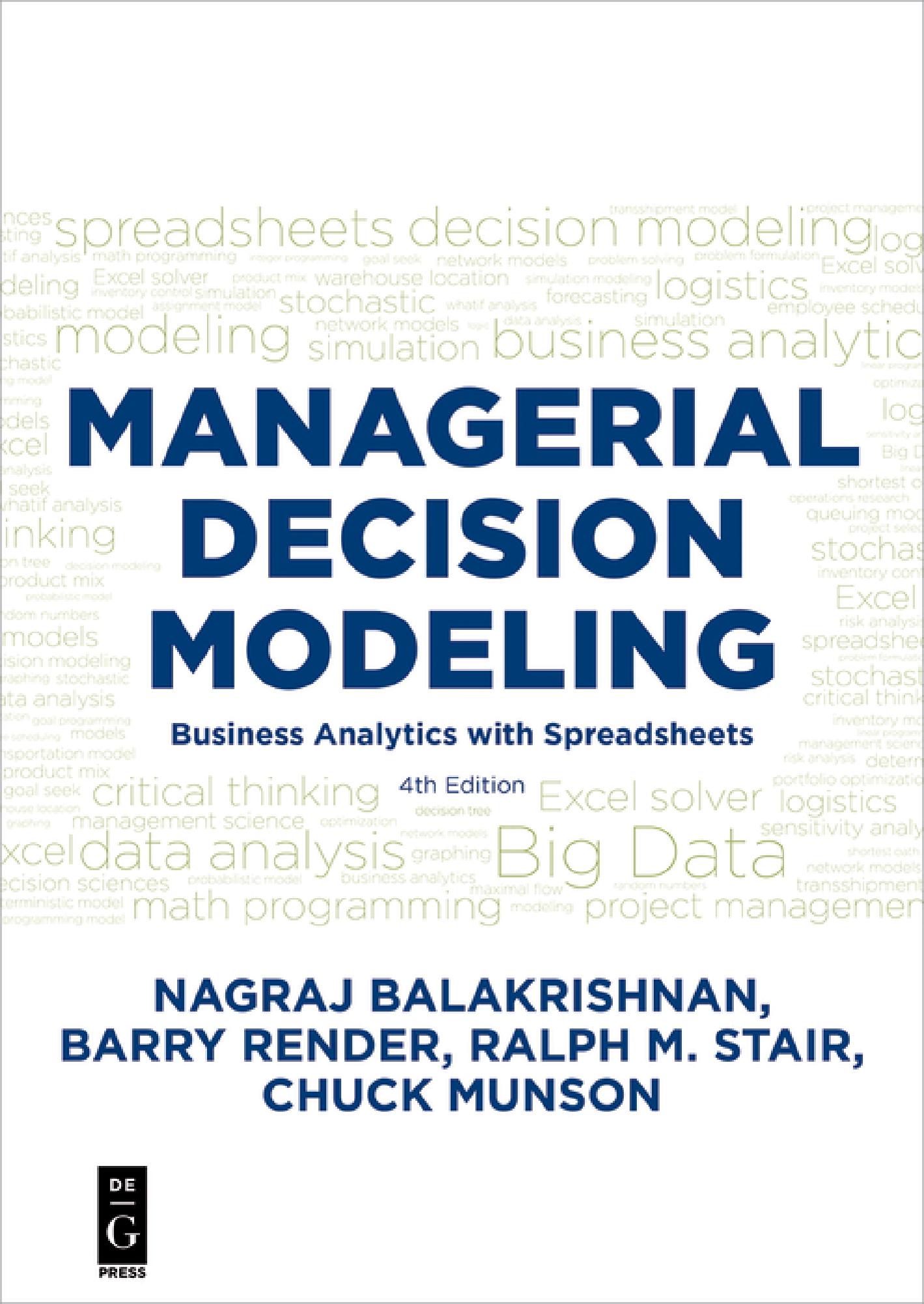
MANAGERIAL DECISION MODELING
Business Analytics with Spreadsheets
4th Edition
NAGRAJ BALAKRISHNAN,
BARRY RENDER, RALPH M. STAIR,
CHUCK MUNSON
DE G PRESS

Nagraj (Raju) Balakrishnan, Barry Render, Ralph M. Stair, Chuck Munson
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To my children, Nitin and Nandita, and most of all to my darling wife, Meena,
my rock – N.B.

