# CHAPTER 1

# Introduction

**CONTENTS**

Management science, an approach to decision making based on the scientific method, makes extensive use of quantitative analysis. A variety of names exists for the body of knowledge involving quantitative approaches to decision making; in addition to management science, two other widely known and accepted names are operations research and decision science. Today, many use the terms *management science*, *operations research*, and *decision science* interchangeably.

The scientific management revolution of the early 1900s, initiated by Frederic W. Taylor, provided the foundation for the use of quantitative methods in management. But modern management science research is generally considered to have originated during the World War II period, when teams were formed to deal with strategic and tactical problems faced by the military. These teams, which often consisted of people with diverse specialties (e.g., mathematicians, engineers, and behavioral scientists), were joined together to solve a common problem through the utilization of the scientific method. After the war, many of these team members continued their research in the field of management science.

Two developments that occurred during the post–World War II period led to the growth and use of management science in nonmilitary applications. First, continued research resulted in numerous methodological developments. Probably the most significant development was the discovery by George Dantzig, in 1947, of the simplex method for solving linear programming problems. At the same time these methodological developments were taking place, digital computers prompted a virtual explosion in computing power. Computers enabled practitioners to use the methodological advances to solve a large variety of problems. The computer technology explosion continues, and personal computers can now be used to solve problems larger than those solved on mainframe computers in the 1990s.

As stated in the Preface, the purpose of the text is to provide students with a sound conceptual understanding of the role that management science plays in the decision-making process. We also said that the text is applications oriented. To reinforce the applications nature of the text and to provide a better understanding of the variety of applications in which management science has been used successfully, Management Science in Action articles are presented throughout the text. Each Management Science in Action article summarizes an application of management science in practice. The first Management Science in Action in this chapter, Revenue Management at American Airlines, describes one of the most significant applications of management science in the airline industry.

## MANAGEMENT SCIENCE IN ACTION

### REVENUE MANAGEMENT AT AMERICAN AIRLINES*

One of the great success stories in management science involves the work done by the operations research (OR) group at American Airlines. In 1982, Thomas M. Cook joined a group of 12 operations research analysts at American Airlines. Under Cook's guidance, the OR group quickly grew to a staff of 75 professionals who developed models and conducted studies to support senior management decision making. Today the OR group is called Sabre and employs 10,000 professionals worldwide.

One of the most significant applications developed by the OR group came about because of the deregulation of the airline industry in the late 1970s. As a result of deregulation, a number of low-cost airlines were able to move into the market by selling seats at a fraction of the price charged by established carriers such as American Airlines. Facing the question of how to compete, the OR group suggested offering different fare classes (discount and full fare) and in the process created a new area of management science referred to as yield or revenue management.

The OR group used forecasting and optimization techniques to determine how many seats to sell at a discount and how many seats to hold for full fare. Although the initial implementation was relatively crude, the group continued to improve the forecasting and optimization models that drive the system and to obtain better data. Tom Cook counts at least four basic generations of revenue management during his tenure. Each produced in excess of $100 million in incremental profitability over its predecessor. This revenue management system at American Airlines generates nearly $1 billion annually in incremental revenue.

Today, virtually every airline uses some sort of revenue management system. The cruise, hotel, and car rental industries also now apply revenue management methods, a further tribute to the pioneering efforts of the OR group at American Airlines and its leader, Thomas M. Cook.

*Based on Peter Horner, "The Sabre Story," *OR/MS Today* (June 2000).

## 1.1 PROBLEM SOLVING AND DECISION MAKING

**Problem solving** can be defined as the process of identifying a difference between the actual and the desired state of affairs and then taking action to resolve the difference. For problems important enough to justify the time and effort of careful analysis, the problem-solving process involves the following seven steps:

1. Identify and define the problem.
2. Determine the set of alternative solutions.
3. Determine the criterion or criteria that will be used to evaluate the alternatives.
4. Evaluate the alternatives.
5. Choose an alternative.
6. Implement the selected alternative.
7. Evaluate the results to determine whether a satisfactory solution has been obtained.

**Decision making** is the term generally associated with the first five steps of the problem-solving process. Thus, the first step of decision making is to identify and define the problem. Decision making ends with the choosing of an alternative, which is the act of making the decision.

Let us consider the following example of the decision-making process. For the moment assume that you are currently unemployed and that you would like a position that will lead to a satisfying career. Suppose that your job search has resulted in offers from companies in Rochester, New York; Dallas, Texas; Greensboro, North Carolina; and Pittsburgh, Pennsylvania. Thus, the alternatives for your decision problem can be stated as follows:

1. Accept the position in Rochester.
2. Accept the position in Dallas.
3. Accept the position in Greensboro.
4. Accept the position in Pittsburgh.

The next step of the problem-solving process involves determining the criteria that will be used to evaluate the four alternatives. Obviously, the starting salary is a factor of some importance. If salary were the only criterion of importance to you, the alternative selected as "best" would be the one with the highest starting salary. Problems in which the objective is to find the best solution with respect to one criterion are referred to as **single-criterion decision problems.**

Suppose that you also conclude that the potential for advancement and the location of the job are two other criteria of major importance. Thus, the three criteria in your decision problem are starting salary, potential for advancement, and location. Problems that involve more than one criterion are referred to as **multicriteria decision problems.**

The next step of the decision-making process is to evaluate each of the alternatives with respect to each criterion. For example, evaluating each alternative relative to the starting

**TABLE 1.1** DATA FOR THE JOB EVALUATION DECISION-MAKING PROBLEM

| Alternative | Starting Salary | Potential for Advancement | Job Location |
|---|---|---|---|
| 1. Rochester | $38,500 | Average | Average |
| 2. Dallas | $36,000 | Excellent | Good |
| 3. Greensboro | $36,000 | Good | Excellent |
| 4. Pittsburgh | $37,000 | Average | Good |

salary criterion is done simply by recording the starting salary for each job alternative. Evaluating each alternative with respect to the potential for advancement and the location of the job is more difficult to do, however, because these evaluations are based primarily on subjective factors that are often difficult to quantify. Suppose for now that you decide to measure potential for advancement and job location by rating each of these criteria as poor, fair, average, good, or excellent. The data that you compile are shown in Table 1.1.

You are now ready to make a choice from the available alternatives. What makes this choice phase so difficult is that the criteria are probably not all equally important, and no one alternative is "best" with regard to all criteria. Although we will present a method for dealing with situations like this one later in the text, for now let us suppose that after a careful evaluation of the data in Table 1.1, you decide to select alternative 3; alternative 3 is thus referred to as the **decision.**

At this point in time, the decision-making process is complete. In summary, we see that this process involves five steps:

1. Define the problem.
2. Identify the alternatives.
3. Determine the criteria.
4. Evaluate the alternatives.
5. Choose an alternative.

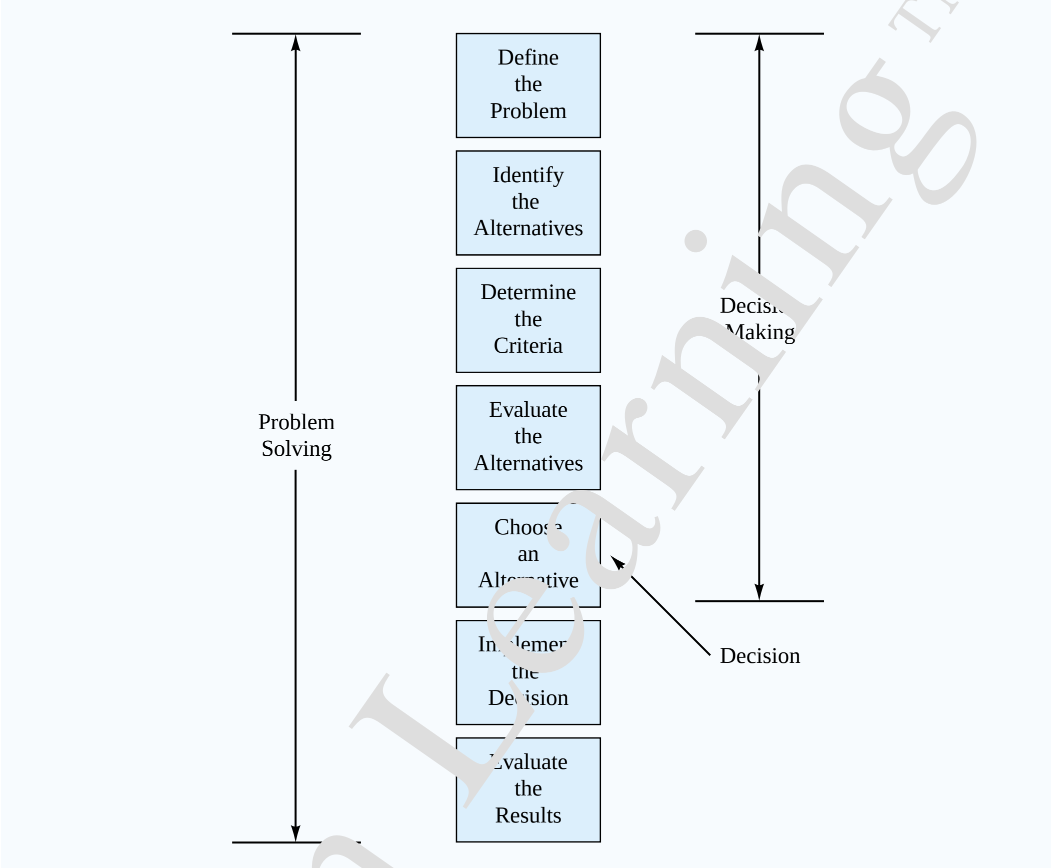
Note that missing from this list are the last two steps in the problem-solving process: implementing the selected alternative and evaluating the results to determine whether a satisfactory solution has been obtained. This omission is not meant to diminish the importance of each of these activities, but to emphasize the more limited scope of the term *decision making* as compared to the term *problem solving.* Figure 1.1 summarizes the relationship between these two concepts.

