Practical Management Science

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5TH EDITION

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Practical Management Science, Fifth Edition

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To Mary, my wonderful wife, best friend, and constant companion

And to our Welsh Corgi, Bryn, who still just wants to play ball   S.C.A.

To my wonderful family

Vivian, Jennifer, and Gregory   W.L.W.

About the Authors

S. Christian Albright got his B.S. degree in Mathematics from Stanford in 1968 and his Ph.D. degree in Operations Research from Stanford in 1972. Until his retirement in 2011, he taught in the Operations & Decision Technologies Department in the Kelley School of Business at Indiana University. His teaching included courses in management science, computer simulation, and statistics to all levels of business students: undergraduates, MBAs, and doctoral students. He has published over 20 articles in leading operations research journals in the area of applied probability, and he has authored several books, including *Practical Management Science, Data Analysis and Decision Making, Data Analysis for Managers, Spreadsheet Modeling and Applications,* and *VBA for Modelers.* He jointly developed *StatTools,* a statistical add-in for Excel, with the Palisade Corporation. In "retirement," he continues to revise his books, he works as a consultant for Palisade, and he has developed a commercial product, ExcelNow!, an extension of the Excel tutorial that accompanies this book.

On the personal side, Chris has been married to his wonderful wife Mary for 43 years. They have a special family in Philadelphia: their son Sam, his wife Lindsay, and their two sons, Teddy and Archer. Chris has many interests outside the academic area. They include activities with his family (especially traveling with Mary), going to cultural events at Indiana University, power walking, and reading. And although he earns his livelihood from statistics and management science, his *real* passion is for playing classical music on the piano.

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Wayne enjoys swimming and basketball, and his passion for trivia won him an appearance several years ago on the television game show *Jeopardy,* where he won two games. He is married to the lovely and talented Vivian. They have two children, Gregory and Jennifer.

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Preface

Practical Management Science provides a spreadsheet-based, example-driven approach to management science. Our initial objective in writing the book was to reverse negative attitudes about the course by making the subject relevant to students. We intended to do this by imparting valuable modeling skills that students can appreciate and take with them into their careers. We are very gratified by the success of the first four editions. The book has exceeded our initial objectives. We are especially pleased to hear about the success of the book at many other colleges and universities around the world. The acceptance and excitement that has been generated has motivated us to revise the book and make the fifth edition even better.

When we wrote the first edition, management science courses were regarded as irrelevant or uninteresting to many business students, and the use of spreadsheets in management science was in its early stages of development. Much has changed since the first edition was published in 1996, and we believe that these changes are for the better. We have learned a lot about the best practices of spreadsheet modeling for clarity and communication. We have also developed better ways of teaching the materials, and we understand more about where students tend to have difficulty with the concepts. Finally, we have had the opportunity to teach this material at several Fortune 500 companies (including Eli Lilly, Price Waterhouse Coopers, General Motors, Tomkins, Microsoft, and Intel). These companies, through their enthusiastic support, have further enhanced the realism of the examples included in this book.

Our objective in writing the first edition was very simple—we wanted to make management science relevant and practical to students and professionals. This book continues to distinguish itself in the market in four fundamental ways:

- **Teach by Example.** The best way to learn modeling concepts is by working through examples and solving an abundance of problems. This active learning approach is not new, but our text has more fully developed this approach than any book in the field. The feedback we have received from many of you has confirmed the success of this pedagogical approach for management science.
- **Integrate Modeling with Finance, Marketing, and Operations Management.** We integrate modeling into all functional areas of business. This is an important feature because the majority of business students major in finance and marketing. Almost all competing textbooks emphasize operations management–related examples. Although these examples are important, and many are included in the book, the application of modeling to problems in finance and marketing is too important to ignore. Throughout the book, we use real examples from all functional areas of business to illustrate the power of spreadsheet modeling to all of these areas. At Indiana University, this has led to the development of two advanced MBA electives in finance and marketing that build upon the content in this book. The inside front cover of the book illustrates the integrative applications contained in the book.
- **Teach Modeling, Not Just Models.** Poor attitudes among students in past management science courses can be attributed to the way in which they were taught: emphasis on algebraic formulations and memorization of models. Students gain more insight into the power of management science by developing skills in modeling. Throughout the book, we stress the logic associated with model development, and we discuss solutions in this context. Because real problems and real models often include limitations or alternatives, we include many "Modeling Issues" sections to discuss these important matters. Finally, we include "Modeling Problems" in most chapters to help develop these skills.
- **Provide Numerous Problems and Cases.** Whereas all textbooks contain problem sets for students to practice, we have carefully and judiciously crafted the problems and cases contained in this book. Each chapter contains four types of problems: Level A Problems, Level B Problems, Modeling Problems, and Cases. Most of the problems following sections of chapters ask students to extend the examples in the preceding section. The end-of-chapter problems then ask students to explore new

