Chapter One

Introduction

Learning Objectives

After completing this chapter, you should be able to

1. Define the term *management science.*
2. Describe the nature of management science.
3. Explain what a mathematical model is.
4. Use a mathematical model to perform break-even analysis.
5. Use a spreadsheet model to perform break-even analysis.
6. Identify the levels of annual savings that management science sometimes can provide to organizations.
7. Identify some special features of this book.

Welcome to the field of *management science!* We think that it is a particularly exciting and interesting field. Exciting because management science is having a dramatic impact on the profitability of numerous business firms around the world. Interesting because the methods used to do this are so ingenious. We are looking forward to giving you a guided tour to introduce you to the special features of the field.

Some students approach a course (and textbook) about management science with a certain amount of anxiety and skepticism. The main source of the anxiety is the reputation of the field as being highly mathematical. This reputation then generates skepticism that such a theoretical approach can have much relevance for dealing with practical managerial problems. Most traditional courses (and textbooks) about management science have only reinforced these perceptions by emphasizing the mathematics of the field rather than its practical application.

Rest easy. This is not a traditional management science textbook. We realize that most readers of this book are aspiring to become managers, not mathematicians. Therefore, the emphasis throughout is on conveying what a future manager needs to know about management science. Yes, this means including a little mathematics here and there, because it is a major language of the field. The mathematics you do see will be at the level of high school algebra plus (in the later chapters) basic concepts of elementary probability theory. We think you will be pleasantly surprised by the new appreciation you gain for how useful and intuitive mathematics at this level can be. However, managers do not need to know any of the heavy mathematical theory that underlies the various techniques of management science. Therefore, the use of mathematics plays only a strictly secondary role in the book.

One reason we can deemphasize mathematics is that powerful *spreadsheet software* now is available for applying management science. Spreadsheets provide a comfortable and familiar environment for formulating and analyzing managerial problems. The spreadsheet takes care of applying the necessary mathematics automatically in the background with only a minimum of guidance by the user. This has begun to revolutionize the use of management science. In the past, technically trained management scientists were needed to carry out significant management science studies for management. Now spreadsheets are bringing many of the tools and concepts of management science within the reach of managers for conducting their own analyses. Although busy managers will continue to call upon management science teams to conduct major studies for them, they are increasingly becoming direct users themselves

through the medium of spreadsheet software. Therefore, since this book is aimed at future managers (and management consultants), we will emphasize the use of spreadsheets for applying management science.

What does an enlightened future manager need to learn from a management science course?

1. Gain an appreciation for the relevance and power of management science. (Therefore, we include many *application vignettes* throughout the book that give examples of *actual applications* of management science and the *impact* they had on the organizations involved.)
2. Learn to recognize when management science can (and cannot) be fruitfully applied. (Therefore, we will emphasize the *kinds of problems* to which the various management science techniques can be applied.)
3. Learn how to apply the major techniques of management science to analyze a variety of managerial problems. (Therefore, we will focus largely on how spreadsheets enable many such applications with no more background in management science than provided by this book.)
4. Develop an understanding of how to interpret the results of a management science study. (Therefore, we will present many *case studies* that illustrate management science studies and how their results depend on the assumptions and data that were used.)

The objectives just described are the key teaching goals of this book.

We begin this process in the next two sections by introducing the nature of management science and the impact that it is having on many organizations. (These themes will continue throughout the remaining chapters as well.) Section 1.4 then points out some of the special features of this book that you can look forward to seeing in the subsequent chapters.

1.1 THE NATURE OF MANAGEMENT SCIENCE

What is the name *management science* (sometimes abbreviated MS) supposed to convey? It does involve *management* and *science* or, more precisely, *the science of management,* but this still is too vague. Here is a more suggestive definition.

> Management science is a *discipline* that attempts to *aid managerial decision making* by applying a *scientific approach* to managerial problems that involve *quantitative factors.*

Now let us see how elaborating upon each of the italicized terms in this definition conveys much more about the nature of management science.

Management Science Is a Discipline

As a discipline, management science is a whole body of knowledge and techniques that are based on a scientific foundation. For example, it is analogous in some ways to the medical field. A medical doctor has been trained in a whole body of knowledge and techniques that are based on the scientific foundations of the medical field. After receiving this training and entering practice, the doctor must diagnose a patient's illness and then choose the appropriate medical procedures to apply to the illness. The patient then makes the final decision on which medical procedures to accept. For less serious cases, the patient may choose not to consult a doctor and instead use his own basic knowledge of medical principles to treat himself. Similarly, a management scientist must receive substantial training (albeit considerably less than for a medical doctor). This training also is in a whole body of knowledge and techniques that are based on the scientific foundations of the discipline. After entering practice, the management scientist must diagnose a managerial problem and then choose the appropriate management science techniques to apply in analyzing the problem. The cognizant manager then makes the final decision as to which conclusions from this analysis to accept. For less extensive managerial problems where management science can be helpful, the manager may choose not to consult a management scientist and instead use his or her own basic knowledge of management science principles to analyze the problem.

Although it has considerably longer roots, the rapid development of the discipline began in the 1940s and 1950s. The initial impetus came early in World War II, when large numbers of scientists were called upon to apply a scientific approach to the management of the war

effort for the allies. Another landmark event was the discovery in 1947 by George Dantzig of the *simplex method* for solving linear programming problems. (Linear programming is the subject of several early chapters.) Another factor that gave great impetus to the growth of the discipline was the onslaught of the computer revolution.

operations research
Management science began its rapid development during World War II with the name *operations research.*

The traditional name given to the discipline (and the one that still is widely used today outside of business schools) is **operations research.** This name was applied because the teams of scientists in World War II were doing *research* on how to manage military *operations.* The abbreviation OR also is widely used. This abbreviation often is combined with the one for management science (MS), thereby referring to the discipline as OR/MS. According to projections from the U.S. Bureau of Labor Statistics for the year 2013, there are approximately 65,000 individuals working as operations research analysts in the United States with an average annual salary of about $79,000.

Another discipline that is closely related to management science is **business analytics.** Like management science, business analytics attempts to aid managerial decision making but with particular emphasis on three types of analysis: (1) *descriptive analytics*—the use of data (sometimes massive amounts of data) to analyze trends, (2) *predictive analytics*—the use of data to predict what will happen in the future (perhaps by using the forecasting techniques described in Chapter 10), and (3) *prescriptive analytics*—the use of data to prescribe the best course of action (frequently by using the optimization techniques described throughout this book). Broadly speaking, the techniques of the management science discipline provide the firepower for prescriptive analytics and, to a lesser extent, for predictive analytics, but not so much for descriptive analytics.

One major international professional society for the management science discipline (as well as for business analytics) is the *Institute for Operations Research and the Management Sciences* (INFORMS). Headquartered in the United States, with over 10,000 members, this society holds major conferences in the United States each year (including an annual Conference for Business Analytics and Operations Research) plus occasional conferences elsewhere. It also publishes several prominent journals, including *Management Science, Operations Research, Analytics,* and *Interfaces.* (Articles describing actual applications of management science are featured in *Interfaces,* so you will see many references and links to this journal throughout the book.) In addition, a few dozen countries around the world have their own national operations research societies. (More about this in Section 1.3.)

Thus, operations research/management science (OR/MS) is a truly international discipline. (We hereafter will just use the name *management science* or the abbreviation MS.)

Management Science Aids Managerial Decision Making

The key word here is that management science *aids* managerial decision making. Management scientists don't make managerial decisions. Managers do. A management science study only provides an analysis and recommendations, based on the quantitative factors involved in the problem, as input to the cognizant managers. Managers must also take into account various intangible considerations that are outside the realm of management science and then use their best judgment to make the decision. Sometimes managers find that qualitative factors are as important as quantitative factors in making a decision.

A small informal management science study might be conducted by just a single individual, who may be the cognizant manager. However, management science *teams* normally are used for larger studies. (We often will use the term *team* to cover both cases throughout the book.) Such a team often includes some members who are not management scientists but who provide other types of expertise needed for the study. Although a management science team often is entirely *in-house* (employees of the company), part or all of the team may instead be *consultants* who have been hired for just the one study. Consulting firms that partially or entirely specialize in management science currently are a growing industry.

Management Science Uses a Scientific Approach

Management science is based strongly on some scientific fields, including mathematics and computer science. It also draws on the social sciences, especially economics. Since the field

is concerned with the practical management of organizations, a management scientist should have solid training in business administration, including its various functional areas, as well.

To a considerable extent, a management science team will attempt to use the *scientific method* in conducting its study. This means that the team will emphasize conducting a *systematic investigation* that includes careful data gathering, developing and testing hypotheses about the problem (typically in the form of a mathematical model), and then applying sound logic in the subsequent analysis.