To Donna, Charlie, and Jesse – B.R.

To Ken Ramsing and Alan Eliason – R.M.S.

To my wife Kim and my sons Christopher and Mark
for their unwavering support and encouragement – C.M

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It is no secret that unlike courses in functional areas such as finance, marketing, and accounting, decision modeling courses always face an uphill battle in getting students interested and excited about the material (despite its increased value in today's business world). We hope that this book will be an ally to all in this endeavor.

About the Authors

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Preface

In recent years, the use of spreadsheets to teach decision modeling (alternatively referred to as *business analytics*, *management science*, *operations research*, and *quantitative analysis*) has become standard practice in many business programs. This emphasis has revived interest in the field significantly, and several books have attempted to discuss spreadsheet-based decision modeling. However, some of these books have become too spreadsheet oriented, focusing more on the spreadsheet commands to use than on the underlying decision model. Other books have maintained their algorithmic approach to decision modeling, adding spreadsheet instructions almost as an afterthought. In the fourth edition of *Managerial Decision Modeling: Business Analytics with Spreadsheets*, we have continued to build on our success with the first three editions in trying to achieve the perfect balance between the decision modeling process and the use of spreadsheets to set up and solve decision models. In so doing, the book not only serves the needs of students but those of professionals who wish to use the techniques presented here. In keeping with the growing emphasis on *business analytics* and the use of many of the decision modeling techniques in this field, we have retitled the book.

It is important that books that support decision modeling try to combine the power to logically model and analyze diverse decision-making scenarios with software-based solution procedures. Therefore, this edition continues to focus on teaching the reader the skills needed to apply decision models to different kinds of organizational decision-making situations. The discussions are very application oriented and software based, with a view toward how a manager can effectively apply the models learned here to improve the decision-making process. The target audiences for this book are students in undergraduate and graduate level introductory decision modeling courses in business and engineering schools and professionals who need to use the content delivered in this book every day. However, this book will also be useful in other introductory courses that cover some of the core decision modeling topics, such as linear programming, network modeling, project management, decision analysis, and simulation.

Although the emphasis in this edition continues to be on using spreadsheets for decision modeling, the book remains, at heart, a *decision modeling* book. That is, while we use spreadsheets as a tool to quickly set up and solve decision models, our aim is not to teach students how to blindly use a spreadsheet without understanding how and why it works. To accomplish this, we discuss the fundamental concepts, assumptions, and limitations behind each decision modeling technique, show how each decision model works, and illustrate the real-world usefulness of each technique with many applications from both for-profit and not-for-profit organizations.

Basic knowledge of algebra and Excel are the only prerequisites. For your convenience, we have included brief introductions to Excel 2016 and probability in the appendices.

This book's chapters, supplements, and software package cover virtually every major topic in the decision modeling field and are arranged to provide a distinction between techniques that deal with deterministic environments and those that deal with probabilistic environments. We have included more material than most instructors can cover in a typical first course. We hope that the resulting flexibility of topic selection is appreciated by instructors who need to tailor their courses to different audiences and curricula.

Overall Approach

While writing this fourth edition, we have continued to adhere to certain themes that have worked very well in the first three editions:

- First, we have tried to separate the discussion of each decision modeling technique into three distinct issues:
  1. Formulation or problem setup
  2. Model solution
  3. Interpretation of the results and what-if analysis

  In this three-step framework, steps 1 and 3 (formulation and interpretation) call upon the manager's expertise. Mastering these steps now will give readers a competitive advantage later, in the marketplace, when it is necessary to make business decisions.
- Second, that most business and engineering professionals or students are not developers. Hence, to deal with step 2 (model solution), we have fully integrated Excel into our discussions so that readers can take full advantage of the wide availability and acceptability of spreadsheet-based software for decision modeling techniques.