models. Selected solutions are available to students who purchase the Student Solution Files online and are denoted by the second-color numbering of the problem. Solutions for all of the problems and cases are provided to adopting instructors. In addition, shell files (templates) are available for most of the problems for adopting instructors. The shell files contain the basic structure of the problem with the relevant formulas omitted. By adding or omitting hints in individual solutions, instructors can tailor these shell files to best meet the individual/specific needs of their students.

New to the Fifth Edition

The main reason for the fifth edition was the introduction of Excel 2013. Admittedly, this is not really a game changer, but it does provide new features that ought to be addressed. In addition, once we were motivated by Excel 2013 to revise the book, we saw the possibility for many other changes that will hopefully improve the book. Important changes to the fifth edition include the following:

- The book is now entirely geared to Excel 2013. In particular, all screenshots are from this newest version of Excel. However, the changes are not dramatic, and users of Excel 2010 and even Excel 2007 should have no trouble following. Also, the latest changes in the accompanying @RISK, PrecisionTree, and StatTools add-ins have been incorporated into the text.
- In the optimization and simulation chapters, it has always been difficult for many students to go from a verbal description of a problem to an eventual spreadsheet model. In this edition, we include "big picture" diagrams of the model that will hopefully act as a bridge from the verbal description to the spreadsheet model. These diagrams have been created from the latest add-in in the Palisade DecisionTools Suite, the BigPicture add-in. Users of the book have access to BigPicture, just like @RISK and the other Palisade add-ins.(At production time, the BigPicture add-in had not yet been released to the public. But it will be available to users as soon as it is released.)
- In addition to the "big picture" diagrams, many videos have been developed to explain important concepts and examples. These are available to all users.
- Chapter 9, Decision Making under Uncertainty, has been rewritten completely. Now, a single "new product decisions" example is developed and extended throughout the chapter to promote continuity.
- Several out-of-date cases have been removed, and they have been replaced by new cases. Specifically, the two (new) cases in Chapter 2 extend over several chapters.
- Chapter 16, Multiobjective Decision Making, is located online only. It has been rewritten to be more conceptual. In particular, the section on AHP no longer contains the step-by-step spreadsheet details. (We believe these details distract from an understanding of the basic procedure.)
- To help students learn, we created tutorial videos that explain concepts and work through examples. Students can access the videos for free on the textbook companion Web site. A complete list of videos is available on the Web site and video icons appear in the margins of the textbook next to relevant topics.

Student Web Site

For all purchasing options, please go to CengageBrain.com or contact your local Learning Consultant. These include the student problem files, example files, case files, the Excel tutorial, SolverTable, Chapter 15, Chapter 16, and the new tutorial videos. The link to Palisade's software can also be found on this Web site.

Software

We continue to be very excited about offering the most comprehensive suite of software ever available with a management science textbook. The commercial value of the software available with this text exceeds $1,000 if purchased directly. This software is available free with *new* copies of the fifth edition. The following Palisade software is available from www.cengagebrain.com.

- Palisade's **DecisionTools™ Suite,** including the award-winning **@RISK, PrecisionTree, StatTools, TopRank, NeuralTools, Evolver**, and **BigPicture.** This software is not available with any competing textbook and comes in an educational version that is only slightly scaled down from the expensive commercial version. (StatTools replaces Albright's StatPro add-in that came with the second edition. If you are interested, StatPro is still freely available from http://www.kelley.iu.edu/albrightbooks.) For more information about the Palisade Corporation and the DecisionTools Suite, visit Palisade's Web site at http://www.palisade.com.

- To make sensitivity analysis for optimization models useful and intuitive, we continue to provide Albright's **SolverTable** add-in (which is also freely available from http://www.kelley.iu.edu/albrightbooks). SolverTable provides data table–like sensitivity output for optimization models that is easy to interpret.