When conducting this systematic investigation, the management science team typically will follow the (overlapping) steps outlined and described below.

Step 1: Define the problem and gather data. In this step, the team consults with management to clearly identify the problem of concern and ascertain the appropriate objectives for the study. The team then typically spends a surprisingly large amount of time gathering relevant data about the problem with the assistance of other key individuals in the organization. A common frustration is that some key data are either very rough or completely unavailable. This may necessitate installing a new computer-based management information system.

Another increasingly common problem is that there may be *too much* data available to be easily analyzed. Dramatic advances in computerized data capture, processing power, data transmission, and storage capabilities are enabling organizations to integrate their various databases into massive *data warehouses*. This has led to the development of *data-mining software* for extracting hidden predictive information, correlations, and patterns from large databases.

Fortunately, the rapid development of the *information technology (IT)* field in recent years is leading to a dramatic improvement in the quantity and quality of data that may be available to the management science (MS) team. Corporate IT now is often able to provide the computational resources and databases, as well as any helpful data mining, that are needed by the MS team. Thus, the MS team often will collaborate closely with the IT group.

Step 2: Formulate a model (typically a mathematical model) to represent the problem. Models, or approximate representations, are an integral part of everyday life. Common examples include model airplanes, portraits, globes, and so on. Similarly, models play an important role in science and business, as illustrated by models of the atom, models of genetic structure, mathematical equations describing physical laws of motion or chemical reactions, graphs, organization charts, and industrial accounting systems. Such models are invaluable for abstracting the essence of the subject of inquiry, showing interrelationships, and facilitating analysis.

Mathematical models are also approximate representations, but they are expressed in terms of mathematical symbols and expressions. Such laws of physics as $F = ma$ and $E = mc^2$ are familiar examples. Similarly, the mathematical model of a business problem is the system of equations and related mathematical expressions that describes the essence of the problem.

With the emergence of powerful spreadsheet technology, **spreadsheet models** now are widely used to analyze managerial problems. A spreadsheet model lays out the relevant data, measures of performance, interrelationships, and so forth, on a spreadsheet in an organized way that facilitates fruitful analysis of the problem. It also frequently incorporates an underlying mathematical model to assist in the analysis, but the mathematics is kept in the background so the user can concentrate on the analysis.

The *modeling process* is a creative one. When dealing with real managerial problems (as opposed to some cut-and-dried textbook problems), there normally is no single "correct" model but rather a number of alternative ways to approach the problem. The modeling process also is typically an evolutionary process that begins with a simple "verbal model" to define the essence of the problem and then gradually evolves into increasingly more complete mathematical models (perhaps in a spreadsheet format).

We further describe and illustrate such mathematical models in the next section.

Step 3: Develop a computer-based procedure for deriving solutions to the problem from the model. The beauty of a well-designed mathematical model is that it enables the

use of mathematical procedures to find good solutions to the problem. These procedures usually are run on a computer because the calculations are too extensive to be done by hand. In some cases, the management science team will need to develop the procedure. In others, a standard software package already will be available for solving the model. When the mathematical model is incorporated into a spreadsheet, the spreadsheet software normally includes a Solver that usually will solve the model.

Step 4: Test the model and refine it as needed. Now that the model can be solved, the team needs to thoroughly check and test the model to make sure that it provides a sufficiently accurate representation of the real problem. A number of questions should be addressed, perhaps with the help of others who are particularly familiar with the problem. Have all the relevant factors and interrelationships in the problem been accurately incorporated into the model? Does the model seem to provide reasonable solutions? When it is applied to a past situation, does the solution improve upon what was actually done? When assumptions about costs and revenues are changed, do the solutions change in a plausible manner?

Step 5: Apply the model to analyze the problem and develop recommendations for management. The management science team now is ready to solve the model, perhaps under a variety of assumptions, in order to analyze the problem. The resulting recommendations then are presented to the managers who must make the decisions about how to deal with the problem.

If the model is to be applied repeatedly to help guide decisions on an ongoing basis, the team might also develop a **decision support system.** This is an interactive computer-based system that aids managerial decision making. The system draws current data from *databases* or *management information systems* and then solves the various versions of the model specified by the manager.

Step 6: Help to implement the team's recommendations that are adopted by management. Once management makes its decisions, the management science team normally is asked to help oversee the implementation of the new procedures. This includes providing some information to the operating management and personnel involved on the rationale for the changes that are being made. The team also makes sure that the new operating system is consistent with its recommendations as they have been modified and approved by management. If successful, the new system may be used for years to come. With this in mind, the team monitors the initial experience with the system and seeks to identify any modifications that should be made in the future.

Management Science Considers Quantitative Factors

Many managerial problems revolve around such quantitative factors as production quantities, revenues, costs, the amounts available of needed resources, and so on. By incorporating these quantitative factors into a *mathematical model* and then applying mathematical procedures to solve the model, management science provides a uniquely powerful way of analyzing such managerial problems. Although management science is concerned with the practical management of organizations, including taking into account relevant qualitative factors, its special contribution lies in this unique ability to deal with the quantitative factors.

The Special Products Company example discussed below will illustrate how management science considers quantitative factors.

Review
Questions

1. When did the rapid development of the management science discipline begin?
2. What is the traditional name given to this discipline that still is widely used outside of business schools?
3. What does a management science study provide to managers to aid their decision making?
4. Upon which scientific fields and social sciences is management science especially based?
5. What is a *decision support system?*
6. What are some common quantitative factors around which many managerial problems revolve?

1.2 AN ILLUSTRATION OF THE MANAGEMENT SCIENCE APPROACH: BREAK-EVEN ANALYSIS

The **Special Products Company** produces expensive and unusual gifts to be sold in stores that cater to affluent customers who already have everything. The latest new-product proposal to management from the company's Research Department is a first-of-its-kind iWatch. This iWatch would combine the features of a top-of-the-line atomic wristwatch and a next-generation smartphone, including the ability to respond to voice commands or questions with voice responses. It also would connect to the Internet wirelessly to provide weather, sports scores, stock quotes, and more. An extensive research-and-development project would be needed to develop the iWatch. The proposal is to provide a generous budget of $10 million for this project in order to provide as many desirable features as possible within this budget. It is clear that the production costs for the iWatch would be very large because of the extreme miniaturization that would be required, so the selling price would need to be far beyond the reach of middle-class customers. Therefore, the marketing of the iWatch would be aimed at wealthy customers who want the most advanced products regardless of cost.

Management needs to decide whether to develop and market this new product and, if so, how many of these watches to produce. Before making these decisions, a sales forecast will be obtained to estimate how many watches can be sold. Since most of these sales would occur quickly during the relatively brief time before the "next big thing" arrives to take over the market, there would be only one production run for the iWatch and the number produced would be set equal to the sales forecast. Following the production run, the iWatch would be marketed as aggressively as needed to sell this entire inventory if possible. Management now needs a management science study to be conducted to determine how large this sales potential needs to be to make the iWatch profitable after considering all the prospective revenues and costs, so let's next look at the estimates of these financial figures.

If the company goes ahead with this product, the research-and-development cost of $10 million is referred to as a *fixed cost* because it remains the same regardless of how many watches are produced and sold. (However, note that this cost would *not* be incurred if management decides not to introduce the product since the research-and-development project then would not be undertaken.)

A cost that remains the same regardless of the production volume is referred to as a fixed cost, whereas a cost that varies with the production volume is called a variable cost.

In addition to this fixed cost, there is a production cost that varies with the number of watches produced. This *variable cost* is $1,000 per watch produced, which adds up to $1,000 *times* the number of watches produced. (The cost for each additional unit produced, $1,000, is referred to as the *marginal cost.*) Each watch sold would generate a unit revenue of $2,000 for the company.

Spreadsheet Modeling of the Problem

You will see throughout this book that spreadsheets provide a very convenient way of using a management science approach for modeling and analyzing a wide variety of managerial problems. This certainly is true for the Special Products Company problem as well, as we now will demonstrate.

Figure 1.1 shows a spreadsheet formulation of this problem after obtaining a sales forecast that indicates 30,000 watches can be sold. The data have been entered into cells C4 to C7. Cell C9 is used to record a trial value for the decision as to how many watches to produce. As one of the many possibilities that eventually might be tried, Figure 1.1 shows the specific trial value of 20,000.