## 1.2 QUANTITATIVE ANALYSIS AND DECISION MAKING

Consider the flowchart presented in Figure 1.2. Note that it combines the first three steps of the decision-making process under the heading of "Structuring the Problem" and the latter two steps under the heading "Analyzing the Problem." Let us now consider in greater detail how to carry out the set of activities that make up the decision-making process.

Figure 1.3 shows that the analysis phase of the decision-making process may take two basic forms: qualitative and quantitative. Qualitative analysis is based primarily on the manager's judgment and experience; it includes the manager's intuitive "feel" for the problem and is more an art than a science. If the manager has had experience with similar prob-

**FIGURE 1.1** THE RELATIONSHIP BETWEEN PROBLEM SOLVING AND DECISION MAKING




lems, or if the problem is relatively simple, heavy emphasis may be placed upon a qualitative analysis. However, if the manager has had little experience with similar problems, or if the problem is sufficiently complex, then a quantitative analysis of the problem can be an especially important consideration in the manager's final decision.

When using the quantitative approach, an analyst will concentrate on the quantitative facts or data associated with the problem and develop mathematical expressions that

**FIGURE 1.2** AN ALTERNATE CLASSIFICATION OF THE DECISION-MAKING PROCESS

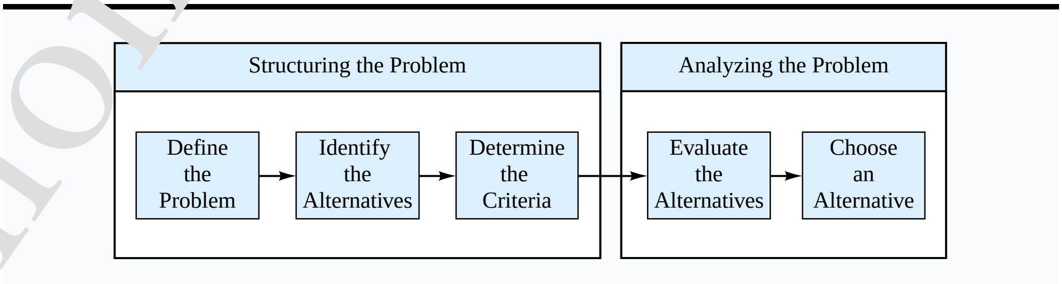
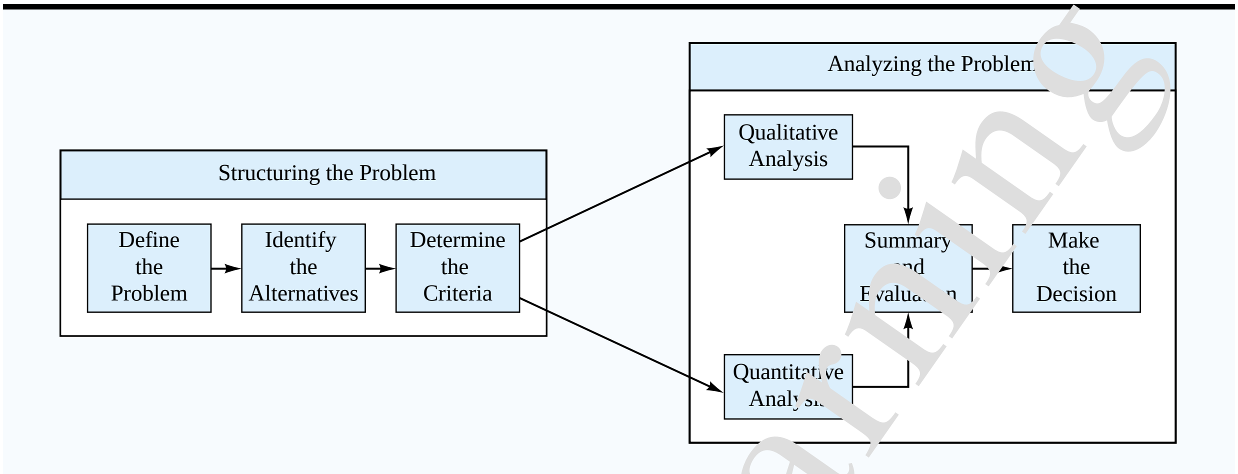


FIGURE 1.3 THE ROLE OF QUALITATIVE AND QUANTITATIVE ANALYSIS




*Quantitative methods are especially helpful with large, complex problems. For example, in the coordination of the thousands of tasks associated with landing Apollo 11 safely on the moon, quantitative techniques helped to ensure that more than 300,000 pieces of work performed by more than 400,000 people were integrated smoothly.*

describe the objectives, constraints, and other relationships that exist in the problem. Then, by using one or more quantitative methods, the analyst will make a recommendation based on the quantitative aspects of the problem.

Although skills in the qualitative approach are inherent in the manager and usually increase with experience, the skills of the quantitative approach can be learned only by studying the assumptions and methods of management science. A manager can increase decision-making effectiveness by learning more about quantitative methodology and by better understanding its contribution to the decision-making process. A manager who is knowledgeable in quantitative decision-making procedures is in a much better position to compare and evaluate the qualitative and quantitative sources of recommendations and ultimately to combine the two sources in order to make the best possible decision.

The box in Figure 1.3 entitled "Quantitative Analysis" encompasses most of the subject matter of this text. We will consider a managerial problem, introduce the appropriate quantitative methodology, and then develop the recommended decision.

In closing this section, let us briefly state some of the reasons why a quantitative approach might be used in the decision-making process:

*Try Problem 4 to test your understanding of why quantitative approaches might be needed in a particular problem.*

1. The problem is complex, and the manager cannot develop a good solution without the aid of quantitative analysis.
2. The problem is especially important (e.g., a great deal of money is involved), and the manager desires a thorough analysis before attempting to make a decision.
3. The problem is new, and the manager has no previous experience from which to draw.
4. The problem is repetitive, and the manager saves time and effort by relying on quantitative procedures to make routine decision recommendations.

## 1.3 QUANTITATIVE ANALYSIS

From Figure 1.3 we see that quantitative analysis begins once the problem has been structured. It usually takes imagination, teamwork, and considerable effort to transform a rather general problem description into a well-defined problem that can be approached via quantitative analysis. The more the analyst is involved in the process of structuring the problem, the more likely the ensuing quantitative analysis will make an important contribution to the decision-making process.

To successfully apply quantitative analysis to decision making, the management scientist must work closely with the manager or user of the results. When both the management scientist and the manager agree that the problem has been adequately structured, work can begin on developing a model to represent the problem mathematically. Solution procedures can then be employed to find the best solution for the model. This best solution for the model then becomes a recommendation to the decision maker. The process of developing and solving models is the essence of the quantitative analysis process.

## Model Development

**Models** are representations of real objects or situations and can be presented in various forms. For example, a scale model of an airplane is a representation of a real airplane. Similarly, a child's toy truck is a model of a real truck. The model airplane and toy truck are examples of models that are physical replicas of real objects. In modeling terminology, physical replicas are referred to as **iconic models.**

A second classification includes models that are physical in form but do not have the same physical appearance as the object being modeled. Such models are referred to as **analog models.** The speedometer of an automobile is an analog model; the position of the needle on the dial represents the speed of the automobile. A thermometer is another analog model representing temperature.

A third classification of models—the type we will primarily be studying—includes representations of a problem by a system of symbols and mathematical relationships or expressions. Such models are referred to as **mathematical models** and are a critical part of any quantitative approach to decision making. For example, the total profit from the sale of a product can be determined by multiplying the profit per unit by the quantity sold. If we let $x$ represent the number of units sold and $P$ the total profit, then, with a profit of \$10 per unit, the following mathematical model defines the total profit earned by selling $x$ units:

$$P = 10x \tag{1.1}$$

The purpose, or value, of any model is that it enables us to make inferences about the real situation by studying and analyzing the model. For example, an airplane designer might test an iconic model of a new airplane in a wind tunnel to learn about the potential flying characteristics of the full-size airplane. Similarly, a mathematical model may be used to make inferences about how much profit will be earned if a specified quantity of a particular product is sold. According to the mathematical model of equation (1.1), we would expect selling three units of the product ($x = 3$) would provide a profit of $P = 10(3) = \$30$.

In general, experimenting with models requires less time and is less expensive than experimenting with the real object or situation. A model airplane is certainly quicker and less expensive to build and study than the full-size airplane. Similarly, the mathematical model in equation (1.1) allows a quick identification of profit expectations without actually requiring the manager to produce and sell $x$ units. Models also have the advantage of reducing the risk associated with experimenting with the real situation. In particular, bad designs or bad decisions that cause the model airplane to crash or a mathematical model to project a \$10,000 loss can be avoided in the real situation.