Example Files, Data Sets, Problem Files, and Cases

Also on the student Web site are the Excel files for all of the examples in the book, as well as many data files required for problems and cases. As in previous editions, there are two versions of the example files: a completed version and a template to get students started. Because this book is so example- and problem-oriented, these files are absolutely essential. There are also a few extra example files, in Extra Examples folders, that are available to instructors and students. These extras extend the book examples in various ways.

Ancillaries

Instructor Materials

Adopting instructors can obtain all resources online. Please go to http://login.cengage.com to access the following resources:

- **PMS5e Problem Database.xlsx** file, which contains information about all problems in the book and the correspondence between them and those in the previous edition
- Solution files (in Excel format) for all of the problems and cases in the book and solution shells (templates) for selected problems
- PowerPoint® presentation files
- Test Bank in Word format and now also in the online testing service, Cognero

Albright also maintains his own Web site at http://www.kelley.iu.edu/albrightbooks. Among other things, the instructor Web site includes errata for each edition.

Student Solutions

Student Solutions for many of the problems (indicated in the text with a colored box on the problem number) are available in Excel format. Students can purchase an instant access code online at www.cengagebrain.com to access the files. In the search window of this Web site, type in the ISBN for the Instant Access Code (9781305250925) and press Enter. Students can then purchase access to the files as a study tool.

Companion VBA Book

Soon after the first edition appeared, we began using Visual Basic for Applications (VBA), the programming language for Excel, in some of our management science courses. VBA allows you to develop decision support systems around the spreadsheet models. (An example appears at the end of Chapter 3.) This use of VBA has been popular with our students, and many instructors have expressed interest in learning how to do it. For additional support on this topic, a companion book, *VBA for Modelers, 4e* (ISBN 9781133190875) is available. It assumes no prior experience in computer programming, but it progresses rather quickly to the development of interesting and nontrivial applications. The fifth edition of *Practical Management Science* depends in no way on this companion VBA book, but we encourage instructors to incorporate some VBA into their management science courses. This is not only fun, but students quickly learn to appreciate its power. If you are interested in adopting *VBA for Modelers,* contact your local Cengage Learning representative.

Acknowledgments

This book has gone through several stages of reviews, and it is a much better product because of them. The majority of the reviewers' suggestions were very good ones, and we have attempted to incorporate them. We would like to extend our appreciation to:

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is a consummate professional. He was both patient and thorough, and his experience in the publishing business ensured that the tradition Curt started was carried on. Third, after Charles's retirement, we were fortunate to be assigned to one more great editor, Aaron Arnsparger, for the current edition. We hope to continue working with Aaron far into the future.

We would also enjoy hearing from you—we can be reached by e-mail. And please visit either of the following Web sites for more information and occasional updates:

- http://www.kelley.iu.edu/albrightbooks
- www.cengagebrain.com

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Practical Management Science

CHAPTER

1

Introduction to Modeling

BUSINESS ANALYTICS PROVIDES INSIGHTS AND IMPROVES PERFORMANCE

This book is all about using quantitative modeling to help companies make better decisions and improve performance. We have been teaching management science for decades, and companies have been using the management science methods discussed in this book for decades to improve performance and save millions of dollars. Indeed, the applied journal *Interfaces*, discussed later in this chapter, has chronicled management science success stories for years. Therefore, we were a bit surprised when a brand new term, Business Analytics (BA), became hugely popular several years ago. All of a sudden, BA promised to be the road to success. By using quantitative BA methods—data analysis, optimization, simulation, prediction, and others—companies could drastically improve business performance. Haven't those of us in management science been doing this for years? What is different about BA that has made it so popular, both in the academic world and even more so in the business world?

The truth is that BA *does* use the same quantitative methods that have been the hallmark of management science for years, the same methods you will learn in this book. BA has not all of a sudden invented brand new quantitative methods to eclipse traditional management science methods. The main difference is that BA uses *big data* to solve business problems and provide insights. Companies now have access to huge sources of data, and the technology is now available to use huge data sets for statistical and quantitative analysis, predictive modeling, optimization, and simulation. In short, the same quantitative methods that have been available for years can now be even more effective by utilizing big data and the corresponding technology.

