

EIGHTH EDITION

8

Spreadsheet Modeling and Decision Analysis

A Practical Introduction to Business Analytics



Cliff T. Ragsdale

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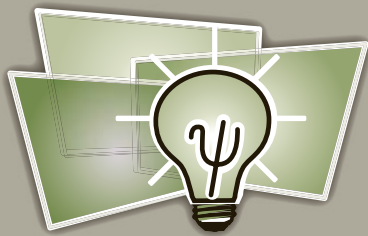
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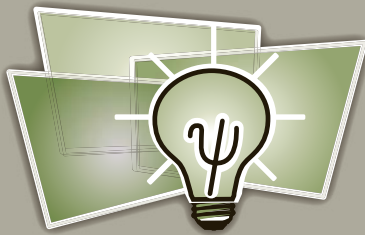
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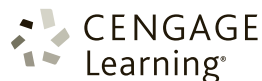
A Practical Introduction to Business Analytics



Cliff T. Ragsdale

Virginia Polytechnic Institute
and State University

In memory of those who were killed and injured
in the noble pursuit of education here at
Virginia Tech on April 16, 2007



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**Spreadsheet Modeling and Decision
Analysis, 8e**
Cliff Ragsdale

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Preface

Spreadsheets are one of the most popular and ubiquitous software packages on the planet. Every day, millions of business people use spreadsheet programs to build models of the decision problems they face as a regular part of their work activities. As a result, employers look for experience and ability with spreadsheets in the people they recruit.

Spreadsheets have also become the standard vehicle for introducing undergraduate and graduate students in business and engineering to the concepts and tools covered in the introductory business analytics course. This simultaneously develops students' skills with a standard tool of today's business world and opens their eyes to how a variety of quantitative analysis techniques can be used in this modeling environment. Spreadsheets also capture students' interest and add a new relevance to business analytics, as they see how it can be applied with popular commercial software being used in the business world.

Spreadsheet Modeling & Decision Analysis provides an introduction to the most commonly used descriptive, predictive, and prescriptive business analytics techniques and shows how these tools can be implemented using Microsoft® Excel. Prior experience with Excel is certainly helpful, but is not a requirement for using this text. In general, a student familiar with computers and the spreadsheet concepts presented in most introductory computer courses should have no trouble using this text. Step-by-step instructions and screen shots are provided for each example, and software tips are included throughout the text as needed.

What's New in the Eighth Edition?

The eighth edition introduces a brand new MindTap product. For each chapter, this all-digital version of the book enhances learning with an engagement video and discussion, a quiz with rich feedback, videos by the author that explain chapter concepts, and end-of-chapter assignments that are tailored to work well digitally. If you're interested in all these features, talk to your Cengage learning consultant.

The most significant feature in the eighth edition of *Spreadsheet Modeling & Decision Analysis* is its focus on business analytics and extensive coverage and use of Analytic Solver Platform for Education by Frontline Systems, Inc. Analytic Solver Platform for Education is an add-in for Excel that provides access to analytical tools for performing optimization, simulation, sensitivity analysis, and decision tree analysis, as well as a variety of tools for data mining. Analytic Solver Platform for Education makes it easy to run multiple parameterized optimizations and simulations and apply optimization techniques to simulation models in one integrated, coherent interface. Analytic Solver Platform also offers amazing interactive simulation features in which simulation results are automatically updated in real-time whenever a manual change is made to a spreadsheet. Additionally, when run in its optional "Guided Mode," Analytic Solver Platform provides students with over 100 customized dialog boxes that provide diagnoses of various model conditions and explain the steps involved in solving problems. Analytic Solver Platform also includes Frontline's XLMiner Platform product that offers easy access to a variety of data mining techniques including discriminant analysis, logistic

regression, neural networks, classification and regression trees, k-nearest neighbor classification, cluster analysis, and affinity analysis. Analytic Solver Platform offers numerous other features and, I believe, will transform the way we approach education in quantitative analysis now and in the future.