  Excel is a very important part of what would be considered the two main topics in any *basic* decision modeling book: linear programming and simulation. However, we recognize that some topics are not well suited for spreadsheet-based software, such as project management, where Excel is generally not the best choice.
- Third, we try to ensure that readers focus on *what* they are doing and *why* they are doing it, rather than just mechanically learning which Excel formula to use, or button to press. To facilitate this, we also *briefly* discuss the steps and rationale of the solution process in many cases.
- Finally, we note that most of the students in decision modeling courses are likely to specialize in *other* functional areas, such as finance, marketing, accounting, operations, and human resources. In addition, we expect that a wide array of professionals will find the book a best solution. We therefore try to integrate decision modeling techniques with problems drawn from these different areas so that readers can recognize the importance of what they are learning and the potential benefits of using decision modeling in real-world settings. In addition, we have included summaries of selected articles from journals such as *Interfaces* that discuss the actual application of decision modeling techniques to real-world problems.

Features in This Book

The features of the first three editions of this book that have been well received as effective aids to the learning process have been updated and expanded in this fourth edition.

In creating this edition, we not only updated the content, we analyzed how we could best present the content from a learning point of view. Readers benefit from being able to deep dive into a chapter filled with examples and exercises, carefully explained, so that they can master the content. But readers also need quick review whether it be for a student cramming for a test or a professional wanting to recall something not used in a while. So, we created a Summary section that includes an overview of the chapter, then dozens of detailed Key Points, backed up with a Glossary of the terms used in the chapter, highlighted in red in the text as they appear.

We hope that the features listed below will continue to elp readers better understand the material:

- *Consistent layout and format for creating effective Excel models*—The consistent layout and format for creating spreadsheet models for all linear, integer, goal, and nonlinear programming problems is best suited to the beginner in using these types of decision models.
- *Functional use of color—We* have standardized the use of colors so that the various components of the models are easily identifiable.
- *Excel Notes and Excel Extra boxes—We have added separate* Excel Notes *boxes to provide simple Excel tips to make the spreadsheet usage as easy and error-free as possible. In addition, in each chapter, we have provided an* Excel Extra *box that illustrate advanced Excel techniques or commands.*
- *Description of the algebraic formulation and its spreadsheet implementation for all examples*—For each model, we first discuss the algebraic formulation so that the reader can understand the logic and rationale behind the decision model. The spreadsheet implementation then closely follows for ease of understanding.
- *Numerous screen captures of Excel outputs, with detailed callouts*—We have included numerous screen captures of Excel files with detailed callouts explaining the important entries and components of the model. Excel files are located at *degruyter.com/view/product/486941* and, for your convenience, the callouts are shown as comments on appropriate cells in these Excel files.
- *Ability to teach topics without the use of additional software*—Several topics can be studied using only Excel's standard built-in add-ins and commands. For example, we have discussed how Excel's Data Table and Scenario Manager procedures can be used to analyze and replicate even large simulation models.
- *Extensive discussion of linear programming sensitivity analysis, using the Solver report*—The discussion of linear programming sensitivity analysis in this book is more comprehensive than that in any competing book.
- *Decision Modeling In Action boxes*—These boxes summarize published articles that illustrate how real-world organizations have used decision models to solve problems.
- *ExcelModules*—This software package from Professor Howard Weiss of Temple University solves problems in queuing models (Chapter 9), forecasting models (Chapter 11), and inventory control models (in an optional Chapter 12 found online and downloadable from the Companion Website). Readers can see the power of this software package in modeling and solving problems in these chapters. ExcelModules is menu driven and easy to use, and it is available at *degruyter.com/view/product/486941*. A Mac version of the program is also available for the first time.

Major Changes in the FOURTH Edition

We have made the following major changes in this fourth edition—All spreadsheet applications have been fully updated to Excel 2016. The software program ExcelModules that accompanies this book has also been updated to suit Excel 2016 as well as 32-bit and 64-bit systems. In addition a Mac version of this software is now available.

- *Significant number of new end-of-chapter exercises*—We have added at least eight new exercises in each chapter. On average, there are now more than 45 end-of-chapter exercises per chapter.