For a quick introduction to BA, you should visit the BA Wikipedia site (search the Web for "business analytics"). Among other things, it lists areas where BA plays a prominent role, including the following: retail sales analytics; financial services analytics; risk and credit analytics; marketing analytics; pricing analytics; supply chain analytics; and transportation analytics. If you glance through the examples and problems in this book, you will see that most of them come from these same areas. Again, the difference is that we use relatively small data sets to get you started—we do not want to overwhelm you with gigabytes of data—whereas real applications of BA use huge data sets to advantage.

A more extensive discussion of BA can be found in the Fall 2011 research report, *Analytics: The Widening Divide*, published in the MIT Sloan Management Review in collaboration with IBM, a key developer of BA software (search the Web for the article's title). This 22-page article discusses what BA is and provides several case studies. In addition, it lists three key competencies people need to compete successfully in the BA world—and hopefully you will be one of these people.

- **Competency 1: Information management skills to manage the data.** This competency involves expertise in a variety of techniques for managing data. Given the key role of data in BA methods, data quality is extremely important. With data coming from a number of disparate sources, both internal and external to an organization, achieving data quality is no small feat.
- **Competency 2: Analytics skills and tools to understand the data.** We were not surprised, but rather very happy, to see this competency listed among the requirements because these skills are exactly the skills we cover throughout this book—optimization with advanced quantitative algorithms, simulation, and others.
- **Competency 3: Data-oriented culture to act on the data.** This refers to the culture within the organization. Everyone involved, especially top management, must believe strongly in fact-based decisions arrived at using analytical methods.

The article argues persuasively that the companies that have these competencies and have embraced BA have a distinct competitive advantage over companies that are just starting to use BA methods or are not using them at all. This explains the title of the article. The gap between companies that embrace BA and those that do not will only widen in the future.

One final note about the relationship between BA and management science is that, at the time this book was being revised (Winter 2014), a special issue of the journal *Management Science* was about to be published. The entire focus of this special issue is on BA. The following is an excerpt from the Call for Papers for this issue (search the Web for "management science business analytics special issue").

"We envision business analytics applied to many domains, including, but surely not limited to: digital market design and operation; network and social-graph analysis; pricing and revenue management; targeted marketing and customer relationship management; fraud and security; sports and entertainment; retailing to healthcare to financial services to many other industries. We seek novel modeling and empirical work which includes, among others, probability modeling, structural empirical models, and/or optimization methods."

This is even more confirmation of the tight relationship between BA and management science. As you study this book, you will see examples of most of the topics listed in this quote. ■

1.1 INTRODUCTION

The purpose of this book is to expose you to a variety of problems that have been solved successfully with management science methods and to give you experience in modeling these problems in the Excel spreadsheet package. The subject of management science has evolved for more than 60 years and is now a mature field within the broad category of applied mathematics. This book emphasizes both the applied and mathematical aspects of management science. Beginning in this chapter and continuing throughout the rest of the book, we discuss many successful management science applications, where teams of highly trained people have implemented solutions to the problems faced by major companies and have saved these companies millions of dollars. Many airlines, banks, and oil companies, for example, could hardly operate as they do today without the support of management science. In this book, we will lead you through the solution procedure for many interesting and realistic problems, and you will experience firsthand what is required to solve these problems successfully. Because we recognize that most of you are not highly trained in mathematics, we use Excel spreadsheets to solve problems, which makes the quantitative analysis much more understandable and intuitive.

The key to virtually every management science application is a *mathematical model*. In simple terms, a **mathematical model** is a quantitative representation, or idealization, of a real problem. This representation might be phrased in terms of mathematical expressions (equations and inequalities) or as a series of related cells in a spreadsheet. We prefer the latter, especially for teaching purposes, and we concentrate primarily on spreadsheet models in this book. However, in either case, the purpose of a mathematical model is to represent the essence of a problem in a concise form. This has several advantages. First, it enables managers to understand the problem better. In particular, the model helps to define the scope of the problem, the possible solutions, and the data requirements. Second, it allows analysts to use a variety of the mathematical solution procedures that have been developed over the past half century. These solution procedures are often computer-intensive, but with today's cheap and abundant computing power, they are usually feasible. Finally, the modeling process itself, if done correctly, often helps to "sell" the solution to the people who must work with the system that is eventually implemented.

In this introductory chapter, we begin by discussing a relatively simple example of a mathematical model. Then we discuss the distinction between modeling and a collection of models. Next, we discuss a seven-step modeling process that can be used, in essence if not in strict conformance, in most successful management science applications. Finally, we discuss why the study of management science is valuable, not only to large corporations, but also to students like you who are about to enter the business world.