Additional changes in the eighth edition of *Spreadsheet Modeling & Decision Analysis* from the seventh edition include:

- Microsoft® Office 2016 is featured throughout.
- Data files and software to accompany the book are now available for download online at the book's companion site, which you can access at www.CengageBrain.com. There, enter this book's ISBN number and you'll be able to access the accompanying materials.
- Chapter 1 includes an expanded discussion and definition of good decision making.
- Chapter 6 features a new section on the topic of line balancing problems.
- Chapter 10 has undergone extensive revision to reflect changes in XLMiner Platform and was expanded to include discussion of precision, recall (sensitivity), specificity, F1 scores, and ROC curves.
- Chapter 11 introduces new, simplified techniques for producing forecasts for stationary time series data.
- Several new and revised end-of-chapter problems are included throughout.

Innovative Features

Aside from its strong spreadsheet orientation, the eighth edition of *Spreadsheet Modeling & Decision Analysis* contains several other unique features that distinguish it from other texts.

- Algebraic formulations and spreadsheets are used side-by-side to help develop conceptual thinking skills.
- Step-by-step instructions and numerous annotated screen shots make examples easy to follow and understand.
- Emphasis is placed on model formulation and interpretation rather than on algorithms.
- Realistic examples motivate the discussion of each topic.
- Solutions to example problems are analyzed from a managerial perspective.
- Spreadsheet files for all the examples are provided on a data disk bundled with the text.
- A unique and accessible chapter covering data mining is provided.
- Sections entitled "The World of Business Analytics" show how each topic has been applied in a real company.

Organization

The table of contents for *Spreadsheet Modeling & Decision Analysis* is laid out in a fairly traditional format, but topics may be covered in a variety of ways. The text begins with an overview of business analytics in Chapter 1. Chapters 2 through 8 cover various topics in prescriptive modeling techniques: linear programming, sensitivity analysis, networks, integer programming, goal programming and multiple objective optimization, and non-linear and evolutionary programming. Chapters 9 through 11 cover predictive modeling and forecasting techniques: regression analysis, data mining, and time series analysis.

Chapters 12 and 13 cover descriptive modeling techniques: simulation and queuing theory. Chapter 14 covers decision analysis, and Chapter 15 (available exclusively in MindTap) provides an introduction to project management.

After completing Chapter 1, a quick refresher on spreadsheet fundamentals (entering and copying formulas, basic formatting and editing, etc.) is always a good idea. Suggestions for the Excel review may be found at this book's companion site. (To access, go to www.CengageBrain.com and add this book to your bookshelf by searching its ISBN.) Following this, an instructor could cover the material on optimization, regression, forecasting, data mining, or simulation, depending on personal preferences. The chapters on queuing and project management make general references to simulation and, therefore, should follow the discussion of that topic.

Ancillary Materials

Several excellent ancillaries for the instructor accompany this edition of *Spreadsheet Modeling & Decision Analysis*. All instructor ancillaries are provided at www.CengageBrain.com. Included in this convenient format are:

- **Instructor's Manual.** The Instructor's Manual, prepared by the author, contains solutions to all the text problems and cases.
- **Test Bank.** The Test Bank, prepared by Tom Bramorski, University of Georgia, includes multiple choice, true/false, and short answer problems for each text chapter. Cengage Learning Testing Powered by Cognero is a flexible, online system that allows you to author, edit, and manage test bank content, create multiple test versions in an instant, and deliver tests from your LMS, in your classroom or through CengageNOW.

On the book's companion site, you'll also find the test bank in Microsoft® Word format.

- **PowerPoint Presentation Slides.** PowerPoint presentation slides, prepared by the author, provide ready-made lecture material for each chapter in the book.

Acknowledgments

I thank the following colleagues who made important contributions to the development and completion of this book. The reviewers for the eighth edition were:

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My sincere thanks goes to all students and instructors who have used previous editions of this book and provided many valuable comments and suggestions for making it better. I also thank the wonderful SMDA team at Cengage: Aaron Arnsparger, Senior Product Manager; and Conor Allen, Content Developer. I feel very fortunate and privileged to work with them both.

A very special word of thanks to my friend Dan Fylstra and the crew at Frontline Systems (<http://www.solver.com>) for conceiving and creating Analytic Solver Platform and supporting me so graciously and quickly throughout my revision work on this book. In my opinion, Analytic Solver Platform is the most significant development in business analytics education since the creation of personal computers and the electronic spreadsheet. (Dan, you get my vote for a lifetime achievement award in analytical modeling and induction in the OR/MS Hall of Fame!)