Cells F4 to F7 give the resulting total revenue, total costs, and profit (loss) by using the Excel equations shown under the spreadsheet in Figure 1.1. The Excel equations could have been written using cell references (e.g., F6 = C6*C9). However, the spreadsheet model is made clearer by giving "range names" to key cells or blocks of cells. (A **range name** is a descriptive name given to a cell or range of cells that immediately identifies what is there. Appendix A provides details about how to incorporate range names into a spreadsheet model.) To define a name for a selected cell (or range of cells), click on the name box (on the left of the formula bar above the spreadsheet) and type a name. These cell names then can be used in other formulas to create an equation that is easy to decipher (e.g., TotalVariable-Cost = MarginalCost*ProductionQuantity rather than the more cryptic F6 = C6*C9). Note

Excel Tip: To update formulas throughout the spreadsheet to incorporate a newly defined range name, choose Apply Names from the Define Name menu on the Formulas tab

FIGURE 1.1

A spreadsheet formulation of the Special Products Company problem.

	A	B	C	D	E	F
1		**Special Products Co. Break-Even Analysis**				
2						
3			**Data**			**Results**
4		Unit Revenue	$2,000		Total Revenue	$40,000,000
5		Fixed Cost	$10,000,000		Total Fixed Cost	$10,000,000
6		Marginal Cost	$1,000		Total Variable Cost	$20,000,000
7		Sales Forecast	30,000		Profit (Loss)	$10,000,000
8						
9		Production Quantity	20,000			

Range Name	Cell
FixedCost	C5
MarginalCost	C6
ProductionQuantity	C9
Profit	F7
SalesForecast	C7
TotalFixedCost	F5
TotalRevenue	F4
TotalVariableCost	F6
UnitRevenue	C4

	E	F
3		**Results**
4	Total Revenue	=UnitRevenue * MIN(SalesForecast, ProductionQuantity)
5	Total Fixed Cost	=IF(ProductionQuantity > 0, FixedCost, 0)
6	Total Variable Cost	=MarginalCost * ProductionQuantity
7	Profit (Loss)	=TotalRevenue − (TotalFixedCost + TotalVariableCost)

Excel Tip: A list of all the defined names and their corresponding cell references can be pasted into a spreadsheet by choosing Paste Names from the Use in Formula menu on the Formulas tab, and then clicking on Paste List.

that spaces are not allowed in range names. When a range name has more than one word, we have used capital letters to distinguish the start of each new word (e.g., ProductionQuantity).

The lower left-hand corner of Figure 1.1 lists the names of the quantities in the spreadsheet in alphabetical order and then gives cell references where the quantities are found. Although this isn't particularly necessary for such a small spreadsheet, you should find it helpful for the larger spreadsheets found later in the book.

This same spreadsheet is provided for you live in your MS Courseware on the CD-ROM. (All the spreadsheets in the book are included in your MS Courseware.) As you can see for yourself by bringing up and playing with the spreadsheet, it provides a straightforward way of performing *what-if analysis* on the problem. What-if analysis involves addressing such questions as what happens if the sales forecast should have been considerably lower? What happens if some of the cost and revenue estimates are wrong? Simply enter a variety of new values for these quantities in the spreadsheet and see what happens to the profit shown in cell F7.

A spreadsheet is a convenient tool for performing what-if analysis.

The lower right-hand corner of Figure 1.1 introduces two useful Excel functions, the MIN(a, b) function and the IF(a, b, c) function. The equation for cell F4 uses the MIN(a, b) function, which gives the minimum of a and b. In this case, the estimated number of watches that will be sold is the minimum of the sales forecast and the production quantity, so

The Excel function MIN (a, b) gives the minimum of the numbers in the cells whose addresses are a and b.

$$F4 = \text{UnitRevenue*MIN(SalesForecast, ProductionQuantity)}$$

enters the unit revenue (from cell C4) times the minimum of the sales forecast (from C7) and the production quantity (from C9) into cell F4.

The Excel function IF (a, b, c) tests if a is true. If so, it uses b; otherwise it uses c.

Also note that the equation for cell F5 uses the IF(a, b, c) function, which does the following: If statement a is true, it uses b; otherwise, it uses c. Therefore,

$$F5 = \text{IF(ProductionQuantity} > 0, \text{FixedCost, 0)}$$

says to enter the fixed cost (C5) into cell F5 if the production quantity (C9) is greater than zero, but otherwise enter 0 (the fixed cost is avoided if production is not initiated).

The spreadsheet in Figure 1.1, along with its equations for the results in column F, constitutes a *spreadsheet model* for the Special Products Company problem. You will see many examples of such spreadsheet models throughout the book.

This particular spreadsheet model is based on an underlying *mathematical model* that uses algebra to spell out the equations in cells F4:F7 and then to derive some additional useful information. Let us take a look at this mathematical model next.

Expressing the Problem Mathematically

The issue facing management is to make the following decision.

Decision to be made: Number of watches to produce (if any).

Since this number is not yet known, we introduce an algebraic variable Q to represent this quantity. Thus,

$$Q = \text{Number of watches to produce,}$$

where Q is referred to as a **decision variable.** Naturally, the value chosen for Q should not exceed the sales forecast for the number of watches that can be sold. Choosing a value of 0 for Q would correspond to deciding not to introduce the product, in which case none of the costs or revenues described in the preceding paragraph would be incurred.

The objective is to choose the value of Q that maximizes the company's profit from this new product. The management science approach is to formulate a mathematical model to represent this problem by developing an equation that expresses the profit in terms of the decision variable Q. To get there, it is necessary first to develop equations in terms of Q for the total cost and revenue generated by the watches.

If $Q = 0$, no cost is incurred. However, if $Q > 0$, there is both a fixed cost and a variable cost.

$$\text{Fixed cost} = \$10 \text{ million (if } Q > 0)$$
$$\text{Variable cost} = \$1{,}000\ Q$$

Therefore, the total cost would be

$$\text{Total cost} = \begin{cases} 0 & \text{if } Q = 0 \\ \$10 \text{ million} + \$1{,}000Q & \text{if } Q > 0 \end{cases}$$

Since each watch sold would generate a revenue of \$2,000 for the company, the total revenue from selling Q watches would be

$$\text{Total revenue} = \$2{,}000Q$$

Consequently, the profit from producing and selling Q watches would be

$$\text{Profit} = \text{Total revenue} - \text{Total cost}$$
$$= \begin{cases} 0 & \text{if } Q = 0 \\ \$2{,}000Q - (\$10 \text{ million} + \$1{,}000Q) & \text{if } Q > 0 \end{cases}$$

Thus, since $\$2{,}000Q - \$1{,}000Q = \$1{,}000Q$,

$$\text{Profit} = -\$10 \text{ million} + \$1{,}000Q \quad \text{if } Q > 0$$

Analysis of the Problem

This last equation shows that the attractiveness of the proposed new product depends greatly on the value of Q, that is, on the number of watches that can be produced and sold. A small value of Q means a loss (negative profit) for the company, whereas a sufficiently large value would generate a positive profit for the company. For example, look at the difference between $Q = 2{,}000$ and $Q = 20{,}000$.

$$\text{Profit} = -\$10 \text{ million} + \$1{,}000\ (2{,}000) = -\$8 \text{ million} \quad \text{if } Q = 20$$
$$\text{Profit} = -\$10 \text{ million} + \$1{,}000\ (20{,}000) = \$10 \text{ million} \quad \text{if } Q = 200$$

Figure 1.2 plots both the company's total cost and total revenue for the various values of Q. Note that the cost line and the revenue line intersect at $Q = 10{,}000$. For any value of $Q < 10{,}000$, cost exceeds revenue, so the gap between the two lines represents the *loss* to the company. For any $Q > 10{,}000$, revenue exceeds cost, so the gap between the two lines now

FIGURE 1.2

Break-even analysis for the Special Products Company shows that the cost line and revenue line intersect at $Q = 10,000$ watches, so this is the break-even point for the proposed new product.
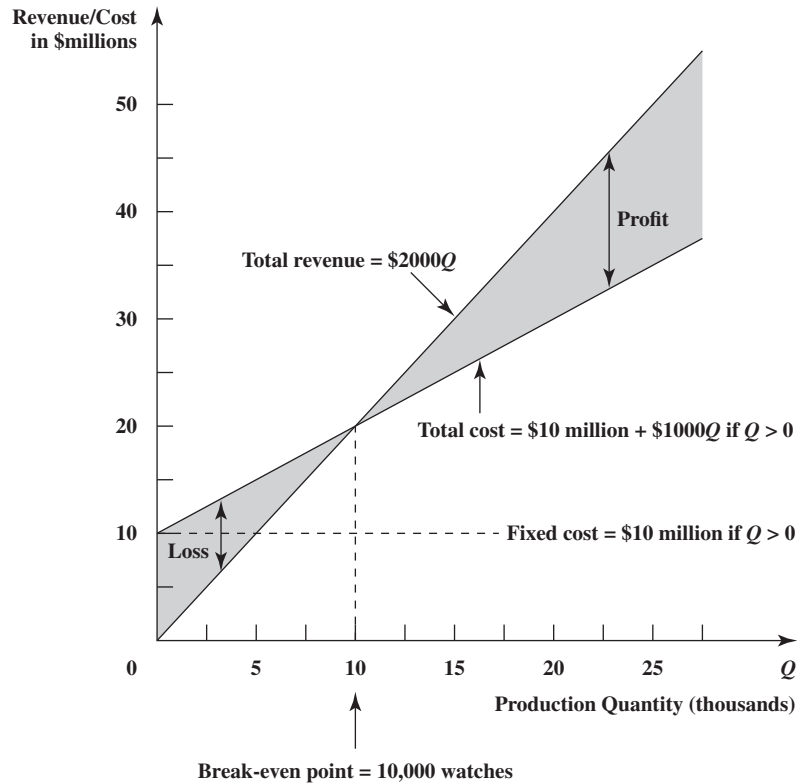
shows positive profit. At $Q = 10,000$, the profit is 0. Since 10,000 units is the production and sales volume at which the company would break even on the proposed new product, this volume is referred to as the **break-even point.** This is the point that must be exceeded to make it worthwhile to introduce the product. Therefore, the crucial question is whether the sales forecast for how many watches can be sold is above or below the break-even point.