1.2 A CAPITAL BUDGETING EXAMPLE

As indicated earlier, a mathematical model is a set of mathematical relationships that represent, or approximate, a real situation. Models that simply describe a situation are called **descriptive models.** Other models that suggest a desirable course of action are called **optimization models.** To get started, consider the following simple example of a mathematical model. It begins as a descriptive model, but it then becomes an optimization model.

A Descriptive Model

A company faces capital budgeting decisions. (This model is discussed in detail in Chapter 6.). There are seven potential investments. Each has an investment cost and a corresponding stream of cash flows (including the investment cost) summarized by a net

Figure 1.1
Costs and NPVs for Capital Budgeting Model

	A	B	C	D	E	F	G	H
1	**Capital budgeting model**							
2								
3	**Input data on potential investments ($ millions)**							
4	Investment	1	2	3	4	5	6	7
5	Cost	$5.0	$2.4	$3.5	$5.9	$6.9	$4.5	$3.0
6	NPV	$5.6	$2.7	$3.9	$6.8	$7.7	$5.1	$3.3
7	ROI	12.0%	12.5%	11.4%	15.3%	11.6%	13.3%	10.0%

present value (NPV). These are listed in Figure 1.1. Row 7 also lists the return on investment (ROI) for each investment, the ratio of NPV to cost, minus 1.

The company must decide which of these seven investments to make. There are two constraints that affect the decisions. First, each investment is an all-or-nothing decision. The company either invests entirely in an investment, or it ignores the investment completely. It is not possible to go part way, incurring a fraction of the cost and receiving a fraction of the revenues. Second, the company is limited by a budget of $15 million. The total cost of the investments it chooses cannot exceed this budget. With these constraints in mind, the company wants to choose the investments that maximize the total NPV.

A descriptive model can take at least two forms. One form is to show all of the elements of the problem in a diagram, as in Figure 1.2. This method, which will be used extensively in later chapters, helps the company to visualize the problem and to better understand how the elements of the problem are related. Our conventions are to use red ovals for decisions, blue rectangles for given inputs, yellow rounded rectangles for calculations, and gray-bordered rectangles for objectives to optimize. (These colors are visible when you open the files in Excel.)

Although the diagram in Figure 1.2 helps the company visualize the problem, it does not provide any numeric information. This can be accomplished with the second descriptive form of the model in Figure 1.3. *Any* set of potential decisions, 0/1 values, can be entered in row 10 to indicate which of the investments are undertaken. Then simple Excel formulas that relate the decisions to the inputs in rows 5 and 6 can be used to calculate the total investment cost and the total NPV in cells B14 and B17. For example, the formula in cell B14 is

=SUMPRODUCT(B5:H5,B10:H10)

(If you don't already know Excel's SUMPRODUCT function, you will learn it in the next chapter and then use it extensively in later chapters.) The company can use this model to investigate various decisions. For example, the current set of decisions looks good in terms of total NPV, but it is well over budget. By trying other sets of 0/1 values in row 10, the company can play "what-if" to attempt to find a good set of decisions that stays within budget.

Because there are two possible values for each cell in row 10, 0 or 1, there are $2^7 = 128$ possible sets of decisions, some of which will be within the budget and some of which will be over the budget. This is not a *huge* number, so the company could potentially try each of these to find the optimal investment strategy. However, you can probably see that