Once again, I thank my dear wife, Kathy, for her unending patience, support, encouragement, and love. This book is dedicated to my parents, Roy and Mamie Ragsdale, who both departed the planet we call Earth during the preparation of this revision but whose influence and memory endure.

Final Thoughts

I hope you enjoy the spreadsheet approach to teaching business analytics as much as I do and that you find this book to be very interesting and helpful. If you find creative ways to use the techniques in this book or need help applying them, I would love to hear from you. Also, any comments, questions, suggestions, or constructive criticism you have concerning this text are always welcome.

Cliff T. Ragsdale
e-mail: Cliff.Ragsdale@vt.edu

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Chapter 1

Introduction to Modeling and Decision Analysis

1.0 Introduction

This book is titled *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Business Analytics*, so let's begin by discussing exactly what this title means. By the very nature of life, all of us must continually make decisions that we hope will solve problems and lead to increased opportunities, for ourselves or the organizations for which we work. But making good decisions is rarely an easy task. The problems faced by decision makers in today's competitive, data-intensive, fast-paced business environment are often extremely complex and can be addressed by numerous possible courses of action. Evaluating these alternatives and choosing the best course of action represents the essence of decision analysis.

Since the inception of the electronic spreadsheet in the early 1980s, millions of business people have discovered that one of the most effective ways to analyze and evaluate decision alternatives involves using a spreadsheet package to build computer models of the business opportunities and decision problems they face. A **computer model** is a set of mathematical relationships and logical assumptions implemented in a computer as a representation of some real-world object, decision problem, or phenomenon. Today, electronic spreadsheets provide the most convenient and useful way for business people to implement and analyze computer models. Indeed, most business people would probably rate the electronic spreadsheet as their most important analytical tool—apart from their brain! Using a **spreadsheet model** (a computer model implemented via a spreadsheet), a business person can analyze decision alternatives before having to choose a specific plan for implementation.

This book introduces you to a variety of techniques from the field of business analytics that can be applied in spreadsheet models to assist in the decision-analysis process. For our purposes, we will define **business analytics** as a field of study that uses data, computers, statistics, and mathematics to solve business problems. It involves using the methods and tools of science to drive business decision making. It is the science of making better decisions. Business analytics is also sometimes referred to as operations research, management science, or decision science. See Figure 1.1 for a summary of how business analytics has been applied successfully in a number of real-world situations.

In the not too distant past, business analytics was a highly specialized field that generally could be practiced only by those who had access to mainframe computers and who possessed an advanced knowledge of mathematics, computer programming languages, and specialized software packages. However, the proliferation of powerful

FIGURE 1.1

*Examples of
successful
business analytics
applications*

Home Runs in Business Analytics

Over the past decade, thousands of business analytics projects saved or generated millions of dollars for companies across a variety of industries. Each year, the Institute for Operations Research and the Management Sciences (INFORMS) sponsors the Franz Edelman Awards competition to recognize some of the most outstanding business analytics projects during the past year. Here are some of the “home runs” from the 2013 and 2014 Edelman Awards (described in *Interfaces*, Vol. 44, No. 1, January–February, 2014 and Vol. 45, No. 1, January–February 2015).