Figure 1.2 illustrates the *graphical procedure* for finding the break-even point. Another alternative is to use an *algebraic procedure* to solve for the point. Because the profit is 0 at this point, the procedure consists of solving the following equation for the unknown Q.

$$\text{Profit} = -\$10 \text{ million} + \$1{,}000Q = 0$$

Thus,

$$\$1{,}000Q = \$10 \text{ million}$$

$$Q = \frac{\$10 \text{ million}}{\$1{,}000}$$

$$Q = 10{,}000$$

A Complete Mathematical Model for the Problem

The preceding analysis of the problem made use of a basic mathematical model that consisted of the equation for profit expressed in terms of Q. However, implicit in this analysis were some additional factors that can be incorporated into a complete mathematical model for the problem.

Two of these factors concern restrictions on the values of Q that can be considered. One of these is that the number of watches produced cannot be less than 0. Therefore,

$$Q \geq 0$$

constraints

A *constraint* in a mathematical model is an inequality or equation that expresses some restrictions on the values that can be assigned to the decision variables.

is one of the **constraints** for the complete mathematical model. Another restriction on the value of Q is that it should not exceed the number of watches that can be sold. A sales forecast has not yet been obtained, so let the symbol s represent this currently unknown value.

s = Sales forecast (not yet available) of the number of watches that can be sold

Consequently,

$$Q \leq s$$

parameter

The constants in a mathematical model are referred to as the *parameters* of the model.

is another constraint, where *s* is a **parameter** of the model whose value has not yet been chosen.

The final factor that should be made explicit in the model is the fact that management's objective is to make the decision that maximizes the company's profit from this new product. Therefore, the complete mathematical model for this problem is to find the value of the decision variable *Q* so as to

$$\text{Maximize profit} = \begin{cases} 0 & \text{if } Q = 0 \\ -\$10 \text{ million} + \$1{,}000Q & \text{if } Q > 0 \end{cases}$$

subject to

$$Q \leq s$$
$$Q \geq 0$$

objective function

The *objective function* for a mathematical model is a mathematical expression that gives the measure of performance for the problem in terms of the decision variables.

where the algebraic expression given for Profit is called the **objective function** for the model. The value of *Q* that solves this model depends on the value that will be assigned to the parameter *s* (the future forecast of the number of units that can be sold). Because the break-even point is 10,000 here is how the solution for *Q* depends on *s*.

Solution for Mathematical Model

$$\text{Break-even point} = \frac{\text{Fixed cost}}{\text{Unit revenue} - \text{Marginal cost}} = \frac{\$10 \text{ million}}{\$2{,}000 - \$1{,}000} = 10{,}000$$

$$\text{If } s \leq 10{,}000, \text{ then set } Q = 0$$
$$\text{If } s > 10{,}000, \text{ then set } Q = s$$

Therefore, the company should introduce the product and produce the number of units that can be sold *only* if this production and sales volume exceeds the break-even point.

What-if Analysis of the Mathematical Model

A mathematical model is intended to be only an approximate representation of the problem. For example, some of the numbers in the model inevitably are only estimates of quantities that cannot be determined precisely at this time.

The above mathematical model is based on four numbers that are only estimates—the fixed cost of $10 million, the marginal cost of $1,000, the unit revenue of $2,000, and the sales forecast (after it is obtained). A management science study usually devotes considerable time to investigating what happens to the recommendations of the model if any of the estimates turn out to considerably miss their targets. This is referred to as **what-if analysis.**

what-if analysis

Since estimates can be wrong, *what-if analysis* is used to check the effect on the recommendations of a model if the estimates turn out to be wrong.

To assist you in performing what-if analysis on this kind of model in a straightforward and enjoyable way, we have provided a *Break-Even Analysis* module in the *Interactive Management Science Modules* at **www.mhhe.com/hillier5e**. (All of the modules in this software package also are included on your CD-ROM.) By following the simple directions given there, you can drag either the cost line or the revenue line to change the fixed cost, the marginal cost, or the unit revenue. This immediately enables you to see the effect on the break-even point if any of these cost or revenue numbers should turn out to have values that are somewhat different than their estimates in the model.

Incorporating the Break-Even Point into the Spreadsheet Model

A key finding of the above mathematical model is its formula for the break-even point,

$$\text{Break-even point} = \frac{\text{Fixed cost}}{\text{Unit revenue} - \text{Marginal cost}}$$

Therefore, once both the quantities in this formula and the sales forecast have been carefully estimated, the solution for the mathematical model specifies what the production quantity should be.

By contrast, although the spreadsheet in Figure 1.1 enables trying a variety of trial values for the production quantity, it does not directly indicate what the production quantity should be. Figure 1.3 shows how this spreadsheet can be expanded to provide this additional guidance.

FIGURE 1.3

An expansion of the spreadsheet in Figure 1.1 that uses the solution for the mathematical model to calculate the break-even point.

	A	B	C	D	E	F
1		**Special Products Co. Break-Even Analysis**				
2						
3			**Data**			**Results**
4		Unit Revenue	$2,000		Total Revenue	$60,000,000
5		Fixed Cost	$10,000,000		Total Fixed Cost	$10,000,000
6		Marginal Cost	$1,000		Total Variable Cost	$30,000,000
7		Sales Forecast	30,000		Profit (Loss)	$20,000,000
8						
9		Production Quantity	30,000		Break-Even Point	10,000

Range Name	Cell
BreakEvenPoint	F9
FixedCost	C5
MarginalCost	C6
ProductionQuantity	C9
Profit	F7
SalesForecast	C7
TotalFixedCost	F5
TotalRevenue	F4
TotalVariableCost	F6
UnitRevenue	C4

	E	F
3		**Results**
4	Total Revenue	=UnitRevenue * MIN(SalesForecast, ProductionQuantity)
5	Total Fixed Cost	=IF(ProductionQuantity > 0, FixedCost, 0)
6	Total Variable Cost	=MarginalCost * ProductionQuantity
7	Profit (Loss)	=TotalRevenue – (TotalFixedCost + TotalVariableCost)
8		
9	Break-Even Point	=FixedCost/(UnitRevenue – MarginalCost)

Suppose that a sales forecast of 30,000 has been obtained, as shown in cell C7. As indicated by its equation at the bottom of the figure, cell F9 calculates the break-even point by dividing the fixed cost ($10 million) by the net profit per watch sold ($1,000), where this net profit is the unit revenue ($2,000) *minus* the marginal cost ($1,000). Since the sales forecast of 30,000 exceeds the break-even point of 10,000 this forecast has been entered into cell C9.

If desired, the complete mathematical model for break-even analysis can be *fully* incorporated into the spreadsheet by requiring that the model solution for the production quantity be entered into cell C9. This would be done by using the equation

$$C9 = IF(SalesForecast > BreakEvenPoint, SalesForecast, 0)$$

However, the disadvantage of introducing this equation is that it would eliminate the possibility of trying other production quantities that might still be of interest. For example, if management does not have much confidence in the sales forecast and wants to minimize the danger of producing more watches than can be sold, consideration would be given to production quantities smaller than the forecast. For example, the trial value shown in cell C9 of Figure 1.1 might be chosen instead. As in any application of management science, a mathematical model can provide useful guidance but management needs to make the final decision after considering factors that may not be included in the model.

Review Questions

1. How do the production and sales volume of a new product need to compare to its break-even point to make it worthwhile to introduce the product?
2. What are the factors included in the complete mathematical model for the Special Products Company problem, in addition to an equation for profit?
3. What is the purpose of what-if analysis?
4. How can a spreadsheet be used to perform what-if analysis?
5. What does the MIN(a, b) Excel function do?
6. What does the IF(a, b, c) Excel function do?