- *More challenging chapter examples and end-of-chapter exercises*—Many of the chapter examples and end-of-chapter exercises have been revised to make them more current, rigorous, and better suited to a computer-based solution environment inviting readers to modify the Excel models contained in the chapters to incorporate new constraints or conditions. This requires readers to first thoroughly understand the original Excel models before attempting to modify them.
- *New Excel Extra Boxes*—In addition to the Excel Notes boxes that provide quick tips on Excel commands and procedures relevant to the topic being discussed, we have added new Excel Extra boxes. These boxes illustrate advanced Excel techniques and commands including descriptions of cell comments; locking cells; data validation; drop-down lists; linked charts; VBA for user interaction; sorting; identifying the owner of a max or min search; hiding rows, columns, sheets, and formulas; automating with macros; conditional formatting; and scroll bars and other form controls.
- *Updated Decision Modeling In Action boxes*—Decision Modeling In Action boxes illustrate the use of decision modeling in real-world scenarios. Many of these examples are from recent issues of *Interfaces*.
- *Streamlined network problem formulations*—We have modified the algebraic formulation and Excel implementation of certain network problems in Chapters 5 and 6 to provide a more streamlined presentation.
- *Excel functions*—We have added an extensive list of common Excel functions for your reference in Appendix B.
- *Better introductions*—Set expectations in each chapter.

Companion Website

The following items can be downloaded at *degruyter.com/view/product/486941*:

1. Data Files—Excel files for all examples discussed in the book. (For easy reference, the relevant file names are printed below the titles of the corresponding figures at appropriate places in the book.)
2. *Online Chapter*—The electronic-only Chapter 12: Inventory Control Models (PDF).
3. *ExcelModules Software*—This program solves problems and examples in the queuing models (Chapter 9), forecasting models (Chapter 11), and the downloadable inventory control models (Chapter 12) chapters in this book. Available in both Windows and Mac versions.
4. *Solutions to End-of-Chapter Exercises*—Detailed Excel solutions for all end-of-chapter exercises. Access is available to faculty adopters only.

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Chapter 1
Introduction to Managerial Decision Modeling

Do you frequently struggle to make decisions? Some people argue incessantly over relatively trivial choices, such as where to go for lunch. More life-altering decisions, such as where to go to college, whether or not to take that new job offer, or whether or not to say yes to a marriage proposal, can hound us for days and keep us up at night. And when we make a wrong decision, the regret that we feel can haunt us for weeks, months, or even years.

Managers face similar dilemmas as they struggle to make the best decisions for their respective organizations. Great decisions can lead to millions of extra dollars for the company and personal promotions or bonuses for the decision maker. Poor decisions can lead to huge financial losses for the company and potential job loss for the decision maker. People make many decisions on a personal level and even for their companies based on "gut feel." That may be the best approach for some decisions. But for many decisions, decision-making tools can provide tremendous guidance by illustrating the pros and cons of various alternatives. This is the essence of decision modeling.

We begin this chapter by defining decision modeling and then delineating the two major types of decision models. Next, we discuss the three major steps involved in decision modeling. The vast majority of the models covered in this book are quantitative in nature. Fortunately, these generally *do not* require the skills of a professional mathematician to set up or solve. Most of these models require only standard algebra and arithmetic, along with little bit of statistical background. An important reason for this is that we let the computer do most of the "heavy mathematical lifting" for us. And while many specialized computer optimization packages exist to solve large-scale decision models, it turns out that the standard spreadsheet, Microsoft Excel, can solve many types of modeling problems of reasonable size. We focus exclusively in this book on using Excel to solve the models that we present.

Most managers around the globe have Excel on their computers, and many use Excel frequently. As such, Excel can be a great tool for modeling because co-workers may be more comfortable with spreadsheets than they would be with unfamiliar specialized programs. Excel has allowed the "common manager" to use and even build his or her own decision models without the need to hire a specialist.

We introduce two models in this chapter that illustrate the standard approach for modeling with Excel that we will use for the rest of the book. The first illustrates how to compute estimated income taxes, and the second utilizes the Excel feature Goal Seek to perform a simple profit break-even analysis for a small firm. We conclude Chapter 1 by describing certain pitfalls that may arise in the modeling process and some challenges with implementation.

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Chapter Objectives

After completing this chapter, you will be able to:

1. Define *decision model* and describe the importance of such models.
2. Understand the two types of decision models: deterministic and probabilistic models.
3. Understand the steps involved in developing decision models in practical situations.
4. Understand the use of spreadsheets in developing decision models.
5. Discuss possible problems in developing decision models.