Figure 1.2
Relationships among Elements of the Model

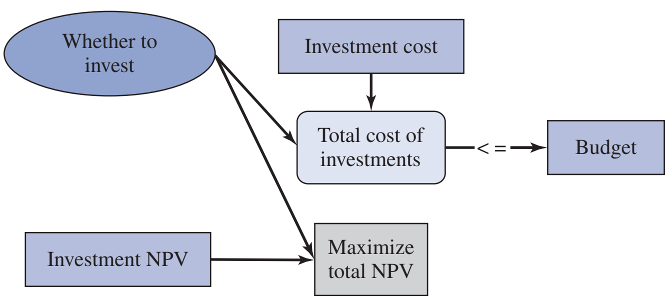


Figure 1.3
Descriptive Model for What-If Analysis

	A	B	C	D	E	F	G	H
1	**Capital budgeting model**							
2								
3	**Input data on potential investments ($ millions)**							
4	Investment	1	2	3	4	5	6	7
5	Cost	$5.0	$2.4	$3.5	$5.9	$6.9	$4.5	$3.0
6	NPV	$5.6	$2.7	$3.9	$6.8	$7.7	$5.1	$3.3
7	ROI	12.0%	12.5%	11.4%	15.3%	11.6%	13.3%	10.0%
8								
9	**Decisions: whether to invest**							
10	1 if yes, 0 if no	0	1	1	0	1	1	0
11								
12	**Budget constraint**							
13		Total cost		Budget				
14		$17.3		$15				
15								
16	**Objective to maximize**							
17	Total NPV	$19.4						

this "exhaustive search" strategy can easily become overwhelming. For example, if there were 14 potential investments, the number of possible sets of decisions would increase to $2^{14} = 16{,}384$. The company would certainly not want to search through all of these, which is why the optimization model discussed next is so useful.

An Optimization Model

The company's dream at this point is to have software that can quickly search through all potential sets of decisions and find the one that maximizes total NPV while staying within the budget. Fortunately, this software exists, and you own it! It is called Solver, an add-in to Excel, and it is discussed in detail in Chapters 3 to 8. All the company needs to do, after creating the descriptive model in Figure 1.3, is to invoke Solver. This opens a dialog box (not shown here) where the company can specify the objective cell, the range of decision variable cells, and any constraints. Then Solver finds the optimal solution, usually in a matter of seconds.

The optimal solution for this particular model appears in Figure 1.4. The company should undertake investments 3, 5, and 6, and it should ignore the others. Although not

Figure 1.4
Optimal Solution

	A	B	C	D	E	F	G	H
1	**Capital budgeting model**							
2								
3	**Input data on potential investments ($ millions)**							
4	Investment	1	2	3	4	5	6	7
5	Cost	$5.0	$2.4	$3.5	$5.9	$6.9	$4.5	$3.0
6	NPV	$5.6	$2.7	$3.9	$6.8	$7.7	$5.1	$3.3
7	ROI	12.0%	12.5%	11.4%	15.3%	11.6%	13.3%	10.0%
8								
9	**Decisions: whether to invest**							
10	1 if yes, 0 if no	0	0	1	0	1	1	0
11								
12	**Budget constraint**							
13		Total cost		Budget				
14		$14.9		$15				
15								
16	**Objective to maximize**							
17	Total NPV	$16.7						

quite all of the budget is used, the company is guaranteed that no other set of decisions can obtain a higher total NPV while staying within the budget.

Optimal solutions are sometimes surprising. You might have expected the company to choose the investments with the largest ROIs, at least until the budget runs out. However, this is not what the optimal solution prescribes. For example, investment 4 has the largest ROI, but it is not chosen, and investment 5, which *is* chosen, has a lower ROI than three of the investments that are not chosen. As this example illustrates, an optimization model often provides insights that your intuition alone does not provide.

Incorporating Uncertainty

Most of the optimization models in this book are *deterministic*, meaning that there is no uncertainty about any of the model inputs. Specifically, the NPVs in row 6 of the capital budgeting model are assumed to be known when the company makes its investment decisions. This is clearly a strong assumption; uncertainties about future revenues almost surely exist. This uncertainty can be built into the model by replacing fixed input values by probability distributions. This takes us into the realm of *simulation* models, which are discussed in detail in Chapters 10 and 11. Simulation lets the company see how an output such as total NPV varies, for any given set of decisions, as uncertain inputs vary over their ranges of possible values. Fortunately, another Excel add-in called @RISK for performing simulations is available with this book, and it is used extensively in Chapters 10 and 11. @RISK even has a tool called RISKOptimizer that can be used to find the optimal set of decisions in the face of uncertainty. We discuss RISKOptimizer only briefly, but it is very powerful software.

1.3 MODELING VERSUS MODELS

Management science, at least as it has been taught in many traditional courses, has evolved as a collection of mathematical models. These include various linear programming models (the transportation model, the product mix model, the shortest route model, and others), inventory models, queueing models, and more. Much time has been devoted to teaching the intricacies of these particular models. Management science *practitioners,* however, have justifiably criticized this emphasis on specific models. They argue that the majority of real-world management science problems cannot be neatly categorized as one of the handful of models typically included in a management science textbook. That is, often no "off-the-shelf" model can be used, at least not without modification, to solve a company's real problem. Unfortunately, management science students might get the impression that all problems must be "shoe-horned" into one of the textbook models.