An Application Vignette

Federal Express (FedEx) is the world's largest express transportation company. Every working day, it delivers more than 6.5 million documents, packages, and other items throughout the United States and more than 220 countries and territories around the world. In some cases, these shipments can be guaranteed overnight delivery by 10:30 AM the next morning.

The logistical challenges involved in providing this service are staggering. These millions of daily shipments must be individually sorted and routed to the correct general location (usually by aircraft) and then delivered to the exact destination (usually by motorized vehicle) in an amazingly short period of time. How is this possible?

Management science (which usually is referred to as operations research within FedEx) is the technological engine that drives this company. Ever since the company's founding in 1973, management science (MS) has helped make its major business decisions, including equipment investment, route structure, scheduling, finances, and location of facilities. After MS was credited with literally saving the company during its early years, it became the custom to have MS represented at the weekly senior management meetings and, indeed, several of the senior corporate vice presidents have come up from the outstanding FedEx MS group.

FedEx has come to be acknowledged as a world-class company. It routinely ranks among the top companies on *Fortune* magazine's annual listing of the "World's Most Admired Companies." It also was the first winner (in 1991) of the prestigious prize now known as the INFORMS Prize, which is awarded annually for the effective and repeated integration of management science into organizational decision making in pioneering, varied, novel, and lasting ways.

1.3 THE IMPACT OF MANAGEMENT SCIENCE

Management science (or *operations research* as it is commonly called by practitioners) has had an impressive impact on improving the efficiency of numerous organizations around the world. In the process, management science has made a significant contribution to increasing the productivity of the economies of various countries. There now are a few dozen member countries in the International Federation of Operational Research Societies (IFORS), with each country having a national operations research society. Both Europe and Asia have federations of such societies to coordinate holding international conferences and publishing international journals in those continents. In addition, we described in Section 1.1 how the Institute for Operations Research and the Management Sciences (INFORMS) is a particularly prominent international society in this area. Among its various journals is one called *Interfaces* that regularly publishes articles describing major management science studies and the impact they had on their organizations.

The most important applications of management science in business and industry have resulted in annual savings in the hundreds of millions of dollars.

Management science (MS) has had numerous applications of various types in business and industry, sometimes resulting in annual savings of millions, or even hundreds of millions, of dollars. As an example, many hundreds of management scientists work on such airline problems as how to most effectively assign airplanes and crews to flights and how to develop fare structures that maximize revenue. For decades, financial services firms have used portfolio selection techniques that were developed by management scientists who won the Nobel Prize in Economics for their work. Management science models have become a core component of the marketing discipline. Multinational corporations rely on MS for guiding the management of their supply chains. There are numerous other examples of MS applications that are having a dramatic impact on the companies involved.

Management science also has had a major impact in the health care area, in guiding key governmental policies, and in military applications.

Management science also is widely used outside business and industry. For example, it is having an increasing impact in the health care area, with applications involving improved management of health care delivery and operations, disease modeling, clinical diagnosis and decision making, radiation therapy, and so on. Applications of MS also abound at various levels of government, ranging from dealing with national security issues at the federal level to managing the delivery of emergency services at the municipal level. Other key governmental applications involve the use of MS modeling to help guide energy, environmental, and global warming policies. Some of the earliest MS applications were military applications, including logistical planning and war gaming, and these continue today.

These are just a sampling of the numerous applications of management science that are having a major impact on the organizations involved. The list goes on and on.

To give you a better notion of the wide applicability of management science, we list some actual applications in Table 1.1. Note the diversity of organizations and applications in the first two columns. The third column identifies the section where an "application vignette" devotes several paragraphs to describing the application and also references an article that provides full details. (You can see the first of these application vignettes in this section.) The last column indicates that these applications typically resulted in annual savings in the many millions of dollars. Furthermore, additional benefits not recorded in the table (e.g., improved service to customers and better managerial control) sometimes were considered to be even more important than these financial benefits. (You will have an opportunity to investigate these less tangible benefits further in Problems 1.9 and 1.10.)

A link to the articles in *Interfaces* that describes these applications in detail is included on our Website, **www.mhhe.com/hillier5e**. We are grateful to INFORMS for our special partnership to make these articles available to you through this link. We think you will find these articles interesting and enlightening in illustrating the dramatic impact that management science sometimes can have on the success of a variety of organizations.

You also will see a great variety of applications of management science throughout the book in the form of case studies, examples, and end-of-chapter cases. Some of the applications are similar to ones described in application vignettes, but many others are quite different. However, they all generally fall into one of three broad categories, namely, applications

TABLE 1.1   **Applications of Management Science to Be Described in Application Vignettes**

Organization	Area of Application	Section	Annual Savings
Federal Express	Logistical planning of shipments	1.3	Not estimated
Swift & Company	Improve sales and manufacturing performance	2.1	$12 million
Samsung Electronics	Reduce manufacturing times and inventory levels	2.6	$200 million more revenue
INDEVAL	Settle all securities transactions in Mexico	3.2	$150 million
United Airlines	Plan employee work schedules at airports and reservations offices	3.3	$6 million
Procter & Gamble	Redesign the production and distribution system	3.5	$200 million
Welch's	Optimize use and movement of raw materials	4.3	$150,000
Pacific Lumber Company	Long-term forest ecosystem management	5.4	$398 million NPV
Hewlett-Packard	Product portfolio management	6.1	$180 million
Norwegian companies	Maximize flow of natural gas through offshore pipeline network	6.3	$140 million
Canadian Pacific Railway	Plan routing of rail freight	6.4	$100 million
Waste Management	Develop a route-management system for trash collection and disposal	7.1	$100 million
MISO	Administer the transmission of electricity in 13 states	7.2	$700 million
Netherlands Railways	Optimize operation of a railway network	7.4	$105 million
Continental Airlines	Reassign crews to flights when schedule disruptions occur	7.5	$40 million
Bank Hapoalim Group	Develop a decision-support system for investment advisors	8.2	$31 million more revenue
DHL	Optimize the use of marketing resources	8.4	$22 million
Workers' Compensation Board	Manage high-risk disability claims and rehabilitation	9.3	$4 million
Westinghouse	Evaluate research and development projects	9.7	Not estimated
Conoco-Phillips	Evaluate petroleum exploration projects	9.9	Not estimated
L. L. Bean	Forecast staffing needs at call centers	10.2	$300,000
Taco Bell	Forecast the level of business throughout the day	10.3	$13 million
CSAV	Optimize global shipping	10.6	$81 million
General Motors	Improve the throughput of its production lines	11.5	$200 million
KeyCorp	Improve efficiency of bank teller service	11.6	$20 million
Federal Aviation Administration	Manage air traffic flows in severe weather	12.2	$200 million
Sasol	Improve the efficiency of its production processes	12.4	$23 million
Merrill Lynch	Pricing analysis for providing financial services	13.5	$50 million more revenue

TABLE 1.2

Case Studies and Examples in the Area of Operations Management

Location	Type of Application
Sec. 2.1 onward	A case study: What is the most profitable mix of products?
Case 2-1	Which mix of car models should be produced?
Case 2-2	Which mix of ingredients should go into the casserole in a university cafeteria?
Case 2-3	Which mix of customer–service agents should be hired to staff a call center?
Sec. 3.3	Personnel scheduling of customer–service agents
Sec. 3.5	Minimize the cost of shipping a product from factories to customers
Sec. 3.7	Optimize the assignment of personnel to tasks
Case 3-1	How should a product be shipped to market?
Case 3-3	Which mix of women's clothing should be produced for next season?
Cases 3-5, 5-4, 7-3	Develop a plan for assigning students to schools so as to minimize busing costs
Case 3-6	Which mixes of solid waste materials should be amalgamated into different grades of a salable product?
Case 3-7	How should qualified managers be assigned to new R&D projects?
Case 5-2	Develop and analyze a steel company's plan for pollution abatement
Case 5-3	Plan the mix of livestock and crops on a farm with unpredictable weather
Sec. 6.1	Minimize the cost of operating a distribution network
Secs. 6.2, 6.3	A case study: Maximize the flow of goods through a distribution network
Sec. 6.4	Find the shortest path from an origin to a destination
Case 6-1	Logistical planning for a military campaign
Case 6-3	Develop the most profitable flight schedules for an airline
Cases 6-4, 7-4	Operate and expand a private computer network
Sec. 7.2	Choose the best combination of R&D projects to pursue
Sec. 7.3	Select the best sites for emergency services facilities
Sec. 7.4	Airline crew scheduling
Sec. 7.5	Production planning when setup costs are involved
Case 7-2	Make inventory decisions for a retailer's warehouse
Sec. 8.3	Production planning when overtime is needed
Sec. 8.5	Find the shortest route to visit all the American League ballparks
Sec. 11.2	Many examples of commercial service systems, internal service systems, and transportation service systems that can be analyzed with queueing models
Sec. 11.4 onward	A case study: An analysis of competing proposals for more quickly providing maintenance services to customers
Cases 11-2, 12-2	Analysis of proposals for reducing in-process inventory
Sec. 12.1	Comparison of whether corrective maintenance or preventive maintenance is better
Secs. 12.2, 12.3	A case study: Would it be profitable for the owner of a small business to add an associate?
Case 12-1	Analysis of proposals for relieving a production bottleneck
Sec. 13.1	A case study: How much of a perishable product should be added to a retailer's inventory?
Sec. 13.3	Plan a complex project to ensure a strong likelihood of meeting the project deadline

in the areas of operations management, finance, and marketing. Tables 1.2, 1.3, and 1.4 list these applications in these three respective areas, where the first column identifies where the application is described. In the second column of each table, note the many different ways in which management science can have a real impact in helping improve managerial decisions.