1.1 What is Decision Modeling?

Although there are several definitions of *decision modeling*, we define it here as a scientific approach to managerial decision making. Alternatively, we can define it as the development of a *model* (usually mathematical) of a real-world problem scenario or environment. The resulting model typically should be such that the decision-making process is not affected by personal bias, whim, emotions, or guesswork. This model can then be used to provide insights into the solution of the managerial problem. Decision modeling is also commonly referred to as *quantitative analysis*, *management science*, or *operations research*. In this book, we prefer the term *decision modeling* because we will discuss all modeling techniques in a managerial decision-making context.

You may have heard about the explosion of "big data" or "data analytics" in the business world. The increasing power of technology to collect massive amounts of data from customers and other sources, along with never-ending comments appearing in social media, have opened possibilities for companies that were heretofore unimaginable. Just imagine the amount of data being collected daily by companies such as Google, Facebook, Twitter, and Yahoo, and the wealth of useful information contained in that data. The term "analytics" is being used in many ways, but at its core it describes transforming data into information, hopefully leading to sound business decisions. This is exactly what decision modeling encompasses. In fact, "data analytics" is now considered by many to be synonymous with decision modeling, quantitative analysis, management science, and operations research. Firms are searching for employees with these skills like never before. If you can master the skills, you will be highly valued by the marketplace.

Organizations such as American Airlines, United Airlines, IBM, Google, UPS, FedEx, and AT&T frequently use decision modeling to help solve complex problems. Although mathematical tools have been in existence for thousands of years, the formal study and application of quantitative (or mathematical) decision modeling techniques to practical decision making is largely a product of the twentieth century. The decision modeling techniques studied here have been applied successfully to an increasingly wide variety of complex problems in business, government, health care,

education, and many other areas. Many such successful uses are discussed throughout this book.

It isn't enough, though, just to know the mathematical details of how a particular decision modeling technique can be set up and solved. It is equally important to be familiar with the limitations, assumptions, and specific applicability of the model. The correct use of decision modeling techniques usually results in solutions that are timely, accurate, flexible, economical, reliable, easy to understand, and easy to use.

1.2 Types of Decision Models

Decision models can be broadly classified into two categories, based on the type and nature of the decision-making problem environment under consideration: (1) deterministic models and (2) probabilistic models. We define each type in the following sections.

Deterministic Models

Deterministic models assume that all the relevant input data values are known with certainty; that is, they assume that all the information needed for modeling a decision-making problem environment is available, with fixed and known values. An example of such a model is the case of Dell Corporation, which makes several different types of PC products (e.g., desktops, laptops), all of which compete for the same resources (e.g., labor, hard disks, chips, working capital). Dell knows the specific amounts of each resource required to make one unit of each type of PC, based on the PC's design specifications. Further, based on the expected selling price and cost prices of various resources, Dell knows the expected profit contribution per unit of each type of PC. In such an environment, if Dell decides on a specific production plan, it is a simple task to compute the quantity required of each resource to satisfy that production plan. For example, if Dell plans to ship 50,000 units of a specific laptop model, and each unit includes a pair of 8.0 GB DDR4 memory chips, then Dell will need 100,000 units of these memory chips. Likewise, it is easy to compute the total profit that will be realized by this production plan (assuming that Dell can sell all the laptops it makes).

Perhaps the most common and popular deterministic modeling technique is linear programming (LP). In Chapter 2, we first discuss how small LP models can be set up and solved. We extend our discussion of LP in Chapter 3 to more complex problems drawn from a variety of business disciplines. In Chapter 4, we study how the solution to LP models produces, as a byproduct, a great deal of information useful for managerial interpretation of the results. Finally, in Chapters 5 and 6, we study a few extensions to LP models. These include several different network flow models (Chapter 5), as well as integer, nonlinear, and multi-objective (goal) programming models (Chapter 6).

As we demonstrate during our study of deterministic models, a variety of important managerial decision-making problems can be set up and solved using these techniques.