The value of model-based conclusions and decisions is dependent on how well the model represents the real situation. The more closely the model airplane represents the real

*Herbert A. Simon, a Nobel Prize winner in economics and an expert in decision making, said that a mathematical model does not have to be exact; it just has to be close enough to provide better results than can be obtained by common sense.*

airplane, the more accurate the conclusions and predictions will be. Similarly, the more closely the mathematical model represents the company's true profit-volume relationship, the more accurate the profit projections will be.

Because this text deals with quantitative analysis based on mathematical models, let us look more closely at the mathematical modeling process. When initially considering a managerial problem, we usually find that the problem definition phase leads to a specific objective, such as maximization of profit or minimization of cost, and possibly a set of restrictions or **constraints,** such as production capacities. The success of the mathematical model and quantitative approach will depend heavily on how accurately the objective and constraints can be expressed in terms of mathematical equations or relationships.

A mathematical expression that describes the problem's objective is referred to as the **objective function.** For example, the profit equation $P = 10x$ would be an objective function for a firm attempting to maximize profit. A production capacity constraint would be necessary if, for instance, 5 hours are required to produce each unit and only 40 hours of production time are available per week. Let $x$ indicate the number of units produced each week. The production time constraint is given by

$$5x \leq 40 \tag{1.2}$$

The value of $5x$ is the total time required to produce $x$ units; the symbol $\leq$ indicates that the production time required must be less than or equal to the 40 hours available.

The decision problem or question is the following: How many units of the product should be scheduled each week to maximize profit? A complete mathematical model for this simple production problem is

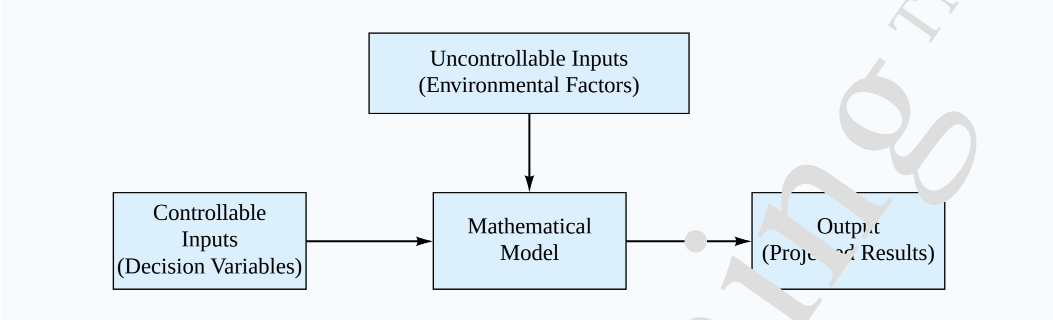
$$\begin{aligned} &\text{Maximize} && P = 10x \quad \text{objective function} \\ &\text{subject to (s.t.)} && \\ & && \left.\begin{aligned} 5x &\leq 40 \\ x &\geq 0 \end{aligned}\right\} \text{constraints} \end{aligned}$$

The $x \geq 0$ constraint requires the production quantity $x$ to be greater than or equal to zero, which simply recognizes the fact that it is not possible to manufacture a negative number of units. The optimal solution to this model can be easily calculated and is given by $x = 8$, with an associated profit of \$80. This model is an example of a linear programming model. In subsequent chapters we will discuss more complicated mathematical models and learn how to solve them in situations where the answers are not nearly so obvious.

In the preceding mathematical model, the profit per unit (\$10), the production time per unit (5 hours), and the production capacity (40 hours) are environmental factors that are not under the control of the manager or decision maker. Such environmental factors, which can affect both the objective function and the constraints, are referred to as **uncontrollable inputs** to the model. Inputs that are controlled or determined by the decision maker are referred to as **controllable inputs** to the model. In the example given, the production quantity $x$ is the controllable input to the model. Controllable inputs are the decision alternatives specified by the manager and thus are also referred to as the **decision variables** of the model.

Once all controllable and uncontrollable inputs are specified, the objective function and constraints can be evaluated and the output of the model determined. In this sense, the output of the model is simply the projection of what would happen if those particular envi-

**FIGURE 1.4** FLOWCHART OF THE PROCESS OF TRANSFORMING MODEL INPUTS INTO OUTPUT

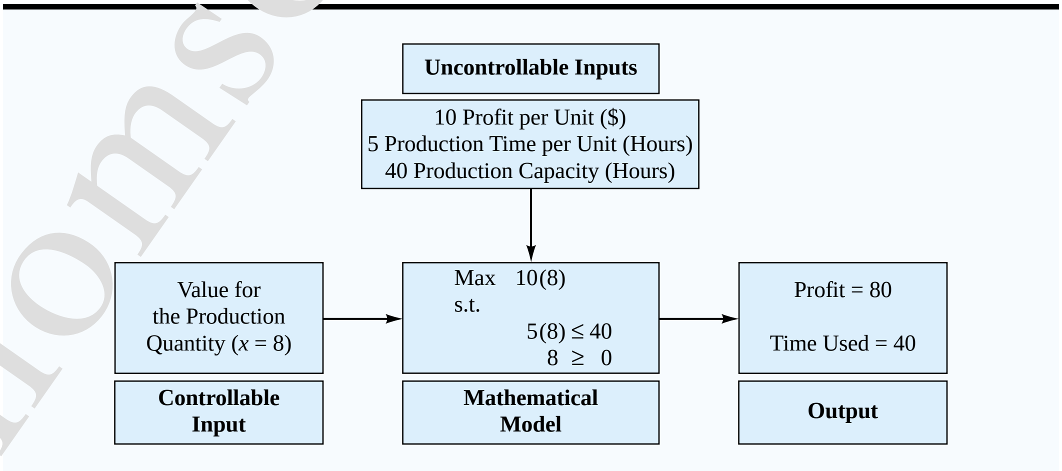



ronmental factors and decisions occurred in the real situation. A flowchart of how controllable and uncontrollable inputs are transformed by the mathematical model into output is shown in Figure 1.4. A similar flowchart showing the specific details of the production model is shown in Figure 1.5.

As stated earlier, the uncontrollable inputs are those the decision maker cannot influence. The specific controllable and uncontrollable inputs of a model depend on the particular problem or decision-making situation. In the production problem, the production time available (40) is an uncontrollable input. However, if it were possible to hire more employees or use overtime, the number of hours of production time would become a controllable input and therefore a decision variable in the model.

Uncontrollable inputs can either be known exactly or be uncertain and subject to variation. If all uncontrollable inputs to a model are known and cannot vary, the model is referred to as a **deterministic model.** Corporate income tax rates are not under the influence of the manager and thus constitute an uncontrollable input in many decision models. Because these rates are known and fixed (at least in the short run), a mathematical model with corporate income tax rates as the only uncontrollable input would be a deterministic model.

**FIGURE 1.5** FLOWCHART FOR THE PRODUCTION MODEL



The distinguishing feature of a deterministic model is that the uncontrollable input values are known in advance.

If any of the uncontrollable inputs are uncertain and subject to variation, the model is referred to as a **stochastic** or **probabilistic model.** An uncontrollable input to many production planning models is demand for the product. A mathematical model that treats future demand—which may be any of a range of values—with uncertainty would be called a stochastic model. In the production model, the number of hours of production time required per unit, the total hours available, and the unit profit were all uncontrollable inputs. Because the uncontrollable inputs were all known to take on fixed values, the model was deterministic. If, however, the number of hours of production time per unit could vary from 3 to 6 hours depending on the quality of the raw material, the model would be stochastic. The distinguishing feature of a stochastic model is that the value of the output cannot be determined even if the value of the controllable input is known because the specific values of the uncontrollable inputs are unknown. In this respect, stochastic models are often more difficult to analyze.

## Data Preparation

Another step in the quantitative analysis of a problem is the preparation of the data required by the model. Data in this sense refer to the values of the uncontrollable inputs to the model. All uncontrollable inputs or data must be specified before we can analyze the model and recommend a decision or solution for the problem.

In the production model, the values of the uncontrollable inputs or data were $10 per unit for profit, 5 hours per unit for production time, and 40 hours for production capacity. In the development of the model, these data values were known and incorporated into the model as it was being developed. If the model is relatively small and the uncontrollable input values or data required are few, the quantitative analyst will probably combine model development and data preparation into one step. In these situations the data values are inserted as the equations of the mathematical model are developed.

However, in many mathematical modeling situations, the data or uncontrollable input values are not readily available. In these situations the management scientist may know that the model will need profit per unit, production time, and production capacity data, but the values will not be known until the accounting, production, and engineering departments can be consulted. Rather than attempting to collect the required data as the model is being developed, the analyst will usually adopt a general notation for the model development step and then a separate data preparation step will be performed to obtain the uncontrollable input values required by the model.

Using the general notation

$$c = \text{profit per unit}$$
$$a = \text{production time in hours per unit}$$
$$b = \text{production capacity in hours}$$

the model development step of the production problem would result in the following general model:

$$\begin{aligned} \text{Max} \quad & cx \\ \text{s.t.} \quad & \\ & ax \le b \\ & x \ge 0 \end{aligned}$$

A separate data preparation step to identify the values for *c*, *a*, and *b* would then be necessary to complete the model.