- Chevron created an optimization software tool used at all of its refineries. The company uses this tool for operational and strategic planning to do such things as optimize the mix of crude oils and products to produce, determine refinery operations settings, and plan capital expenditures. This sort of modeling activity is an integral part of Chevron’s business processes and culture. Annual savings from Chevron’s optimization work is estimated at \$1 billion.
- In the 1980s, Dell became successful by allowing customers to order custom-configured computers. More recently, Dell ventured into the fixed hardware configurations (FHCs) market to address growing competition. Dell’s analytics team used a variety of statistical techniques to create a set of FHCs and to improve its website’s design. The analytics team also created models that analyze supply and demand variability to identify when different promotions should be used. These efforts generated more than \$140 million by reducing required markdowns, increasing online customer conversion rates, improving logistics, and improving customer satisfaction.
- The Kroger Company operates 1,950 in-store pharmacies throughout its grocery chain. Using actual demand data, its analytics team created a simulation-optimization model to determine reorder points and order-up-to levels for items in its pharmacies. This analytics effort reduced annual out of stocks by 1.6 million prescriptions, lowered inventory by more than \$120 million, and increased annual revenue by about \$80 million.
- The National Broadcast Network Company (NBNC) is a government-owned entity responsible for providing broadband network service throughout Australia. NBNC recently worked with an analytics consulting company to develop a set of mixed-integer programming models that automate and optimize the design of a network providing broadband coverage to approximately eight million locations. Reductions in design time and other savings have an estimated value of about \$1.7 billion.
- The Alliance for Paired Donations (APD) seeks to save lives by securing a living donor kidney for every patient who needs a transplant. People needing a kidney transplant often have a relative or friend willing to donate one, but the donor kidney is often incompatible with the intended recipient. Exchanges with other patient-donor pairs can sometimes overcome these incompatibilities. The APD uses integer programming techniques to determine the best paired-matches for this kidney exchange problem. Since 2006, the APD’s efforts have saved more than 220 lives—and those savings are priceless.

PCs and the development of easy-to-use electronic spreadsheets have made the tools of business analytics far more practical and available to a much larger audience. Virtually everyone who uses a spreadsheet today for model building and decision making is a practitioner of business analytics—whether they realize it or not.

1.1 The Modeling Approach to Decision Making

The idea of using models in problem solving and decision analysis is not new, and is certainly not tied to the use of computers. At some point, all of us have used a modeling approach to make a decision. For example, if you have ever moved into a dormitory, apartment, or house, you undoubtedly faced a decision about how to arrange the furniture in your new dwelling. There were probably a number of different arrangements to consider. One arrangement might give you the most open space but require that you build a loft. Another might give you less space but allow you to avoid the hassle and expense of building a loft. To analyze these different arrangements and make a decision, you did not build the loft. You more likely built a **mental model** of the two arrangements, picturing what each looked like in your mind's eye. Thus, a simple mental model is sometimes all that is required to analyze a problem and make a decision.

For more complex decisions, a mental model might be impossible or insufficient and other types of models might be required. For example, a set of drawings or blueprints for a house or building provides a **visual model** of the real-world structure. These drawings help illustrate how the various parts of the structure will fit together when it is completed. A road map is another type of visual model because it assists a driver in analyzing the various routes from one location to another.

You have probably also seen car commercials on television showing automotive engineers using **physical**, or **scale, models** to study the aerodynamics of various car designs to find the shape that creates the least wind resistance and maximizes fuel economy. Similarly, aeronautical engineers use scale models of airplanes to study the flight characteristics of various fuselage and wing designs. And civil engineers might use scale models of buildings and bridges to study the strengths of different construction techniques.

Another common type of model is a **mathematical model**, which uses mathematical relationships to describe or represent an object or decision problem. Throughout this book we will study how various mathematical models can be implemented and analyzed on computers using spreadsheet software. But before we move to an in-depth discussion of spreadsheet models, let's look at some of the more general characteristics and benefits of modeling.

1.2 Characteristics and Benefits of Modeling

Although this book focuses on mathematical models implemented in computers via spreadsheets, the examples of nonmathematical models given earlier are worth discussing a bit more because they help illustrate a number of important characteristics and benefits of modeling in general. First, the models mentioned earlier are usually simplified versions of the object or decision problem they represent. To study the aerodynamics of a car design, we do not need to build the entire car complete with engine and stereo. Such components have little or no effect on aerodynamics. So, although a model is often a simplified representation of reality, the model is useful as long as it is valid. A **valid** model is one that accurately represents the relevant characteristics of the object or decision problem being studied.

Second, it is often less expensive to analyze decision problems using a model. This is especially easy to understand with respect to scale models of big-ticket items such as cars and planes. Besides the lower financial cost of building a model, the analysis of a model can help avoid costly mistakes that might result from poor decision making. For example, it is far less costly to discover a flawed wing design using a scale model of an aircraft than after the crash of a fully loaded jet liner.