Probabilistic Models

In contrast to deterministic models, probabilistic models (also called *stochastic models*) assume that some *input data* values are not known with certainty. That is, they assume that the values of some important variables will not be known *before* decisions are made. It is therefore important to incorporate this "ignorance" into the model. An example of this type of model is the decision of whether to start a new business venture. As we have seen with the high variability in the stock market during the past several years, the success of such ventures is uncertain. However, investors (e.g., venture capitalists, founders) have to make decisions regarding this type of venture based on their expectations of future performance. Clearly, such expectations are not guaranteed to occur. In recent years, we have seen several examples of firms that have yielded (or are likely to yield) great rewards to their investors (e.g., Google, Facebook, Twitter) and others that have either failed (e.g., eToys.com, Pets.com) or been much more modest in their returns.

Another example of probabilistic modeling to which students may be able to relate easily is their choice of a major when they enter college. Clearly, there is a great deal of uncertainty regarding several issues in this decision-making problem: the student's aptitude for a specific major, his or her actual performance in that major, the employment situation in that major in four years, etc. Nevertheless, a student must choose a major early in his or her college career. Recollect your own situation. In all likelihood, you used your own assumptions (or expectations) regarding the future to evaluate the various alternatives (i.e., you developed a "model" of the decision-making problem). These assumptions may have been the result of information from various sources, such as parents, friends, and guidance counselors. The important point to note here is that none of this information is guaranteed, and no one can predict with 100% accuracy what exactly will happen in the future. Therefore, decisions made with this information, while well thought out and well intentioned, may still turn out not to be the best choices. For example, how many of your friends changed majors during their college careers?

Because their results are not guaranteed, does this mean that probabilistic decision models are of limited value? As we will see later in this book, the answer is an emphatic no. Probabilistic modeling techniques provide a structured approach for managers to incorporate uncertainty into their models and to evaluate decisions under alternate expectations regarding this uncertainty. They do so by using probabilities on the "random," or unknown, variables. Probabilistic modeling techniques discussed in this book include decision analysis (Chapter 8), queuing (Chapter 9), simulation (Chapter 10), and forecasting (Chapter 11). Two other techniques, project management (Chapter 7) and inventory control (Chapter 12), include aspects of both

deterministic and probabilistic modeling. For each modeling technique, we discuss what kinds of criteria can be used when there is uncertainty and how to use these models to identify the preferred decisions.

Because uncertainty plays a vital role in probabilistic models, some knowledge of basic probability and statistical concepts is useful. Appendix A provides a brief overview of this topic. It should serve as a good refresher while studying these modeling techniques.

Quantitative versus Qualitative Data

Any decision modeling process starts with data. Like raw material for a factory, these data are manipulated or processed into information valuable to people making decisions. This processing and manipulating of raw data into meaningful information is the heart of decision modeling.

In dealing with a decision-making problem, managers may have to consider both qualitative and quantitative factors. For example, suppose we are considering several different investment alternatives, such as certificates of deposit, the stock market, and real estate. We can use *quantitative* factors, such as rates of return, financial ratios, and cash flows, in our decision model to guide our ultimate decision. In addition to these factors, however, we may also wish to consider *qualitative* factors, such as pending state and federal legislation, new technological breakthroughs, and the outcome of an upcoming election. It can be difficult to quantify these qualitative factors.

Due to the presence (and relative importance) of qualitative factors, the role of quantitative decision modeling in the decision-making process can vary. When there is a lack of qualitative factors, and when the problem, model, and input data remain reasonably stable and steady over time, the results of a decision model can automate the decision-making process. For example, some companies use quantitative inventory models to determine automatically when to order additional new materials and how much to order. In most cases, however, decision modeling is an aid to the decision-making process. The results of decision modeling should be combined with other (qualitative) information while making decisions in practice.

Using Spreadsheets in Decision Modeling

In keeping with the ever-increasing presence of technology in modern times, computers have become an integral part of the decision modeling process in today's business environments. Until the early 1990s, many of the modeling techniques discussed here required specialized software packages in order to be solved using a computer. However, spreadsheet packages such as Microsoft Excel have become increasingly capable of setting up and solving most of the decision modeling techniques commonly used in practical situations. For this reason, the current trend in many college courses on decision modeling focuses on spreadsheet-based instruction. In keeping

with this trend, we discuss the role and use of spreadsheets (specifically Microsoft Excel) during our study of the different decision modeling techniques presented here.

