey the present for hints about the future, but also they must consolidate the accumulated results into a pattern that is susceptible to analysis and then select a decision rule to yield a verdict. The complexities involved are similar to going through a maze, as depicted in Fig. 1.7.

It would take a much larger maze to portray all the pitfalls and challenges of economic analyses, but enough are included to expose the anatomy of engineering economics and to map the contents of this book. All the channels within the maze represent subjects treated in chapters to follow. As is apparent in the decision labyrinth, there are many paths by which we could travel to get from a problem to a solution. Which path is utilized depends on the nature of the problem and the type of analysis that is most appropriate. Because problems come in such profuse variety and there are so many ways to evaluate them, engineering economics is rich in application opportunities and offers rewarding challenges to its practitioners.

1.7 OVERVIEW OF CHEER AND SHEER

CHEER and SHEER (*C*omputerized *H*elp **or** *S*preadsheet *H*elp for *E*ngineering *E*conomy *R*esults) are two computer programs that provide support for solving engineering economy problems. A text objective is to emphasize fundamentals so that the manual approach to any problem should be thoroughly understood before you use any program. CHEER can be used with no knowledge of the program structure or the programming language; CHEER provides a WINDOWS-like environment. User interface with CHEER is through structured screens and menus. The system provides complete file manipulation and data editing capabilities. "Logical"

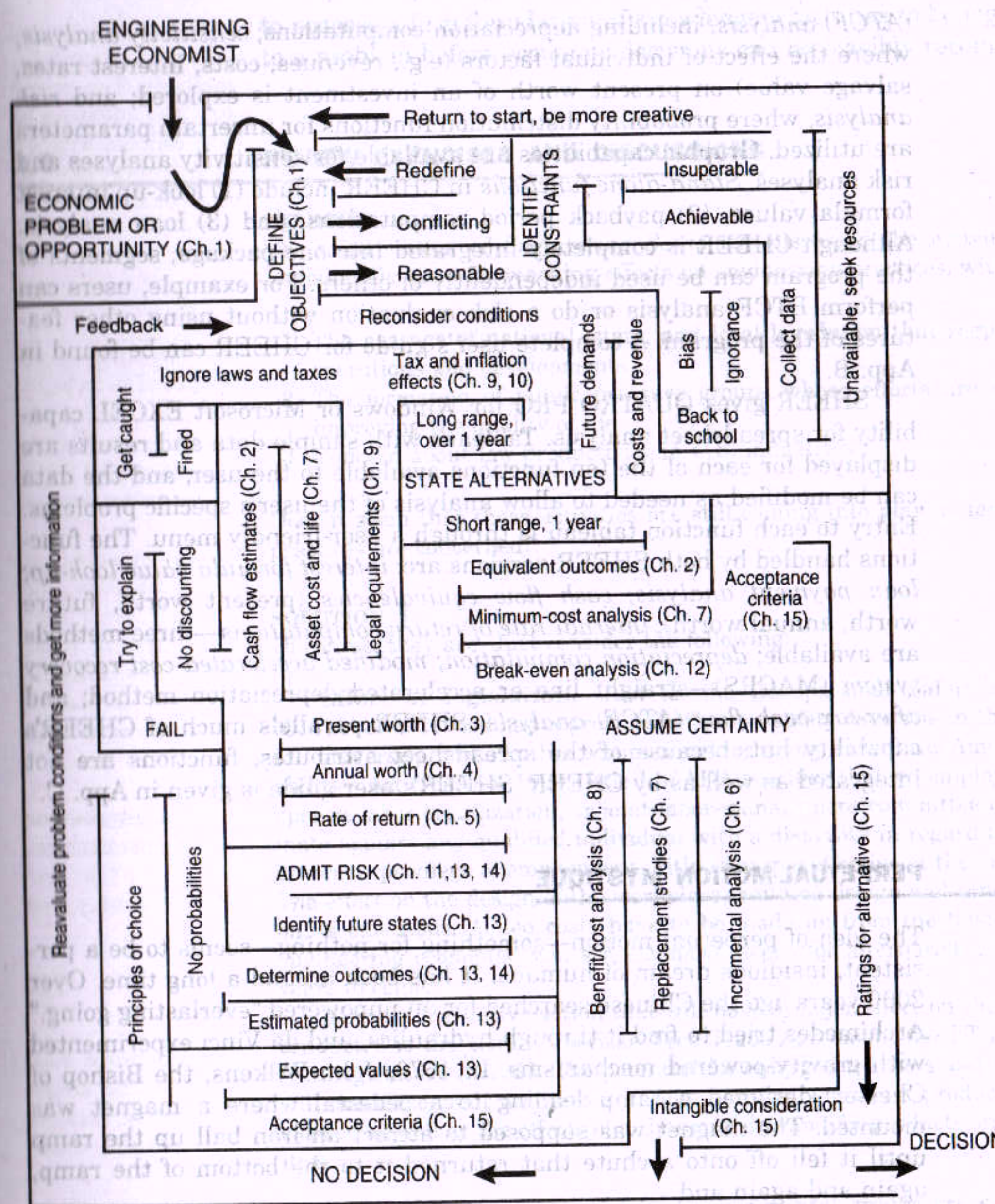

FIGURE 1.7 Engineering economic decision maze with a few related chapter numbers in parentheses (only a few of the starting and ending path arrows are shown).

error checks are built into the system; thus users are prompted for action if "out-of-bound" conditions are encountered.