The good news is that this emphasis on specific models has been changing in the past decade or two, and our goal in this book is to embrace this change. Specifically, this book stresses *modeling,* not models. The distinction between modeling and models will become clear as you proceed through the book. Learning specific models is essentially a memorization process—memorizing the details of a particular model, such as the transportation model, and possibly learning how to "trick" other problems into looking like a transportation model. Modeling, on the other hand, is a *process* in which you abstract the essence of a real problem into a model, spreadsheet or otherwise. Although many problems fall naturally into several categories, successful modelers do not try to shoe-horn each problem into one of a small number of well-studied models. Instead, they treat each problem on its own merits and model it appropriately, using all of the logical, analytical, and spreadsheet skills they have at their disposal—and, of course, using their experience with previous models they have developed. This way, if they come across a problem that does not look exactly like anything they have ever seen, they still have the skills and flexibility to model it successfully.

This doesn't mean you won't learn some "classical" models from management science in this book; in fact, we will discuss the transportation model in linear programming, the *M/M/*1 model in queueing, the EOQ model in inventory, and other classics. These are important models that should not be ignored; however, you certainly do not have to memorize these specific models. They are simply a few of the many models you will learn how to develop. The real emphasis throughout is on the modeling *process*—how a real-world problem is abstracted into a spreadsheet model of that problem. We discuss this modeling process in more detail in the following section.

1.4 A SEVEN-STEP MODELING PROCESS

The discussion of the capital budgeting model in section 1.2 presented some of the basic principles of management science modeling. This section further expands on these ideas by characterizing modeling as the following seven-step process.

Step 1: Problem Definition

The analyst first defines the organization's problem. Defining the problem includes specifying the organization's objectives and the parts of the organization that must be studied before the problem can be solved. In the capital budgeting example, the organization's problem is to choose the best set of investments, given a spending budget.

Step 2: Data Collection

After defining the problem, the analyst collects data to estimate the value of parameters that affect the organization's problem. These estimates are used to develop a mathematical model (step 3) of the organization's problem and predict solutions (step 4). In the capital budgeting example, the company's financial analysts must determine the stream of cash flows from the various investments. As discussed in the Business Analytics opener to this chapter, data are becoming more important than ever to the decision-making process, both because of the huge amounts of data available and because of the powerful technology available to take advantage of it.

Step 3: Model Development

In the third step, the analyst develops a model of the problem. In this book, we present a variety of examples to show how this can be done.[1] Some of these are deterministic optimization models, where all of the problem inputs are assumed to be known and the goal is to determine values of decision variables that maximize or minimize an objective. Others are simulation models, where some of the inputs are modeled with probability distributions. Occasionally, the models are so complex mathematically that no simple formulas can be used to relate inputs to outputs. Prime examples of this are the analytic

[1]All of these models can generically be called **mathematical models.** However, because we implement them in spreadsheets, we generally refer to them as **spreadsheet models.**

queuing models in Chapter 13. Nevertheless, such models can still be analyzed by appealing to extensive academic research and possibly implementing complex formulas with Excel macros.

Step 4: Model Verification

The analyst now tries to determine whether the model developed in the previous step is an accurate representation of reality. At the very least, the model must pass "plausibility checks." In this case, various input values and decision variable values are entered into the model to see whether the resulting outputs are plausible.

Step 5: Optimization and Decision Making

Given a model and a set of possible decisions, the analyst must now choose the decision or strategy that best meets the organization's objectives. We briefly discussed an optimization model for the capital budgeting example, and we will discuss many other optimization models throughout the book.

Step 6: Model Communication to Management

The analyst presents the model and the recommendations from the previous steps to the organization. In some situations, the analyst might present several alternatives and let the organization choose the best one.

Step 7: Model Implementation

If the organization has accepted the validity and usefulness of the model, the analyst then helps to implement its recommendations. The implemented system must be monitored constantly (and updated dynamically as the environment changes) to ensure that the model enables the organization to meet its objectives.