Even these long lists of applications in Tables 1.1 to 1.4 are just a sample of the numerous important ways in which management science is applied in organizations around the world. We do not have enough space to provide a more comprehensive compilation of the important applications. (Other applications are included in the supplementary chapters on the CD-ROM.) A hallmark of management science is its great flexibility in dealing with new managerial problems as they arise.

1.4 SOME SPECIAL FEATURES OF THIS BOOK

The focus of this book is on teaching what an enlightened future manager needs to learn from a management science course. It is not on trying to train technical analysts. This focus has led us to include a number of special features that we hope you enjoy.

TABLE 1.3
Case Studies and Examples in the Area of Finance

Location	Type of Application
Sec. 1.2	Break-even analysis
Case 1-1	Break-even analysis and what-if analysis
Sec. 3.2	An airline choosing which airplanes to purchase
Sec. 3.2	Capital budgeting of real-estate development projects
Case 3-2	Develop a schedule for investing in a company's computer equipment
Sec. 4.1 onward	A case study: Develop a financial plan for meeting future cash flow needs
Case 4-1	Develop an investment and cash flow plan for a pension fund
Sec. 6.4	Minimize the cost of car ownership
Case 6-2	Find the most cost-effective method of converting various foreign currencies into dollars
Sec. 7.1	A case study: Determine the most profitable combination of investments
Case 7-1	Develop an investment plan for purchasing art
Sec. 8.2	Portfolio selection that balances expected return and risk
Sec. 8.5	Select a portfolio to beat the market as frequently as possible
Case 8-2	Determine an optimal investment portfolio of stocks
Case 8-3	Develop a long-range plan to purchase and sell international bonds
Sec. 9.1 onward	A case study: Choose whether to drill for oil or sell the land instead
Case 9-1	Choose a strategy for the game show, "Who Wants to Be a Millionaire?"
Sec. 12.1	Analysis of a new gambling game
Sec. 13.2	Choose the bid to submit in a competitive bidding process
Sec. 13.4	Develop a financial plan when future cash flows are somewhat unpredictable
Sec. 13.5	Risk analysis when assessing financial investments
Sec. 13.6	How much overbooking should be done in the travel industry?
Case 13-1	Analysis of how a company's cash flows might evolve over the next year
Case 13-2	Calculate the value of a European call option

TABLE 1.4
Case Studies and Examples in the Area of Marketing

Location	Type of Application
Secs. 2.6, 3.3	Determine the best mix of advertising media
Case 2-1	Evaluate whether an advertising campaign would be worthwhile
Secs. 3.1, 3.4	A case study: Which advertising plan best achieves managerial goals?
Case 3-4	Develop a representative marketing survey
Case 5-1	Analysis of the trade-off between advertising costs and the resulting increase in sales of several products
Sec. 6.4	Balance the speed of bringing a new product to market and the associated costs
Sec. 8.3	Deal with nonlinear marketing costs
Case 8-1	Refine the advertising plan developed in the case study presented in Sections 3.1 and 3.4
Case 9-2	Should a company immediately launch a new product or test-market it first?
Case 9-3	Should a company buy additional marketing research before deciding whether to launch a new product?
Case 9-4	Plan a sequence of decisions for a possible new product
Sec. 10.2 onward	A case study: Manage a call center for marketing goods over the telephone
Case 10-1	Improve forecasts of demand for a call center
Case 11-1	Estimate customer waiting times for calling into a call center

One special feature is that the entire book revolves around *modeling* as an aid to managerial decision making. This is what is particularly relevant to a manager. Although they may not use this term, all managers often engage in at least informal modeling (abstracting the essence of a problem to better analyze it), so learning more about the art of modeling is important. Since managers instigate larger management science studies done by others, they also need to be able to recognize the kinds of managerial problems where such a study might be helpful. Thus, a future manager should acquire the ability both to recognize when a management science model might be applicable and to properly interpret the results from analyzing the model. Therefore, rather than spending substantial time in this book on mathematical theory, the mechanics of solution procedures, or the manipulation of spreadsheets, the focus is on the art of model formulation, the role of a model, and the analysis of model results. A wide range of model types is considered.

Another special feature is a heavy emphasis on *case studies* to better convey these ideas in an interesting way in the context of applications. Every subsequent chapter includes at least one case study that introduces and illustrates the application of that chapter's techniques in a realistic setting. In a few instances, the entire chapter revolves around a case study. Although considerably smaller and simpler than most real studies (to maintain clarity), these case studies are patterned after actual applications requiring a major management science study. Consequently, they convey the whole process of such a study, some of the pitfalls involved, and the complementary roles of the management science team and the manager responsible for the decisions to be made.

To complement these case studies, every chapter also includes major cases at the end. These realistic cases can be used for individual assignments, team projects, or case studies in class. In addition, the University of Western Ontario Ivey School of Business (the second largest producer of teaching cases in the world) also has specially selected cases from its case collection that match the chapters in this textbook. These cases are available on the Ivey Website, **www.cases.ivey.uwo.ca/cases**, in the segment of the CaseMate area designated for this book.

The book also places heavy emphasis on conveying the impressive impact that management science is having on improving the efficiency of numerous organizations around the world. Therefore, you will see many examples of actual applications throughout the book in the form of boxed *application vignettes,* such as the one already shown in Section 1.3. You then will have the opportunity to learn more about these actual applications by reading the articles fully describing them that are accessed by a link on our Website. As indicated in Table 1.1, these applications sometimes resulted in annual savings of millions, tens of millions, or even hundreds of millions of dollars.

In addition, we try to provide you with a broad perspective about the nature of the real world of management science in practice. It is easy to lose sight of this world when cranking through textbook exercises to master the mechanics of a series of techniques. Therefore, we shift some emphasis from mastering these mechanics to seeing the big picture. The case studies, cases, and descriptions of actual applications are part of this effort.

Another feature is the inclusion of one or more *solved problems* for each chapter to help you get started on your homework for that chapter. The statement of each solved problem is given just above the Problems section of the chapter, and then the complete solution is given on both the CD-ROM and the Website for the book.

The last, but certainly not the least, of the special features of this book is the accompanying software. We will describe and illustrate how to use today's premier spreadsheet package, Microsoft Excel, to formulate many management science models in a spreadsheet format. Excel 2007 implemented a significant overhaul of the user interface. Excel 2010 brought other significant changes and improvements. Many of the models considered in this book can be solved using standard Excel. Some Excel add-ins also are available to solve other models. Appendix A provides a primer on the use of Excel.

Included with the book is an extensive collection of software that we collectively refer to as **MS Courseware.** This collection includes spreadsheet files, Frontline Systems' Risk Solver Platform for Education, and a package of Interactive Management Science Modules. Each of these is briefly described below.

MS Courseware includes numerous spreadsheet files for every chapter in this book. Each time a spreadsheet example is presented in the book, a live spreadsheet that shows the formulation and solution for the example also is available in MS Courseware. This provides a convenient reference, or even useful templates, when you set up spreadsheets to solve similar problems. Also, for many models in the book, template spreadsheet files are provided that already include all the equations necessary to solve the model. You simply enter the data for the model and the solution is immediately calculated.

Included with standard Excel is an add-in, called Solver, which is used to solve most of the optimization models considered in the first half of this book. Solver is a product of Frontline Systems, Inc. New with this edition of the textbook is a very powerful software package from Frontline Systems, Inc., called Risk Solver Platform for Education (RSPE). Some special features of RSPE are a significantly enhanced version of the basic Solver included with Excel, the ability to build decision trees within Excel, as covered in Chapter 9, and tools to build computer simulation models within Excel, as covered in Chapter 13.