CHEER provides functions for most of the concepts in engineering economics: *before-tax cash flow (BTCF) analysis,* with present worth, annual worth, future worth, and internal rate of return results; *after-tax cash flow*

(ATCF) analysis, including depreciation computations; *sensitivity analysis*, where the effect of individual factors (e.g., revenues, costs, interest rates, salvage value) on present worth of an investment is explored; and *risk analysis*, where probability distribution functions for uncertain parameters are utilized. Graphic capabilities are available for sensitivity analyses and risk analyses. *Stand-alone functions* in CHEER include (1) look-up interest formula values, (2) payback period computations, and (3) loan analysis. Although CHEER is completely integrated into one package, segments of the program can be used independently of others. For example, users can perform BTCF analysis or do a risk evaluation without using other features of the program. A complete user's guide for CHEER can be found in App. B.

SHEER gives QUATRO PRO for Windows or Microsoft EXCEL capability for spreadsheet analysis. Tableaus with sample data and results are displayed for each of the ten functions available to the user, and the data can be modified as needed to allow analysis of the user's specific problems. Entry to each function tableau is through a user-friendly menu. The functions handled by both SHEER versions are: *interest formula value look-up; loan payment analysis; cash flow equivalencies* (present worth, future worth, annual worth); *internal rate of return computations*—three methods are available; *depreciation computation; modified accelerated cost recovery system* (MACRS)—straight line or accelerated depreciation method; and *after-tax cash flow (ATCF) analysis*. SHEER parallels much of CHEER's capability but, because of the spreadsheet attributes, functions are not integrated as well as by CHEER. SHEER's user guide is given in App. C.

1.8 PERPETUAL-MOTION MYSTIQUE

The idea of perpetual motion—something for nothing—seems to be a persistent, insidious dream of humans. It has been around a long time. Over 2000 years ago the Chinese searched for an unpowered "everlasting going." Archimedes tried to find it through hydraulics, and da Vinci experimented with gravity-powered mechanisms. In 1670, John Wilkens, the Bishop of Chester, designed a ramp leading to a pedestal where a magnet was mounted. The magnet was supposed to attract an iron ball up the ramp until it fell off onto a chute that returned it to the bottom of the ramp, again and again and . . . .

A perpetual-motion machine was exhibited in New York City in 1813. People paid to see little carriers ceaselessly moving up and down inclined planes to drive a wheel which offered free energy. Robert Fulton, of steamboat fame, exposed the hoax by showing that the contraption was connected by a hidden strand of catgut to a hand-powered crank in an adjacent room.

The mystique of perpetual-motion machines has a counterpart in economic ventures—rewards without inputs. The engineering economist has

to possess a firm foundation of knowledge which has to be logically applied to a problem before economic decisions can be feasibly recommended.

1.9 REVIEW EXERCISES AND DISCUSSIONS

EXERCISE 1
The third edition of *Engineering Economics* discussed the activities that would undoubtedly have far-reaching effects on engineering practices, with emphasis on

1. The passage of national, state, and local legislation that regulates industrial operations and developments
2. The formation of public pressure groups whose efforts are directed toward improving the quality of life
3. Concern about low productivity in U.S. industries

Does it seem that these activities are still coming into play as far as engineering practices are concerned?

SOLUTION 1
Of course, they are. Just consider the following:

Effect of legislation. Just as the Occupational Safety and Health Act (OSHA) of 1971 has had a profound effect on safety concerns in the factory, hospital, university, and all other occupational locations, so will the Americans with Disabilities Act (ADA) of 1990. Title I of ADA specifies that an employer, employment agency, labor organization, or joint labor-management committee may not discriminate against any qualified individual with a disability in regard to any term, condition, or privilege of employment. Title I became effective at the beginning of 1993. The effect on the design of the workplace, building design and construction, and so on, is enormous. Added costs have to be made up from the business, and so the engineering economist will see extensive needs for alternative evaluations in the years to come.

Another legislative action that will have a major effect on the way business is conducted is the North American Free Trade Agreement (NAFTA), ratified by the U.S. legislature in 1993. The potential for enlarged markets and freer competition will make economic analyses even more critical when new products are being considered as well as the effects of a changing demand for products on production facilities.

Effect of pressure groups. Environmental groups are still continuing to influence such diverse activities as the Oregon logging industry through protection of the environment and the University of Arizona's observatory and its effect on wildlife. These are systems problems, and more and more we will see management decisions being made in light of the total environment to be affected. The nuclear power plant accidents that have been so detrimental to the environment would have not had such a profound effect if the plants' designers had taken into consideration all the factors surrounding the operation of the facility, including the possibility of human error.