Flowchart of Procedure and Discussion of Steps

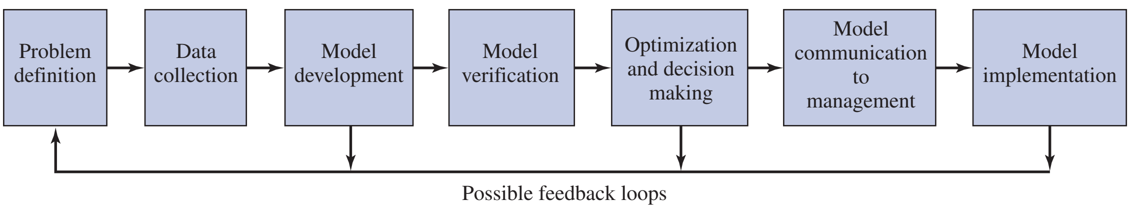
Figure 1.5 illustrates this seven-step process. As the arrows pointing down and to the left indicate, there is certainly room for feedback in the process. For example, at various steps, the analyst might realize that the current model is not capturing some key aspects of the real problem. In this case, the problem definition can be changed or a new model can be developed.

The following discussion explores these seven steps in more detail.

Step 1: Problem Definition

Typically, a management science model is initiated when an organization believes it has a problem. Perhaps the company is losing money, perhaps its market share is declining,

Figure 1.5 Flowchart for the Seven-Step Process



perhaps its customers are waiting too long for service—any number of problems might be evident. The organization (which we refer to as the client) calls in a management scientist (the analyst) to help solve this problem.[2] In such cases, the problem has probably already been defined by the client, and the client hires the analyst to solve *this particular problem*.

As Miser (1993) and Volkema (1995) point out, however, the analyst should do some investigating before accepting the client's claim that the problem has been properly defined. Failure to do so could mean solving the wrong problem and wasting valuable time, money, and energy.

It is important to solve the correct problem, and defining that problem is not always easy.

For example, Miser cites the experience of an analyst who was hired by the military to investigate overly long turnaround times between fighter planes landing and taking off again to rejoin the battle. The military (the client) was convinced that the problem was caused by inefficient ground crews—if they worked faster, turnaround times would certainly decrease. The analyst nearly accepted this statement of the problem and was about to do classical time-and-motion studies on the ground crew to pinpoint the sources of their inefficiency. However, by investigating further, he found that the problem lay elsewhere. Specifically, he learned that the trucks that refueled the planes were frequently late, which in turn was due to the inefficient way they were refilled from storage tanks at another location. After this latter problem was solved—and its solution was embarrassingly simple—the turnaround times decreased to an acceptable level without any changes on the part of the ground crews. If the analyst had accepted the client's statement of the problem, the *real* problem would never have been located or solved.

The moral of this story is clear: If an analyst defines a problem incorrectly or too narrowly, the solution to the real problem might never emerge. In his article, Volkema (1995) advocates spending as much time thinking about the problem and defining it properly as modeling and solving it. This is undoubtedly good advice, especially in real-world applications where problem boundaries are often difficult to define.

Step 2: Data Collection

The data collection step often takes the most time.

This crucial step in the modeling process is often the most tedious. All organizations keep track of various data on their operations, but the data are often not in the form the analyst requires. In addition, data are often stored in different places throughout the organization and in different formats. Therefore, one of the analyst's first jobs is to gather exactly the right data and put the data into an appropriate and consistent format for use in the model. This typically requires asking questions of key people (such as the cost accountants) throughout the organization, studying existing organizational databases, and performing time-consuming observational studies of the organization's processes. In short, it typically entails a lot of legwork.

In this book, as in most management science textbooks, we shield you from this data-collection process by supplying the appropriate data to develop and solve a model. Although this makes the overall modeling process seem easier than it really is, it is impractical in most class settings to have you go to companies and gather data. (In many cases, it would not even be allowed for proprietary reasons.) Nevertheless, we provide some insights with "Where Do the Numbers Come From?" sections. If nothing else, these sections remind you that in real applications, someone has to gather the necessary data.

Step 3: Model Development

Steps 3 and 5, developing and optimizing models, are the steps emphasized most heavily in this book.

This step, along with step 5, is where the analyst brings his or her quantitative skills into play. After defining the client's problem and gathering the necessary data, the analyst must develop a model of the problem. Several properties are desirable for a good model. First,

[2]Most organizations hire outside consultants, sometimes academics, to help solve problems. However, a number of large organizations employ a staff of management scientists who function as inside consultants.