Many inexperienced quantitative analysts assume that once the problem has been defined and a general model developed, the problem is essentially solved. These individuals tend to believe that data preparation is a trivial step in the process and can be easily handled by clerical staff. Actually, this assumption could not be further from the truth, especially with large-scale models that have numerous data input values. For example, a moderately sized linear programming model with 50 decision variables and 25 constraints could have more than 1300 data elements that must be identified in the data preparation step. The time required to prepare these data and the possibility of data collection errors will make the data preparation step a critical part of the quantitative analysis process. Often, a fairly large database is needed to support a mathematical model, and information systems specialists may become involved in the data preparation step.

## Model Solution

Once the model development and data preparation steps are completed, we can proceed to the model solution step. In this step, the analyst will attempt to identify the values of the decision variables that provide the "best" output for the model. The specific decision-variable value or values providing the "best" output will be referred to as the **optimal solution** for the model. For the production problem, the model solution step involves finding the value of the production quantity decision variable $x$ that maximizes profit while not causing a violation of the production capacity constraint.

One procedure that might be used in the model solution step involves a trial-and-error approach in which the model is used to test and evaluate various decision alternatives. In the production model, this procedure would mean testing and evaluating the model under various production quantities or values of $x$. Referring to Figure 1.5, note that we could input trial values for $x$ and check the corresponding output for projected profit and satisfaction of the production capacity constraint. If a particular decision alternative does not satisfy one or more of the model constraints, the decision alternative is rejected as being **infeasible,** regardless of the objective function value. If all constraints are satisfied, the decision alternative is **feasible** and a candidate for the "best" solution or recommended decision. Through this trial-and-error process of evaluating selected decision alternatives, a decision maker can identify a good—and possibly the best—feasible solution to the problem. This solution would then be the recommended decision for the problem.

Table 1.2 shows the results of a trial-and-error approach to solving the production model of Figure 1.5. The recommended decision is a production quantity of 8 because the feasible solution with the highest projected profit occurs at $x = 8$.

Although the trial-and-error solution process is often acceptable and can provide valuable information for the manager, it has the drawbacks of not necessarily providing the best solution and of being inefficient in terms of requiring numerous calculations if many decision alternatives are tried. Thus, quantitative analysts have developed special solution procedures for many models that are much more efficient than the trial-and-error approach. Throughout this text, you will be introduced to solution procedures that are applicable to the specific mathematical models that will be formulated. Some relatively small models or problems can be solved by hand computations, but most practical applications require the use of a computer.

Model development and model solution steps are not completely separable. An analyst will want both to develop an accurate model or representation of the actual problem situation and to be able to find a solution to the model. If we approach the model development

**TABLE 1.2** TRIAL-AND-ERROR SOLUTION FOR THE PRODUCTION MODEL OF FIGURE 1.5

| Decision Alternative (Production Quantity) $x$ | Projected Profit | Total Hours of Production | Feasible Solution? (Hours Used ≤ 40) |
|---|---|---|---|
| 0 | 0 | 0 | Yes |
| 2 | 20 | 10 | Yes |
| 4 | 40 | 20 | Yes |
| 6 | 60 | 30 | Yes |
| 8 | 80 | 40 | Yes |
| 10 | 100 | 50 | No |
| 12 | 120 | [illegible] | No |

step by attempting to find the most accurate and realistic mathematical model, we may find the model so large and complex that it is impossible to obtain a solution. In this case, a simpler and perhaps more easily understood model with a readily available solution procedure is preferred even if the recommended solution is only a rough approximation of the best decision. As you learn more about quantitative solution procedures, you will have a better idea of the types of mathematical models that can be developed and solved.

*Try Problem 8 to test your understanding of the concept of a mathematical model and what is referred to as the optimal solution to the model.*

After a model solution is obtained, both the management scientist and the manager will be interested in determining how good the solution really is. Even though the analyst has undoubtedly taken many precautions to develop a realistic model, often the goodness or accuracy of the model cannot be assessed until model solutions are generated. Model testing and validation are frequently conducted with relatively small "test" problems that have known or at least expected solutions. If the model generates the expected solutions, and if other output information appears correct, the go-ahead may be given to use the model on the full-scale problem. However, if the model test and validation identify potential problems or inaccuracies inherent in the model, corrective action, such as model modification and/or collection of more accurate input data, may be taken. Whatever the corrective action, the model solution will not be used in practice until the model has satisfactorily passed testing and validation.

## Report Generation

An important part of the quantitative analysis process is the preparation of managerial reports based on the model's solution. Referring to Figure 1.3, we see that the solution based on the quantitative analysis of a problem is one of the inputs the manager considers before making a final decision. Thus, the results of the model must appear in a managerial report that can be easily understood by the decision maker. The report includes the recommended decision and other pertinent information about the results that may be helpful to the decision maker.

## A Note Regarding Implementation

As discussed in Section 1.2, the manager is responsible for integrating the quantitative solution with qualitative considerations in order to make the best possible decision. After completing the decision-making process, the manager must oversee the implementation and follow-up evaluation of the decision. During the implementation and follow-up, the manager should continue to monitor the contribution of the model. At times, this process may lead to requests for model expansion or refinement that will cause the management scientist to return to an earlier step of the quantitative analysis process.

Successful implementation of results is of critical importance to the management scientist as well as the manager. If the results of the quantitative analysis process are not correctly implemented, the entire effort may be of no value. It doesn't take too many unsuccessful implementations before the management scientist is out of work. Because implementation often requires people to do things differently, it often meets with resistance. People want to know, "What's wrong with the way we've been doing it?" and so on. One of the most effective ways to ensure successful implementation is to include users throughout the modeling process. A user who feels a part of identifying the problem and developing the solution is much more likely to enthusiastically implement the results. The success rate for implementing the results of a management science project is much greater for those projects characterized by extensive user involvement. The Management Science in Action, Quantitative Analysis at Merrill Lynch, discusses some of the reasons for the success Merrill Lynch has realized from using quantitative analysis.

## MANAGEMENT SCIENCE IN ACTION

### QUANTITATIVE ANALYSIS AT MERRILL LYNCH*

Merrill Lynch, a brokerage and financial services firm with more than 56,000 employees in 45 countries, serves its client base through two business units. The Merrill Lynch Corporate and Institutional Client Group serves more than 7,000 corporations, institutions, and governments. The Merrill Lynch Private Client Group (MLPC) serves approximately 4 million households, as well as 225,000 small to mid-sized businesses and regional financial institutions, through more than 14,000 financial consultants in 600-plus branch offices. The management science group, established in 1986, has been part of MLPC since 1991. The mission of this group is to provide high-end quantitative analysis to support strategic management decisions and to enhance the financial consultant–client relationship.

The management science group has successfully implemented models and developed systems for asset allocation, financial planning, marketing information technology, database marketing, and portfolio performance measurement. Although technical expertise and objectivity are clearly important factors in any analytical group, the management science group attributes much of its success to communications skills, teamwork, and consulting skills.

Each project begins with face-to-face meetings with the client. A proposal is then prepared to outline the background of the problem, the objectives of the project, the approach, the required resources, the time schedule, and the implementation issues. At this stage, analysts focus on developing solutions that provide significant value and are easily implemented.

As the work progresses, frequent meetings keep the clients up-to-date. Because people with different skills, perspectives, and motivations must work together for a common goal, teamwork is essential. The group's members take classes in team approaches, facilitation, and conflict resolution. They possess a broad range of multifunctional and multidisciplinary capabilities and are motivated to provide solutions that focus on the goals of the firm. This approach to problem solving and the implementation of quantitative analysis has been a hallmark of the management science group. The impact and success of the group translates into hard dollars and repeat business. The group recently received the annual Edelman award given by the Institute for Operations Research and the Management Sciences for effective use of management science for organizational success.

*Based on Russ Labe, Raj Nigam, and Steve Spence, "Management Science at Merrill Lynch Private Client Group," *Interfaces* 29, no. 2 (March/April 1999): 1–14.

## NOTES AND COMMENTS

1. Developments in computer technology have increased the availability of management science techniques to decision makers. Many software packages are now available for personal computers. Versions of The Management Scientist, Microsoft Excel, and LINDO are widely used in management science courses.
2. The Management Scientist is a software package developed by the authors of this text. Version 6.0 is now available for Windows 95 through XP operating systems. This software can be used to solve problems in the text as well as small-scale problems encountered in practice. Appendix 1.1 provides an overview of the features and use of The Management Scientist.
3. Various chapter appendixes provide step-by-step instructions for using The Management Scientist, Excel, and LINDO to solve problems in the text.

## 1.4 MODELS OF COST, REVENUE, AND PROFIT

Some of the most basic quantitative models arising in business and economic applications are those involving the relationship between a volume variable—such as production volume or sales volume—and cost, revenue, and profit. Through the use of these models, a manager can determine the projected cost, revenue, and/or profit associated with an established production quantity or a forecasted sales volume. Financial planning, production planning, sales quotas, and other areas of decision making can benefit from such cost, revenue, and profit models.

### Cost and Volume Models

The cost of manufacturing or producing a product is a function of the volume produced. This cost can usually be defined as a sum of two costs: fixed cost and variable cost. **Fixed cost** is the portion of the total cost that does not depend on the production volume; this cost remains the same no matter how much is produced. **Variable cost,** on the other hand, is the portion of the total cost that is dependent on and varies with the production volume. To illustrate how cost and volume models can be developed, we will consider a manufacturing problem faced by Nowlin Plastics.