As mentioned in Section 1.2, another learning aid accompanying the book is the package of Interactive Management Science Modules provided at **www.mhhe.com/hillier5e**. This innovative tool includes several modules that enable you to interactively explore several management science techniques in depth. For your convenience, an offline version of this package also is included in your MS Courseware on the CD-ROM.

Most of the software used in this book is compatible with both Excel for Windows PCs and Excel for Macintosh computers (Macs). Some software (e.g., Risk Solver Platform for Education) is not directly compatible with Macs, although it works well on any recent (Intel) Mac with Boot Camp or virtualization software. For the most up-to-date information on software compatibility and relevant differences between Windows PC versions and Mac versions, please refer to the Software Compatibility link at **www.mhhe.com/hillier5e**.

We should point out that Excel is not designed for dealing with the really large management science models that occasionally arise in practice. More powerful software packages that are not based on spreadsheets generally are used to solve such models instead. However, management science teams, not managers, primarily use these sophisticated packages (including using *modeling languages* to help input the large models). Since this book is aimed mainly at future managers rather than future management scientists, we will not have you use these packages.

To alert you to relevant material in MS Courseware, the end of each chapter has a list entitled "Learning Aids for This Chapter in Your MS Courseware."

1.5 Summary

Management science is a discipline area that attempts to aid managerial decision making by applying a scientific approach to managerial problems that involve quantitative factors. The rapid development of this discipline began in the 1940s and 1950s. The onslaught of the computer revolution has since continued to give great impetus to its growth. Further impetus now is being provided by the widespread use of spreadsheet software, which greatly facilitates the application of management science by managers and others.

A major management science study involves conducting a systematic investigation that includes careful data gathering, developing and testing hypotheses about the problem (typically in the form of a mathematical model), and applying sound logic in the subsequent analysis. The management science team then presents its recommendations to the managers who must make the decisions about how to resolve the problem. Smaller studies might be done by managers themselves with the aid of spreadsheets.

A major part of a typical management science study involves incorporating the quantitative factors into a mathematical model (perhaps incorporated into a spreadsheet) and then applying mathematical procedures to solve the model. Such a model uses *decision variables* to represent the quantifiable decisions to be made. An *objective function* expresses the appropriate measure of performance in terms of these decision variables. The *constraints* of the model express the restrictions on the values that can be assigned to the decision variables. The *parameters* of the model are the constants that appear in the objective function and the constraints. An example involving *break-even analysis* was used to illustrate a mathematical model.

Management science has had an impressive impact on improving the efficiency of numerous organizations around the world. In fact, many award-winning applications have resulted in annual savings in the millions, tens of millions, or even hundreds of millions of dollars.

The focus of this book is on emphasizing what an enlightened future manager needs to learn from a management science course. Therefore, the book revolves around modeling as an aid to managerial decision making. Many case studies (within the chapters) and cases (at the end of chapters) are used to better convey these ideas.

Glossary

break-even point   The production and sales volume for a product that must be exceeded to achieve a profit. (Section 1.2), 9

business analytics   A discipline closely related to management science that makes extensive use of data to analyze trends, make forecasts, and apply optimization techniques. (Section 1.1), 3

constraint   An inequality or equation in a mathematical model that expresses some restrictions on the values that can be assigned to the decision variables. (Section 1.2), 9

decision support system   An interactive computer-based system that aids managerial decision making. (Section 1.1), 5

decision variable   An algebraic variable that represents a quantifiable decision to be made. (Section 1.2), 8

mathematical model   An approximate representation of, for example, a business problem that is expressed in terms of mathematical symbols and expressions. (Section 1.1), 4

model   An approximate representation of something. (Section 1.1), 4

MS Courseware   The name of the software package that is shrinkwrapped with the book or is on its Website. (Section 1.4), 16

objective function   A mathematical expression in a model that gives the measure of performance for a problem in terms of the decision variables. (Section 1.2), 10

operations research   The traditional name for management science that still is widely used outside of business schools. (Section 1.1), 3

parameter   One of the constants in a mathematical model. (Section 1.2), 10

range name   A descriptive name given to a cell or range of cells that immediately identifies what is there. (Section 1.2), 6

spreadsheet model   An approximate representation of, for example, a business problem that is laid out on a spreadsheet in a way that facilitates analysis of the problem. (Section 1.1), 4

what-if analysis   Analysis of how the recommendations of a model might change if any of the estimates providing the numbers in the model eventually need to be corrected. (Section 1.2), 10

Learning Aids for This Chapter in Your MS Courseware

Chapter 1 Excel Files:

Special Products Co. Example

Interactive Management Science Modules:

Module for Break-Even Analysis

Solved Problem (See the CD-ROM or Website for the Solution)

1.S1. Make or Buy?

Power Notebooks, Inc., plans to manufacture a new line of notebook computers. Management is trying to decide whether to purchase the LCD screens for the computers from an outside supplier or to manufacture the screens in-house. The screens cost $100 each from the outside supplier. To set up the assembly process required to produce the screens in-house would cost $100,000. The company could then produce each screen for $75. The number of notebooks that eventually will be produced (Q) is unknown at this point.

a. Set up a spreadsheet that will display the total cost of both options for any value of Q. Use trial and error with the spreadsheet to determine the range of production volumes for which each alternative is best.

b. Use a graphical procedure to determine the break-even point for Q (i.e., the quantity at which both options yield the same cost).

c. Use an algebraic procedure to determine the break-even point for Q.

Problems

1.1.   The manager of a small firm is considering whether to produce a new product that would require leasing some special equipment at a cost of $20,000 per month. In addition to this leasing cost, a production cost of $10 would be incurred for each unit of the product produced. Each unit sold would generate $20 in revenue.

Develop a mathematical expression for the monthly profit that would be generated by this product in terms of the number of units produced and sold per month. Then determine how large this number needs to be each month to make it profitable to produce the product.

1.2.   Refer to Problem 1.1. A sales forecast has been obtained that indicates that 4,000 units of the new product could be sold. This forecast is considered to be quite reliable, but there is considerable uncertainty about the accuracy of the estimates given for the leasing cost, the marginal production cost, and the unit revenue.

Use the Break-Even Analysis module in the Interactive Management Science Modules to perform what-if analysis on these estimates.

a. How large can the leasing cost be before this new product ceases to be profitable?

b. How large can the marginal production cost be before this new product ceases to be profitable?

c. How small can the unit revenue be before this new product ceases to be profitable?

1.3.   Management of the Toys R4U Company needs to decide whether to introduce a certain new novelty toy for the upcoming Christmas season, after which it would be discontinued. The total cost required to produce and market this toy would be $500,000 plus $15 per toy produced. The company would receive revenue of $35 for each toy sold.

a. Assuming that every unit of this toy that is produced is sold, write an expression for the profit in terms of the number produced and sold. Then find the break-even point that this number must exceed to make it worthwhile to introduce this toy.

b. Now assume that the number that can be sold might be less than the number produced. Write an expression for the profit in terms of these two numbers.

c. Formulate a spreadsheet that will give the profit in part *b* for any values of the two numbers.

d. Write a mathematical expression for the constraint that the number produced should not exceed the number that can be sold.

1.4. A reliable sales forecast has been obtained indicating that the Special Products Company (see Section 1.2) would be able to sell 30,000 iWatches, which appears to be enough to justify introducing this new product. However, management is concerned that this conclusion might change if more accurate estimates were available for the research-and-development cost, the marginal production cost, and the unit revenue. Therefore, before a final decision is made, management wants what-if analysis done on these estimates.

Use the spreadsheet from Figure 1.3 (see this chapter's Excel files) and trial-and-error to perform what-if analysis by *independently* investigating each of the following questions.

a. How large can the research-and-development cost be before the watches cease to be profitable?

b. How large can the marginal production cost be before the watches cease to be profitable?

c. How small can the unit revenue be before the watches cease to be profitable?

1.5. Reconsider the problem facing the management of the Special Products Company as presented in Section 1.2.

A more detailed investigation now has provided better estimates of the data for the problem. The research-and-development cost still is estimated to be $10 million, but the new estimate of the marginal production cost is $1,300. The revenue from each watch sold now is estimated to be $1,700.

a. Use a graphical procedure to find the new break-even point.

b. Use an algebraic procedure to find the new break-even point.

c. State the mathematical model for this problem with the new data.

d. Incorporate this mathematical model into a spreadsheet with a sales forecast of 30,000. Use this spreadsheet model to find the new break-even point, and then determine the production quantity and the estimated total profit indicated by the model.

e. Suppose that management fears that the sales forecast may be overly optimistic and so does not want to consider producing more than 20,000 watches. Use the spreadsheet from part *d* to determine what the production quantity should be and the estimated total profit that would result.