In addition to discussing the use of some of Excel's built-in functions and procedures (e.g., Goal Seek, Data Table, Chart Wizard), we also discuss a few add-ins for Excel. The Data Analysis and Solver add-ins come standard with Excel. A custom add-in called ExcelModules is included on the Companion Website and used in Chapter 9 (Queuing Models), Chapter 11 (Forecasting Models), and the online Chapter 12 (Inventory Control Models).

Because a knowledge of basic Excel commands and procedures facilitates understanding the techniques and concepts discussed here, we recommend reading Appendix B, which provides a brief overview of the Excel features that are most useful in decision modeling. In addition, at appropriate places throughout this book, we discuss several Excel functions and procedures specific to each decision modeling technique.

Decision Modeling In Action

IBM Uses Decision Modeling to Improve the Productivity of Its Sales Force

IBM is a well-known multinational computer technology, software, and services company with more than 380,000 employees and revenue of more than $79 billion. A majority of IBM's revenue comes from services, including outsourcing, consulting, and systems integration.

Recognizing that improving the efficiency and productivity of this large sales force can be an effective operational strategy to drive revenue growth and manage expenses, IBM Research developed two broad decision modeling initiatives to explore this issue. The first initiative provides a set of analytical models designed to identify new sales opportunities at existing IBM accounts and at noncustomer companies. The second initiative allocates sales resources optimally based on field-validated analytical estimates of future revenue opportunities in market segments. IBM estimates the revenue impact of these two initiatives to be in the several hundreds of millions of dollars each year.

Source: Based on R. Lawrence et al. "Operations Research Improves Sales Force Productivity at IBM," *Interfaces* 40, 1 (January-February 2010): 33–46.

1.3 Steps Involved in Decision Modeling

Regardless of the size and complexity of the decision-making problem at hand, the decision modeling process involves three distinct steps: (1) formulation, (2) solution, and (3) interpretation. Figure 1.1 provides a schematic overview of these steps, along with the components, or parts, of each step. We discuss each of these steps in the following sections.

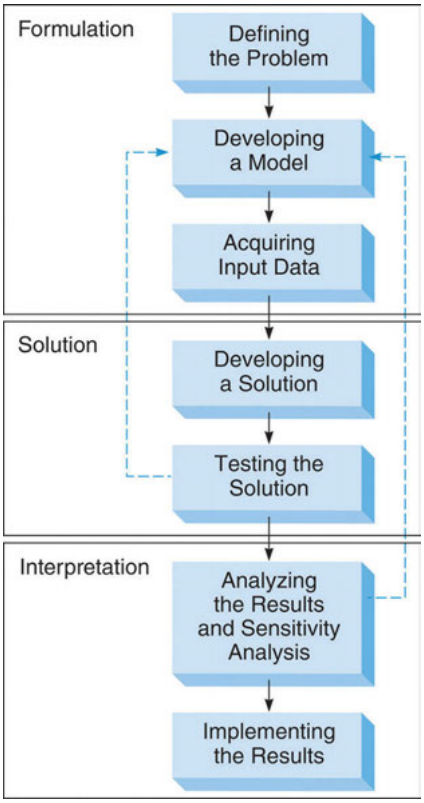

Figure 1.1: The Decision Modeling Approach

It is important to note that it is common to have an iterative process between these three steps before obtaining the final solution. For example, testing the solution (see Figure 1.1) might reveal that the model is incomplete or that some of the input data are being measured incorrectly. This means that the formulation needs to be revised. That, in turn, causes all the subsequent steps to be changed.

Step 1: Formulation

Formulation is the process by which each aspect of a problem scenario is translated and expressed in terms of a mathematical model. This is perhaps the most important and challenging step in decision modeling because the results of a poorly formulated problem will almost surely be incorrect. It is also in this step that the decision maker's ability to analyze a problem rationally comes into play. Even the most sophisticated software program will not automatically formulate a problem. The aim in formulation is to ensure that the mathematical model completely addresses all the issues relevant

to the problem at hand. Formulation can be further classified into three parts: (1) defining the problem, (2) developing a model, and (3) acquiring input data.