Nowlin Plastics produces a variety of compact disc (CD) storage cases. Nowlin's best-selling product is the CD-50, a slim, plastic CD holder with a specially designed lining that protects the optical surface of the disc. Several products are produced on the same manufacturing line, and a setup cost is incurred each time a changeover is made for a new product. Suppose that the setup cost for the CD-50 is $3000. This setup cost is a fixed cost that is incurred regardless of the number of units eventually produced. In addition, suppose that variable labor and material costs are $2 for each unit produced. The cost-volume model for producing $x$ units of the CD-50 can be written as

$$C(x) = 3000 + 2x \tag{1.3}$$

where

$$x = \text{production volume in units}$$
$$C(x) = \text{total cost of producing } x \text{ units}$$

Once a production volume is established, the model in equation (1.3) can be used to compute the total production cost. For example, the decision to produce $x = 1200$ units would result in a total cost of $C(1200) = 3000 + 2(1200) = \$5400$.

**Marginal cost** is defined as the rate of change of the total cost with respect to production volume. That is, it is the cost increase associated with a one-unit increase in the production volume. In the cost model of equation (1.3), we see that the total cost $C(x)$ will increase by \$2 for each unit increase in the production volume. Thus, the marginal cost is \$2. With more complex total cost models, marginal cost may depend on the production volume. In such cases, we could have marginal cost increasing or decreasing with the production volume $x$.

## Revenue and Volume Models

Management of Nowlin Plastics will also want information on the projected revenue associated with selling a specified number of units. Thus, a model of the relationship between revenue and volume is also needed. Suppose that each CD-50 storage unit sells for \$5. The model for total revenue can be written as

$$R(x) = 5x \tag{1.4}$$

where

$$x = \text{sales volume in units}$$
$$R(x) = \text{total revenue associated with selling } x \text{ units}$$

**Marginal revenue** is defined as the rate of change of total revenue with respect to sales volume. That is, it is the increase in total revenue resulting from a one-unit increase in sales volume. In the model of equation (1.4), we see that the marginal revenue is \$5. In this case, marginal revenue is constant and does not vary with the sales volume. With more complex models, we may find that marginal revenue increases or decreases as the sales volume $x$ increases.

## Profit and Volume Models

One of the most important criteria for management decision making is profit. Managers need to be able to know the profit implications of their decisions. If we assume that we will only produce what can be sold, the production volume and sales volume will be equal. We can combine equations (1.3) and (1.4) to develop a profit-volume model that will determine the total profit associated with a specified production-sales volume. Total profit, denoted $P(x)$, is total revenue minus total cost; therefore, the following model provides the total profit associated with producing and selling $x$ units:

$$\begin{aligned} P(x) &= R(x) - C(x) \\ &= 5x - (3000 + 2x) = -3000 + 3x \end{aligned} \tag{1.5}$$

Thus, the profit-volume model can be derived from the revenue-volume and cost-volume models.

## Breakeven Analysis

Using equation (1.5), we can now determine the total profit associated with any production volume *x*. For example, suppose that a demand forecast indicates that 500 units of the product can be sold. The decision to produce and sell the 500 units results in a projected profit of

$$P(500) = -3000 + 3(500) = -1500$$

In other words, a loss of $1500 is predicted. If sales are expected to be 500 units, the manager may decide against producing the product. However, a demand forecast of 1800 units would show a projected profit of

$$P(1800) = -3000 + 3(1800) = 2400$$

This profit may be enough to justify proceeding with the production and sale of the product.

We see that a volume of 500 units will yield a loss, whereas a volume of 1800 provides a profit. The volume that results in total revenue equaling total cost (providing $0 profit) is called the **breakeven point.** If the breakeven point is known, a manager can quickly infer that a volume above the breakeven point will result in a profit, while a volume below the breakeven point will result in a loss. Thus, the breakeven point for a product provides valuable information for a manager who must make a yes/no decision concerning production of the product.

Let us now return to the Nowlin Plastics example and show how the total profit model in equation (1.5) can be used to compute the breakeven point. The breakeven point can be found by setting the total profit expression equal to zero and solving for the production volume. Using equation (1.5), we have

$$\begin{aligned} P(x) = -3000 + 3x &= 0 \\ 3x &= 3000 \\ x &= 1000 \end{aligned}$$

*Try Problem 12 to test your ability to determine the breakeven point for a quantitative model.*

With this information, we know that production and sales of the product must be greater than 1000 units before a profit can be expected. The graphs of the total cost model, the total revenue model, and the location of the breakeven point are shown in Figure 1.6. In Appendix 1.2 we also show how Excel can be used to perform a breakeven analysis for the Nowlin Plastics production example.

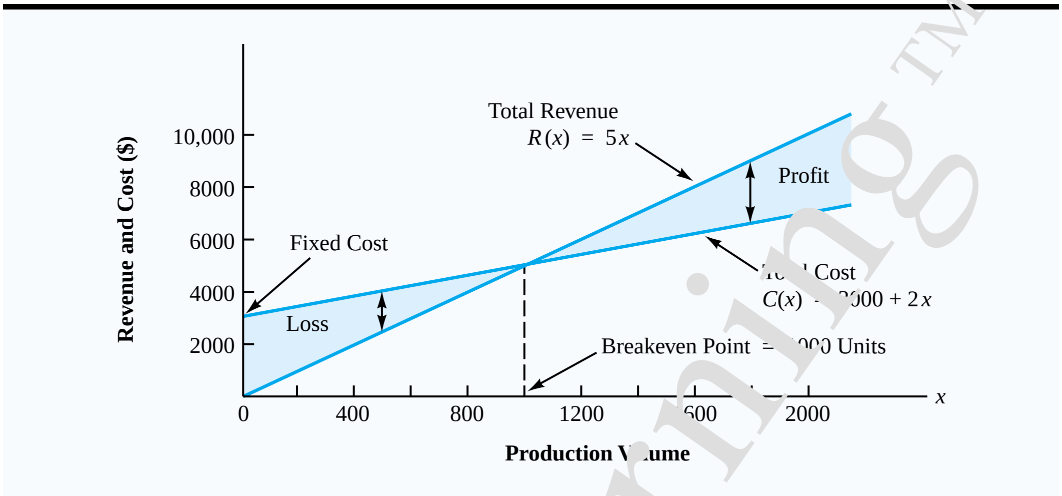
## 1.5 MANAGEMENT SCIENCE TECHNIQUES

In this section we present a brief overview of the management science techniques covered in this text. Over the years, practitioners have found numerous applications for the following techniques:

**Linear Programming.** Linear programming is a problem-solving approach developed for situations involving maximizing or minimizing a linear function subject to linear constraints that limit the degree to which the objective can be pursued. The production model developed in Section 1.3 (see Figure 1.5) is an example of a simple linear programming model.

**Integer Linear Programming.** Integer linear programming is an approach used for problems that can be set up as linear programs with the additional requirement that some or all of the decision recommendations be integer values.

**FIGURE 1.6** GRAPH OF THE BREAKEVEN ANALYSIS FOR NOWLIN PLASTICS




**Network Models.** A network is a graphical description of a problem consisting of circles called nodes that are interconnected by lines called arcs. Specialized solution procedures exist for these types of problems, enabling us to quickly solve problems in such areas as transportation system design, information system design, and project scheduling.

**Project Scheduling: PERT/CPM.** In many situations, managers are responsible for planning, scheduling, and controlling projects that consist of numerous separate jobs or tasks performed by a variety of departments, individuals, and so forth. The PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) techniques help managers carry out their project scheduling responsibilities.

**Inventory Models.** Inventory models are used by managers faced with the dual problems of maintaining sufficient inventories to meet demand for goods and, at the same time, incurring the lowest possible inventory holding costs.

**Waiting Line or Queueing Models.** Waiting-line or queueing models have been developed to help managers understand and make better decisions concerning the operation of systems involving waiting lines.

**Simulation.** Simulation is a technique used to model the operation of a system. This technique employs a computer program to model the operation and perform simulation computations.

**Decision Analysis.** Decision analysis can be used to determine optimal strategies in situations involving several decision alternatives and an uncertain or risk-filled pattern of events.

**Goal Programming.** Goal programming is a technique for solving multicriteria decision problems, usually within the framework of linear programming.

**Analytic Hierarchy Process.** This multicriteria decision-making technique permits the inclusion of subjective factors in arriving at a recommended decision.

**Forecasting.** Forecasting methods are techniques that can be used to predict future aspects of a business operation.

**Markov Process Models.** Markov process models are useful in studying the evolution of certain systems over repeated trials. For example, Markov processes have been used to describe the probability that a machine, functioning in one period, will function or break down in another period.

**Dynamic Programming.** Dynamic programming is an approach that allows us to break up a large problem in such a fashion that once all the smaller problems have been solved, we are left with an optimal solution to the large problem.

## Methods Used Most Frequently

Our experience as both practitioners and educators has been that the most frequently used management science techniques are linear programming, integer programming, network models (including transportation and transshipment models), and simulation. Depending upon the industry, the other methods in the preceding list are used more or less frequently.