1.6. The Best-for-Less Corp. supplies its two retail outlets from its two plants. Plant A will be supplying 30 shipments next month. Plant B has not yet set its production schedule for next month but has the capacity to produce and ship any amount up to a maximum of 50 shipments. Retail outlet 1 has submitted its order for 40 shipments for next month. Retail outlet 2 needs a minimum of 25 shipments next month but would be happy to receive more. The production costs are the same at the two plants but the shipping costs differ. The shipping cost per shipment from each plant to each retail outlet is given below, along with a summary of the other data.

The distribution manager, Jennifer Lopez, now needs to develop a plan for how many shipments to send from each plant to each of the retail outlets next month. Her objective is to minimize the total shipping cost.

| | Unit Shipping Cost | | |
	Retail Outlet 1	Retail Outlet 2	Supply
Plant A	$700	$400	= 30 shipments
Plant B	$800	$600	≤ 50 shipments
Needed = 40 shipments		≥ 25 shipments	

a. Identify the individual decisions that Jennifer needs to make. For each of these decisions, define a decision variable to represent the decision.

b. Write a mathematical expression for the total shipping cost in terms of the decision variables.

c. Write a mathematical expression for each of the constraints on what the values of the decision variables can be.

d. State a complete mathematical model for Jennifer's problem.

e. What do you think Jennifer's shipping plan should be? Explain your reasoning. Then express your shipping plan in terms of the decision variables.

1.7. The Water Sports Company soon will be producing and marketing a new model line of motor boats. The production manager, Michael Jensen, now is facing a *make-or-buy decision* regarding the outboard motor to be installed on each of these boats. Based on the total cost involved, should the motors be produced internally or purchased from a vendor? Producing them internally would require an investment of $1 million in new facilities as well as a production cost of $1,600 for each motor produced. If purchased from a vendor instead, the price would be $2,000 per motor.

Michael has obtained a preliminary forecast from the company's marketing division that 3,000 boats in this model line will be sold.

a. Use spreadsheets to display and analyze Michael's two options. Which option should be chosen?

b. Michael realizes from past experience that preliminary sales forecasts are quite unreliable, so he wants to check on whether his decision might change if a more careful forecast differed significantly from the preliminary forecast. Determine a *break-even point* for the production and sales volume below which the buy option is better and above which the make option is better.

1.8. Reconsider the Special Products Company problem presented in Section 1.2.

Although the company is well qualified to do most of the work in producing the iWatch, it currently lacks much expertise in one key area, namely, developing and producing a miniature camera to be embedded into the iWatch. Therefore, management

now is considering contracting out this part of the job to another company that has this expertise. If this were done, the Special Products Company would reduce its research-and-development cost to $5 million, as well as reduce its marginal production cost to $750. However, the Special Products Company also would pay this other company $500 for each miniature camera and so would incur a total marginal cost of $1,250 (including its payment to the other company) while still obtaining revenue of $2,000 for each watch produced and sold. However, if the company does all the production itself, all the data presented in Section 1.2 still apply. After obtaining an analysis of the sales potential, management believes that 30,000 watches can be sold.

Management now wants to determine whether the *make option* (do all the development and production internally) or the *buy option* (contract out the development and production of the miniature cameras) is better.

> a. Use a spreadsheet to display and analyze the buy option. Show the relevant data and financial output, including the total profit that would be obtained by producing and selling 30,000 watches.
>
> b. Figure 1.3 shows the analysis for the make option. Compare these results with those from part *a* to determine which option (make or buy) appears to be better.
>
> c. Another way to compare these two options is to find a *break-even point* for the production and sales volume, below which the buy option is better and above which the make option is better. Begin this process by developing an expression for the *difference* in profit between the make and buy options in terms of the number of grandfather clocks to produce for sale. Thus, this expression should give the *incremental profit* from choosing the make option rather than the buy option, where this incremental profit is 0 if 0 watches are produced but otherwise

is negative below the break-even point and positive above the break-even point. Using this expression as the objective function, state the overall mathematical model (including constraints) for the problem of determining whether to choose the make option and, if so, how many units of the LCD display (one per watch) to produce.

> d. Use a graphical procedure to find the break-even point described in part *c*.
>
> e. Use an algebraic procedure to find the break-even point described in part *c*.
>
> f. Use a spreadsheet model to find the break-even point described in part *c*. What is the conclusion about what the company should do?

1.9.   Select one of the applications of management science listed in Table 1.1. Read the article that is referenced in the application vignette presented in the section shown in the third column. (A link to all these articles is provided on our Website, **www.mhhe.com/hillier5e**.) Write a two-page summary of the application and the benefits (including nonfinancial benefits) it provided.

1.10.   Select three of the applications of management science listed in Table 1.1. For each one, read the article that is referenced in the application vignette presented in the section shown in the third column. (A link to all these articles is provided on our Website, **www.mhhe.com/hillier5e**.) For each one, write a one-page summary of the application and the benefits (including nonfinancial benefits) it provided.

1.11.   Read the referenced article that fully describes the management science study summarized in the application vignette presented in Section 1.3. Summarize the five major reasons given for why operations research/management science (OR/MS) was so successful.

Case 1-1

Keeping Time

Founded nearly 50 years ago by Alfred Lester-Smith, **Beautiful Clocks** specializes in developing and marketing a diverse line of large ornamental clocks for the finest homes. Tastes have changed over the years, but the company has prospered by continually updating its product line to satisfy its affluent clientele. The Lester-Smith family continues to own a majority share of the company and the grandchildren of Alfred Lester-Smith now hold several of the top managerial positions. One of these grandchildren is Meredith Lester-Smith, the new CEO of the company.

Meredith feels a great responsibility to maintain the family heritage with the company. She realizes that the company needs to continue to develop and market exciting new products. Since the 50th anniversary of the founding of the company is rapidly approaching, she has decided to select a particularly special new product to launch with great fanfare on this anniversary. But what should it be? As she ponders this crucial decision, Meredith's thoughts go back to the magnificent grandfather clock that her grandparents had in their home many years ago. She had

admired the majesty of that clock as a child. How about launching a modern version of this clock?

This is a difficult decision. Meredith realizes that grandfather clocks now are largely out of style. However, if she is so nostalgic about the memory of the grandfather clock in her grandparents' home, wouldn't there be a considerable number of other relatively wealthy couples with similar memories who would welcome the prestige of adding the grandeur of a beautifully designed limited-edition grandfather clock in their home? Maybe. This also would highlight the heritage and continuity of the company. It all depends on whether there would be enough sales potential to make this a profitable product.

Meredith had an excellent management science course as part of her MBA program in college, so she realizes that break-even analysis is needed to help make this decision. With this in mind, she instructs several staff members to investigate this prospective product further, including developing estimates of the related costs and revenues as well as forecasting the potential sales.

One month later, the preliminary estimates of the relevant financial figures come back. The cost of designing the grandfather clock and then setting up the production facilities to produce this product would be approximately $250,000. There would be only one production run for this limited-edition grandfather clock. The additional cost for each clock produced would be roughly $2,000. The marketing department estimates that their price for selling the clocks can be successfully set at about $4,500 apiece, but a firm forecast of how many clocks can be sold at this price has not yet been obtained. However, it is believed that the sales likely would reach into three digits.

Meredith wants all these numbers pinned down considerably further. However, she feels that some analysis can be done now to draw preliminary conclusions.

a. Assuming that all clocks produced are sold, develop a spreadsheet model for estimating the profit or loss from producing any particular number of clocks.

b. Use this spreadsheet to find the break-even point by trial and error.

c. Develop the corresponding mathematical expression for the estimated profit in terms of the number of clocks produced.

d. Use a graphical procedure to find the break-even point.

e. Use the algebraic procedure to find the break-even point.

A fairly reliable forecast now has been obtained indicating that the company would be able to sell 300 of the limited-edition grandfather clocks, which appears to be enough to justify introducing this new product. However, Meredith is concerned that this conclusion might change if more accurate estimates were available for the various costs and revenues. Therefore, she wants sensitivity analysis done on these estimates. Use the Break-Even Analysis module in the Interactive Management Science Modules to perform sensitivity analysis by *independently* investigating each of the following questions.

f. How large can the cost of designing this product and setting up the production facilities be before the grandfather clocks cease to be profitable?

g. How large can the production cost for each additional clock be before the grandfather clocks cease to be profitable?

h. If both of the costs identified in parts *f* and *g* were 50% larger than their initial estimates, would producing and selling the grandfather clocks still be profitable?

i. How small can the price for selling each clock be before the grandfather clocks cease to be profitable?

Now suppose that 300 grandfather clocks are produced but only 200 are sold.

j. Would it still be profitable to produce and sell the grandfather clocks under this circumstance?

Additional Case

An additional case for this chapter is also available at the University of Western Ontario Ivey School of Business Website, **cases.ivey.uwo.ca/cases**, in the segment of the CaseMate area designated for this book.