Defining the Problem The first part in formulation (and in decision modeling) is to develop a clear, concise statement of the problem. This statement gives direction and meaning to all the parts that follow it.

In many cases, defining the problem is perhaps the most important, and the most difficult, part. It is essential to go beyond just the symptoms of the problem at hand and identify the true causes behind it. One problem may be related to other problems, and solving a problem without regard to its related problems may actually worsen the situation. Thus, it is important to analyze how the solution to one problem affects other problems or the decision-making environment in general. Experience has shown that poor problem definition is a major reason for failure of management science groups to serve their organizations well.

When a problem is difficult to quantify, it may be necessary to develop *specific*, *measurable* objectives. For example, say a problem is defined as inadequate health care delivery in a hospital. The objectives might be to increase the number of beds, reduce the average number of days a patient spends in the hospital, increase the physician-to-patient ratio, and so on. When objectives are used, however, the real problem should be kept in mind. It is important to avoid obtaining specific and measurable objectives that may not solve the real problem.

Developing a Model Once we select the problem to be analyzed, the next part is to develop a decision model. Even though you might not be aware of it, you have been using models most of your life. For example, you may have developed the following model about friendship: Friendship is based on reciprocity, an exchange of favors. Hence, if you need a favor, such as a small loan, your model would suggest that you ask a friend.

Of course, there are many other types of models. An architect may make a physical model of a building he or she plans to construct. Engineers develop scale models of chemical plants, called pilot plants. An analog model, e.g., a thermometer measuring temperature or an oil dipstick signaling the level of oil remaining in a car, represents a phenomenon but does not look like it. A schematic model is a picture or drawing of reality. Automobiles, lawn mowers, circuit boards, typewriters, and numerous other devices have schematic models (drawings and pictures) that reveal how these devices work.

What sets decision modeling apart from other modeling techniques is that the models we develop here are mathematical. A *mathematical model* is a set of mathematical relationships. In most cases, these relationships are expressed as equations and inequalities, as they are in a spreadsheet model that computes sums, averages, or standard deviations.

Although there is considerable flexibility in the development of models, most of the models presented here contain one or more variables and parameters. A variable, as the name implies, is a measurable quantity that may vary or that is subject to change. Variables can be controllable or uncontrollable. A controllable variable is also called a *decision variable*. An example is how many inventory items to order. A problem parameter is a measurable quantity that is inherent in the problem, such as the cost of placing an order for more inventory items. In most cases, variables are unknown quantities, whereas parameters (or input data) are known quantities.

All models should be developed carefully. They should be solvable, realistic, and easy to understand and modify, and the required input data should be obtainable. A model developer must be careful to include the appropriate amount of detail for the model to be solvable yet realistic.

Acquiring Input Data Once we have developed a model, we must obtain the input data to be used in the model. Obtaining accurate data is essential because even if the model is a perfect representation of reality, improper data will result in misleading results. This situation is called *garbage in, garbage out (GIGO)*. For larger problems, collecting accurate data can be one of the most difficult aspects of decision modeling.

Several sources can be used in collecting data. In some cases, company reports and documents can be used to obtain the necessary data. Another source is interviews with employees or other persons related to the firm. These individuals can sometimes provide excellent information, and their experience and judgment can be invaluable. A production supervisor, for example, might be able to tell you with a great degree of accuracy the amount of time it takes to manufacture a particular product. Sampling and direct measurement provide other sources of data for the model. You may need to know how many pounds of a raw material are used in producing a new photochemical product. This information can be obtained by going to the plant and actually measuring the amount of raw material being used. In other cases, statistical sampling procedures can be used to obtain data.

Step 2: Solution

The solution step is when the mathematical expressions resulting from the formulation process are solved to identify the optimal solution. Until the mid-1990s, typical courses in decision modeling focused a significant portion of their attention on this step because it was the most difficult aspect of studying the modeling process. As stated earlier, thanks to computer technology, the focus today has shifted away from the detailed steps of the solution process and toward the availability and use of software packages. The solution step can be further classified into two parts: (1) developing a solution and (2) testing the solution.

Developing a Solution Developing a solution involves manipulating the model to arrive at the best (or optimal) solution to the problem. In some cases, this may require