Helping to bridge the gap between the manager and the management scientist is a major focus of the text. We believe that the barriers to the use of management science can best be removed by increasing the manager's understanding of how management science can be applied. The text will help you develop an understanding of which management science techniques are most useful, how they are used, and, most importantly, how they can assist managers in making better decisions.

The Management Science in Action, Taco Bell's SMART Labor Management System, shows how Taco Bell was able to use management science to ensure that the maximum time customers wait in line is between three and five minutes. The SMART system consists of three models: a forecasting model, a simulation model, and an integer programming model. This system has provided Taco Bell with a major competitive advantage and is typical of the widespread role of management science in service industries. Throughout the text we will continue to illustrate the applications of management science with Management Science in Action articles.

### MANAGEMENT SCIENCE IN ACTION

TACO BELL'S SMART LABOR MANAGEMENT SYSTEM*

Taco Bell turned to management science in order to develop methods for better handling customer demand while still keeping labor costs down. The company created the SMART (Scheduling Management and Restaurant Tool) Labor Management System (LMS) in order to determine a method of scheduling employees that will ensure that the maximum time customers wait in line is between three and five minutes. The SMART LMS consists of three integrated models: a forecasting model, a simulation model, and an integer programming model.

The forecasting model determines how many dollars worth of business each store will generate each day. Unlike a manufacturing plant, which makes forecasts in terms of years, months, or weeks, Taco Bell needs to develop predictions of customer arrivals based on 15-minute intervals. Then, using the predictions of how much business a store will generate the following day, a simulation model determines how many employees will be needed and how they should be positioned throughout the facility. To determine the labor table for the next day, the simulation model must take into account the differences in Taco Bell facilities, the build-to-order food preparation approach used by Taco Bell, and the randomness associated with customer demand. Using the labor table generated by the simulation model, the integer programming model determines how many people are needed on the schedule for a particular day and what their shifts should be so that payroll costs are minimized. The integer programming model also takes into account all of the customer-service responsibilities and provides Taco Bell managers with the ability to schedule other tasks such as cleaning and maintenance.

The system is used in all company-owned stores, and by 1996 had been adopted by 70 percent of franchisees. From 1993–1996, the new system resulted in labor costs savings of $40.34 million. Employee feedback is positive, and other fast-food companies have indicated that the new system has provided Taco Bell with a major competitive advantage.

*Based on Nancy Bistritz, "Taco Bell Finds Recipe for Success," *OR/MS Today* (October 1997): 20–21.

## NOTES AND COMMENTS

1. Operations research analyst is listed by the Bureau of Labor Statistics as one of the fastest growing occupations for careers requiring a bachelor's degree. The predicted growth is from 57,000 jobs in 1990 to 100,000 jobs in 2005, an increase of 73%.
2. The Institute for Operations Research and the Management Sciences (INFORMS) and the Decision Sciences Institute (DSI) are two professional societies that publish journals and newsletters dealing with current research and applications of operations research and management science techniques.

## SUMMARY

This text is about how management science may be used to help managers make better decisions. The focus of this text is on the decision-making process and on the role of management science in that process. We discussed the problem orientation of this process and in an overview showed how mathematical models can be used in this type of analysis.

The difference between the model and the situation or managerial problem it represents is an important point. Mathematical models are abstractions of real-world situations and, as such, cannot capture all the aspects of the real situation. However, if a model can capture the major relevant aspects of the problem and can then provide a solution recommendation, it can be a valuable aid to decision making.

One of the characteristics of management science that will become increasingly apparent as we proceed through the text is the search for a best solution to the problem. In carrying out the quantitative analysis, we shall be attempting to develop procedures for finding the "best" or optimal solution.

## GLOSSARY

**Problem solving** The process of identifying a difference between the actual and the desired state of affairs and then taking action to resolve the difference.

**Decision making** The process of defining the problem, identifying the alternatives, determining the criteria, evaluating the alternatives, and choosing an alternative.

**Single-criterion decision problem** A problem in which the objective is to find the "best" solution with respect to just one criterion.

**Multicriteria decision problem** A problem that involves more than one criterion; the objective is to find the "best" solution, taking into account all the criteria.

**Decision** The alternative selected.

**Model** A representation of a real object or situation.

**Iconic model** A physical replica, or representation, of a real object.

**Analog model** Although physical in form, an analog model does not have a physical appearance similar to the real object or situation it represents.

**Mathematical model** Mathematical symbols and expressions used to represent a real situation.

**Constraints** Restrictions or limitations imposed on a problem.

**Objective function** A mathematical expression that describes the problem's objective.

**Uncontrollable inputs** The environmental factors or inputs that cannot be controlled by the decision maker.

**Controllable inputs** The inputs that are controlled or determined by the decision maker.

**Decision variable** Another term for controllable input.

**Deterministic model** A model in which all uncontrollable inputs are known and cannot vary.

**Stochastic (probabilistic) model** A model in which at least one uncontrollable input is uncertain and subject to variation; stochastic models are also referred to as probabilistic models.

**Optimal solution** The specific decision-variable value or values that provide the "best" output for the model.

**Infeasible solution** A decision alternative or solution that does not satisfy one or more constraints.

**Feasible solution** A decision alternative or solution that satisfies all constraints.

**Fixed cost** The portion of the total cost that does not depend on the volume; this cost remains the same no matter how much is produced.

**Variable cost** The portion of the total cost that is dependent on and varies with the volume.

**Marginal cost** The rate of change of the total cost with respect to volume.

**Marginal revenue** The rate of change of total revenue with respect to volume.

**Breakeven point** The volume at which total revenue equals total cost.

## PROBLEMS

1. Define the terms *management science* and *operations research.*
2. List and discuss the steps of the decision-making process.
3. Discuss the different roles played by the qualitative and quantitative approaches to managerial decision making. Why is it important for a manager or decision maker to have a good understanding of both of these approaches to decision making?

SELF test

4. A firm just completed a new plant that will produce more than 500 different products, using more than 50 different production lines and machines. The production scheduling decisions are critical in that sales will be lost if customer demands are not met on time. If no individual in the firm has experience with this production operation, and if new produc-

tion schedules must be generated each week, why should the firm consider a quantitative approach to the production scheduling problem?

5. What are the advantages of analyzing and experimenting with a model as opposed to a real object or situation?

6. Suppose that a manager has a choice between the following two mathematical models of a given situation: (a) a relatively simple model that is a reasonable approximation of the real situation, and (b) a thorough and complex model that is the most accurate mathematical representation of the real situation possible. Why might the model described in part (a) be preferred by the manager?

7. Suppose you are going on a weekend trip to a city that is *d* miles away. Develop a model that determines your round-trip gasoline costs. What assumptions or approximations are necessary to treat this model as a deterministic model? Are these assumptions or approximations acceptable to you?

**SELF test**

8. Recall the production model from Section 1.3:

$$\begin{aligned} \text{Max} \quad & 10x \\ \text{s.t.} \quad & \\ & 5x \leq 40 \\ & x \geq 0 \end{aligned}$$

Suppose the firm in this example considers a second product that has a unit profit of \$5 and requires 2 hours of production time for each unit produced. Use *y* as the number of units of product 2 produced.

a. Show the mathematical model when both products are considered simultaneously.
b. Identify the controllable and uncontrollable inputs for this model.
c. Draw the flowchart of the input-output process for this model (see Figure 1.5).
d. What are the optimal solution values of *x* and *y*?
e. Is the model developed in part (a) a deterministic or a stochastic model? Explain.

9. Suppose we modify the production model in Problem 8 to obtain the following mathematical model:

$$\begin{aligned} \text{Max} \quad & 10x \\ \text{s.t.} \quad & \\ & ax \leq 40 \\ & x \geq 0 \end{aligned}$$

where $a$ is the number of hours of production time required for each unit produced. With $a = 5$, the optimal solution is $x = 8$. If we have a stochastic model with $a = 3$, $a = 4$, $a = 5$, or $a = 6$ as the possible values for the number of hours required per unit, what is the optimal value for $x$? What problems does this stochastic model cause?

10. A retail store in Des Moines, Iowa, receives shipments of a particular product from Kansas City and Minneapolis. Let

$$\begin{aligned} x &= \text{number of units of the product received from Kansas City} \\ y &= \text{number of units of the product received from Minneapolis} \end{aligned}$$

- **a.** Write an expression for the total number of units of the product received by the retail store in Des Moines.
- **b.** Shipments from Kansas City cost $0.20 per unit, and shipments from Minneapolis cost $0.25 per unit. Develop an objective function representing the total cost of shipments to Des Moines.
- **c.** Assuming the monthly demand at the retail store is 5000 units, develop a constraint that requires 5000 units to be shipped to Des Moines.
- **d.** No more than 4000 units can be shipped from Kansas City, and no more than 3000 units can be shipped from Minneapolis in a month. Develop constraints to model this situation.
- **e.** Of course, negative amounts cannot be shipped. Combine the objective function and constraints developed to state a mathematical model for satisfying the demand at the Des Moines retail store at minimum cost.

**11.** For most products, higher prices result in a decreased demand, whereas lower prices result in an increased demand. Let

$$d = \text{annual demand for a product in units}$$
$$p = \text{price per unit}$$

Assume that a firm accepts the following price-demand relationship as being realistic:

$$d = 800 - 10p$$

where $p$ must be between $20 and $70.

- **a.** How many units can the firm sell at the $20 per-unit price? At the $70 per-unit price?
- **b.** Show the mathematical model for the total revenue (TR), which is the annual demand multiplied by the unit price.
- **c.** Based on other considerations, the firm's management will only consider price alternatives of $30, $40, and $50. Use your model from part (b) to determine the price alternative that will maximize the total revenue.
- **d.** What are the expected annual demand and the total revenue corresponding to your recommended price?

**SELF** test

**12.** The O'Neill Shoe Manufacturing Company will produce a special-style shoe if the order size is large enough to provide a reasonable profit. For each special-style order, the company incurs a fixed cost of $1000 for the production setup. The variable cost is $30 per pair, and each pair sells for $40.

- **a.** Let $x$ indicate the number of pairs of shoes produced. Develop a mathematical model for the total cost of producing $x$ pairs of shoes.
- **b.** Let $P$ indicate the total profit. Develop a mathematical model for the total profit realized from an order for $x$ pairs of shoes.
- **c.** How large must the shoe order be before O'Neill will break even?

**13.** Micromedia offers computer training seminars on a variety of topics. In the seminars each student works at a personal computer, practicing the particular activity that the instructor is presenting. Micromedia is currently planning a two-day seminar on the use of Microsoft Excel in statistical analysis. The projected fee for the seminar is $300 per student. The cost for the conference room, instructor compensation, lab assistants, and promotion is $4,800. Micromedia rents computers for its seminars at a cost of $30 per computer per day.

- **a.** Develop a model for the total cost to put on the seminar. Let $x$ represent the number of students who enroll in the seminar.
- **b.** Develop a model for the total profit if $x$ students enroll in the seminar.
- **c.** Micromedia has forecasted an enrollment of 30 students for the seminar. How much profit will be earned if their forecast is accurate?
- **d.** Compute the breakeven point.

**14.** Eastman Publishing Company is considering publishing a paperback textbook on spreadsheet applications for business. The fixed cost of manuscript preparation, textbook design, and production setup is estimated to be $80,000. Variable production and material costs are estimated to be $3 per book. Demand over the life of the book is estimated to be 4000 copies. The publisher plans to sell the text to college and university bookstores for $20 each.

- **a.** What is the breakeven point?
- **b.** What profit or loss can be anticipated with a demand of 4000 copies?
- **c.** With a demand of 4000 copies, what is the minimum price per copy that the publisher must charge to break even?
- **d.** If the publisher believes that the price per copy could be increased to $25.95 and not affect the anticipated demand of 4000 copies, what action would you recommend? What profit or loss can be anticipated?

**15.** Preliminary plans are under way for the construction of a new stadium for a major league baseball team. City officials have questioned the number and profitability of the luxury corporate boxes planned for the upper deck of the stadium. Corporations and selected individuals may buy the boxes for $100,000 each. The fixed construction cost for the upper-deck area is estimated to be $1,500,000, with a variable cost of $50,000 for each box constructed.

- **a.** What is the breakeven point for the number of luxury boxes in the new stadium?
- **b.** Preliminary drawings for the stadium show that space is available for the construction of up to 50 luxury boxes. Promoters indicate that buyers are available and that all 50 could be sold if constructed. What is your recommendation concerning the construction of luxury boxes? What profit is anticipated?

**16.** Financial Analysts, Inc., is an investment firm that manages stock portfolios for a number of clients. A new client is requesting that the firm handle an $80,000 portfolio. As an initial investment strategy, the client would like to restrict the portfolio to a mix of the following two stocks:

| Stock | Price/Share | Maximum Estimated Annual Return/Share | Possible Investment |
|---|---|---|---|
| Oil Alaska | $50 | $6 | $50,000 |
| Southwest Petroleum | $30 | $4 | $45,000 |

Let

$$x = \text{number of shares of Oil Alaska}$$
$$y = \text{number of shares of Southwest Petroleum}$$

- **a.** Develop the objective function, assuming that the client desires to maximize the total annual return.
- **b.** Show the mathematical expression for each of the following three constraints:
  (1) Total investment funds available are $80,000.
  (2) Maximum Oil Alaska investment is $50,000.
  (3) Maximum Southwest Petroleum investment is $45,000.

*Note:* Adding the $x \geq 0$ and $y \geq 0$ constraints provides a linear programming model for the investment problem. A solution procedure for this model will be discussed in Chapter 2.

17. Models of inventory systems frequently consider the relationships among a beginning inventory, a production quantity, a demand or sales, and an ending inventory. For a given production period $j$, let

$s_{j-1}$ = ending inventory from the previous period (beginning inventory for period $j$)
$x_j$ = production quantity in period $j$
$d_j$ = demand in period $j$
$s_j$ = ending inventory for period $j$

a. Write the mathematical relationship or model that describes how these four variables are related.
b. What constraint should be added if production capacity for period $j$ is given by $C_j$?
c. What constraint should be added if inventory requirements for period $j$ mandate an ending inventory of at least $I_j$?

## Case Problem SCHEDULING A GOLF LEAGUE

Chris Lane, the head professional at Royal Oak Country Club, must develop a schedule of matches for the couples' golf league that begins its season at 4:00 P.M. tomorrow. Eighteen couples signed up for the league, and each couple must play every other couple over the course of the 17-week season. Chris thought it would be fairly easy to develop a schedule, but after working on it for a couple of hours, he has been unable to come up with a schedule. Because Chris must have a schedule ready by tomorrow afternoon, he asked you to help him. A possible complication is that one of the couples told Chris that they may have to cancel for the season. They told Chris they will let him know by 1:00 P.M. tomorrow whether they will be able to play this season.

### Managerial Report

Prepare a report for Chris Lane. Your report should include, at a minimum, the following items:

1. A schedule that will enable each of the 18 couples to play every other couple over the 17-week season.
2. A contingency schedule that can be used if the couple that contacted Chris decides to cancel for the season.

## Appendix 1.1 THE MANAGEMENT SCIENTIST SOFTWARE

Developments in computer technology play a major role in making management science techniques available to decision makers. A software package called *The Management Scientist* accompanies this text. Version 6.0 is now available for Windows 95 through Windows XP operating systems.[1] This software can be used to solve problems in the text as well as small-scale problems encountered in practice. Using The Management Scientist

[1]Version 6.0 has been designed to run optimally on computers with screen resolutions of 1024 × 768 or higher. Computers with lower screen resolutions can still run Version 6.0. Scroll bars appear when necessary for working with large problems.

will give you an understanding and appreciation of the role of the computer in applying management science to decision problems.

The Management Scientist contains 12 modules, or programs, that will enable you to solve problems in the following areas:

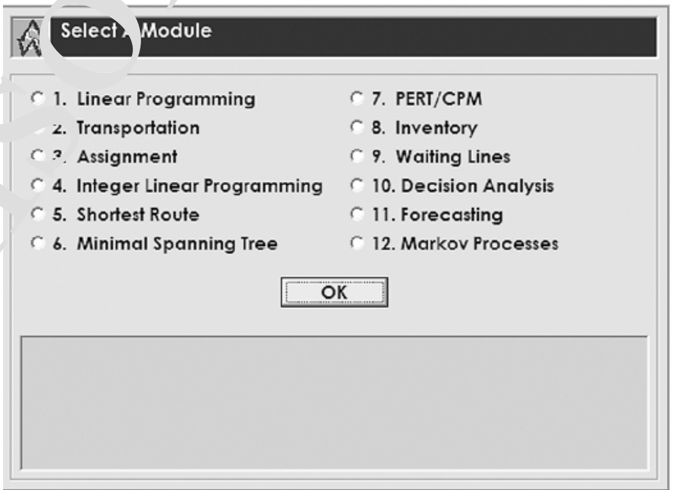
| | |
|---|---|
| Chapters 2–6 | Linear programming |
| Chapter 7 | Transportation and assignment |
| Chapter 8 | Integer linear programming |
| Chapter 9 | Shortest route and minimal spanning tree |
| Chapter 10 | PERT/CPM |
| Chapter 11 | Inventory models |
| Chapter 12 | Waiting line models |
| Chapter 14 | Decision analysis |
| Chapter 16 | Forecasting |
| Chapter 17 | Markov processes |

Use of The Management Scientist with the text is optional. Occasionally, we insert a figure in the text that shows the output The Management Scientist provides for a problem. However, familiarity with the use of the software is not necessary to understand the figure and the text material. The remainder of this appendix provides an overview of the features and the use of the software.

## Selecting a Module

After starting The Management Scientist, you will encounter the module selection screen as shown in Figure 1.7. The choices provide access to the 12 modules. Simply click the desired module and select OK to load the requested module into the computer's memory.

**FIGURE 1.7** MODULE SELECTION SCREEN FOR THE MANAGEMENT SCIENTIST VERSION 6.0



## The File Menu

After a module is loaded, you will need to click the File menu to begin working with a problem. The File menu provides the following options.

**New** Select this option to begin a new problem. Dialog boxes and input templates will guide you through the data input process.

**Open** Select this option to retrieve a problem that has been previously saved. When the problem is selected it will be displayed on the screen for you to verify as the problem you want to solve.

**Save** Once a new problem has been entered, you may want to save it for future use or modification. The Save option will guide you through the naming and saving process. If you create a folder named Problems, the Open and Save options will take you automatically to the Problems folder.

**Change Modules** This option returns control to the screen in Figure 1.7 and another module may be selected.

**Exit** This option will exit The Management Scientist.

## The Edit Menu

After a new problem has been solved, you may want to make one or more modifications to the problem before resolving. The Edit menu provides the option to display the problem and then make revisions in the problem before solving or saving. In the linear and integer programming modules, the Edit menu also includes options to change the problem size by adding or deleting variables and adding or deleting constraints. Similar options to change the problem size are provided in the Edit menu of the transportation and assignment modules.

## The Solution Menu

The Solution menu provides three options.

**Solve** This option solves the current problem and displays the solution on the screen.

**Print** Once the solution is on the screen, the Print option sends the solution to a printer.

**Save As Text File** Once the solution is on the screen, the Save As Text File option enables the solution to be saved as a text file. The text file can be accessed later by a word processor so that the solution output may be displayed as part of a solution report.

## Advice About Data Input

Any time a new problem is selected, the appropriate module will provide dialog boxes and forms for describing the features of the problem and for entering data. When using The Management Scientist, you may find the following data input suggestions helpful.

1. Do not enter commas (,) with your input data. For example, the value 104,000 should be entered with the six digits: 104000.
2. Do not enter the dollar sign ($) for profit or cost data. For example, a cost of $20.00 should be entered as 20.

3. Do not enter the percent sign (%) if percentage is requested. For example, 25% should be entered as 25, not 25% or .25.
4. Occasionally, a model may be formulated with fractional values such as ¼, ⅔, ⅚, and so on. The data input for The Management Scientist must be in decimal form. The fraction ¼ can be entered as .25. However, fractions such as ⅔ and ⅚ have repeating decimal forms. In these cases, we recommend the convention of rounding to five places such as .66667 and .83333.
5. Finally, we recommend that in general you attempt to scale extremely large input data so that smaller numbers may be input and operated on by the computer. For example, costs such as $2,500,000 may be scaled to 2.5 with the understanding that the data used in the problem reflect millions of dollars.

## Appendix 1.2 USING EXCEL FOR BREAKEVEN ANALYSIS

In Section 1.4 we introduced the Nowlin Plastics production example to illustrate how quantitative models can be used to help a manager determine the projected cost, revenue, and/or profit associated with an established production quantity or a forecasted sales volume. In this appendix we introduce spreadsheet applications by showing how to use Microsoft Excel to perform a quantitative analysis of the Nowlin Plastics example.

Refer to the worksheet shown in Figure 1.8. We begin by entering the problem data into the top portion of the worksheet. The value of 3000 in cell B3 is the setup cost, the value of 2 in cell B5 is the variable labor and material costs per unit, and the value of 5 in cell B7 is

**FIGURE 1.8** FORMULA WORKSHEET FOR THE NOWLIN PLASTICS PRODUCTION EXAMPLE

| | A | B | C |
|---|---|---|---|
| 1 | Nowlin Plastics | | |
| 2 | | | |
| 3 | Fixed Cost | 3000 | |
| 4 | | | |
| 5 | Variable Cost Per Unit | 2 | |
| 6 | | | |
| 7 | Selling Price Per Unit | 5 | |
| 8 | | | |
| 9 | | | |
| 10 | Models | | |
| 11 | | | |
| 12 | Production Volume | 800 | |
| 13 | | | |
| 14 | Total Cost | =B3+B5*B12 | |
| 15 | | | |
| 16 | Total Revenue | =B7*B12 | |
| 17 | | | |
| 18 | Total Profit (Loss) | =B16-B14 | |
| 19 | | | |

the selling price per unit. In general, whenever we perform a quantitative analysis using Excel, we will enter the problem data in the top portion of the worksheet and reserve the bottom portion for model development. The label "Models" in cell A10 helps to provide a visual reminder of this convention.

Cell B12 in the models portion of the worksheet contains the proposed production volume in units. Because the values for total cost, total revenue, and total profit depend upon the value of this decision variable, we have placed a border around cell B12 and screened the cell for emphasis. Based upon the value in cell B12, the cell formulas in cells B14, B16, and B18 are used to compute values for total cost, total revenue, and total profit (loss), respectively. First, recall that the value of total cost is the sum of the fixed cost (cell B3) and the total variable cost. The total variable cost—the product of the variable cost per unit (cell B5) and the production volume (cell B12)—is given by B5*B12. Thus, to compute the value of total cost we entered the formula =B3+B5*B12 in cell B14. Next, total revenue is the product of the selling price per unit (cell B7) and the number of units produced (cell B12), which is entered in cell B16 as the formula =B7*B12. Finally, the total profit (or loss) is the difference between the total revenue (cell B16) and the total cost (cell B14). Thus, in cell B18 we have entered the formula =B16−B14. The worksheet shown in Figure 1.8 shows the formulas used to make these computations; we refer to it as a formula worksheet.

To examine the effect of selecting a particular value for the production volume, we entered a value of 800 in cell B12. The worksheet shown in Figure 1.9 shows the values obtained by the formulas; a production volume of 800 units results in a total cost of $4600, a total revenue of $4000, and a loss of $600. To examine the effect of other production vol-

**FIGURE 1.9** SOLUTION USING A PRODUCTION VOLUME OF 800 UNITS FOR THE NOWLIN PLASTICS PRODUCTION EXAMPLE

**EXCEL**file
**Nowlin**

| | A | B | C |
|---|---|---|---|
| 1 | **Nowlin Plastics** | | |
| 2 | | | |
| 3 | **Fixed Cost** | $3,000 | |
| 4 | | | |
| 5 | **Variable Cost Per Unit** | $2 | |
| 6 | | | |
| 7 | **Selling Price Per Unit** | $5 | |
| 8 | | | |
| 9 | | | |
| 10 | **Models** | | |
| 11 | | | |
| 12 | **Production Volume** | 800 | |
| 13 | | | |
| 14 | **Total Cost** | $4,600 | |
| 15 | | | |
| 16 | **Total Revenue** | $4,000 | |
| 17 | | | |
| 18 | **Total Profit (Loss)** | -$600 | |
| 19 | | | |

umes, we only need to enter a different value into cell B12. To examine the effect of different costs and selling prices, we simply enter the appropriate values in the data portion of the worksheet; the results will be displayed in the model section of the worksheet.

In Section 1.4 we illustrated breakeven analysis. Let us now see how Excel's Goal Seek tool can be used to compute the breakeven point for the Nowlin Plastics production example.

## Determining the Breakeven Point Using Excel's Goal Seek Tool

The breakeven point is the production volume that results in total revenue equal to total cost and hence a profit of $0. One way to determine the breakeven point is to use a trial-and-error approach. For example, in Figure 1.9 we saw that a trial production volume of 800 units resulted in a loss of $600. Because this trial solution resulted in a loss, a production volume of 800 units cannot be the breakeven point. We could continue to experiment with other production volumes by simply entering different values into cell B12 and observing the resulting profit or loss in cell B18. A better approach is to use Excel's Goal Seek tool to determine the breakeven point.

Excel's Goal Seek tool allows the user to determine the value for an input cell that will cause the value of a related output cell to equal some specified value (called the *goal*). In the case of breakeven analysis, the "goal" is to set Total Profit to zero by "seeking" an appropriate value for Production Volume. Goal Seek will allow us to find the value of production volume that will set Nowlin Plastics' total profit to zero. The following steps describe how to use Goal Seek to find the breakeven point for Nowlin Plastics:

Step 1. Select the **Tools** menu
Step 2. Choose the **Goal Seek** option
Step 3. When the **Goal Seek** dialog box appears:
Enter B18 in the **Set cell** box
Enter 0 in the **To value** box
Enter B12 in the **By changing cell** box
Click **OK**

The completed Goal Seek dialog box is shown in Figure 1.10, and the worksheet obtained after selecting **OK** is shown in Figure 1.11. The Total Profit in cell B18 is zero, and the Production Volume in cell B12 has been set to the breakeven point of 1000.

**FIGURE 1.10** GOAL SEEK DIALOG BOX FOR THE NOWLIN PLASTICS PRODUCTION EXAMPLE

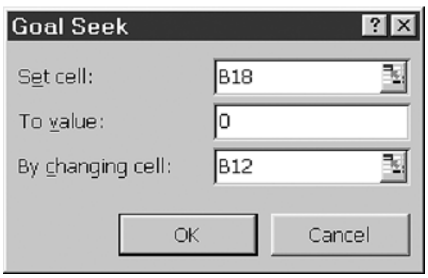


**FIGURE 1.11** BREAKEVEN POINT FOUND USING EXCEL'S GOAL SEEK TOOL FOR THE NOWLIN PLASTICS PRODUCTION EXAMPLE

| | A | B | C |
|---|---|---|---|
| 1 | **Nowlin Plastics** | | |
| 2 | | | |
| 3 | **Fixed Cost** | $3,000 | |
| 4 | | | |
| 5 | **Variable Cost Per Unit** | $2 | |
| 6 | | | |
| 7 | **Selling Price Per Unit** | $5 | |
| 8 | | | |
| 9 | | | |
| 10 | **Models** | | |
| 11 | | | |
| 12 | **Production Volume** | 1000 | |
| 13 | | | |
| 14 | **Total Cost** | 5000 | |
| 15 | | | |
| 16 | **Total Revenue** | 5000 | |
| 17 | | | |
| 18 | **Total Profit (Loss)** | 0 | |
| 19 | | | |