Frank Brock, former executive vice president of the Brock Candy Company, related the following story about blueprints his company prepared for a new production facility. After months of careful design work, he proudly showed the plans to several of his production workers. When he asked for their comments, one worker responded, "It's a fine looking building Mr. Brock, but that sugar valve looks like it's about twenty feet away from the steam valve." "What's wrong with that?" asked Brock. "Well, nothing," said the worker, "except that I have to have my hands on both valves at the same time!"¹ Needless to say, it was far less expensive to discover and correct this "little" problem using a visual model before pouring the concrete and laying the pipes as originally planned.

Third, models often deliver needed information on a more timely basis. Again, it is relatively easy to see that scale models of cars or airplanes can be created and analyzed more quickly than their real-world counterparts. Timeliness is also an issue when vital data will not become available until some later point in time. In these cases, we might create a model to help predict the missing data to assist in current decision making.

Fourth, models are frequently helpful in examining things that would be impossible to do in reality. For example, human models (crash dummies) are used in crash tests to see what might happen to an actual person if a car hits a brick wall at a high speed. Likewise, models of DNA can be used to visualize how molecules fit together. Both of these are difficult, if not impossible, to do without the use of models.

Finally, and probably most importantly, models allow us to gain insight and understanding about the object or decision problem under investigation. The ultimate purpose of using models is to improve decision making. As you will see, the process of building a model can shed important light and understanding on a problem. In some cases, a decision might be made while building the model, as a previously misunderstood element of the problem is discovered or eliminated. In other cases, a careful analysis of a completed model might be required to "get a handle" on a problem and gain the insights needed to make a decision. In any event, it is the insight gained from the modeling process that ultimately leads to better decision making.

1.3 Mathematical Models

As mentioned earlier, the modeling techniques in this book differ quite a bit from scale models of cars and planes or visual models of production plants. The models we will build use mathematics to describe a decision problem. We use the term "mathematics" in its broadest sense, encompassing not only the most familiar elements of math, such as algebra, but also the related topic of logic.

Now, let's consider a simple example of a mathematical model:

$$\text{PROFIT} = \text{REVENUE} - \text{EXPENSES} \qquad \mathbf{1.1}$$

¹ Colson, Charles and Jack Eckerd. *Why America Doesn't Work* (Denver, Colorado: Word Publishing, 1991), 146–147.

Equation 1.1 describes a simple relationship between revenue, expenses, and profit. It is a mathematical relationship that describes the operation of determining profit—or a mathematical model of profit. Of course, not all models are this simple, but taken piece by piece, the models we will discuss are not much more complex than this one.

Frequently, mathematical models describe functional relationships. For example, the mathematical model in equation 1.1 describes a functional relationship between revenue, expenses, and profit. Using the symbols of mathematics, this functional relationship is represented as:

$$\text{PROFIT} = f(\text{REVENUE}, \text{EXPENSES}) \quad 1.2$$

In words, the previous expression means “profit is a function of revenue and expenses.” We could also say that profit *depends* on (or is *dependent* on) revenue and expenses. Thus, the term PROFIT in equation 1.2 represents a **dependent** variable, whereas REVENUE and EXPENSES are **independent** variables. Frequently, compact symbols (such as A, B, and C) are used to represent variables in an equation such as 1.2. For instance, if we let Y, X_1 , and X_2 represent PROFIT, REVENUE, and EXPENSES, respectively, we could rewrite equation 1.2 as follows:

$$Y = f(X_1, X_2) \quad 1.3$$

The notation $f(\cdot)$ represents the function that defines the relationship between the dependent variable Y and the independent variables X_1 and X_2 . In the case of determining PROFIT from REVENUE and EXPENSES, the mathematical form of the function $f(\cdot)$ is quite simple because we know that $f(X_1, X_2) = X_1 - X_2$. However, in many other situations we will model, the form of $f(\cdot)$ is quite complex and might involve many independent variables. But regardless of the complexity of $f(\cdot)$ or the number of independent variables involved, many of the decision problems encountered in business can be represented by models that assume the general form,

$$Y = f(X_1, X_2, \dots, X_k) \quad 1.4$$

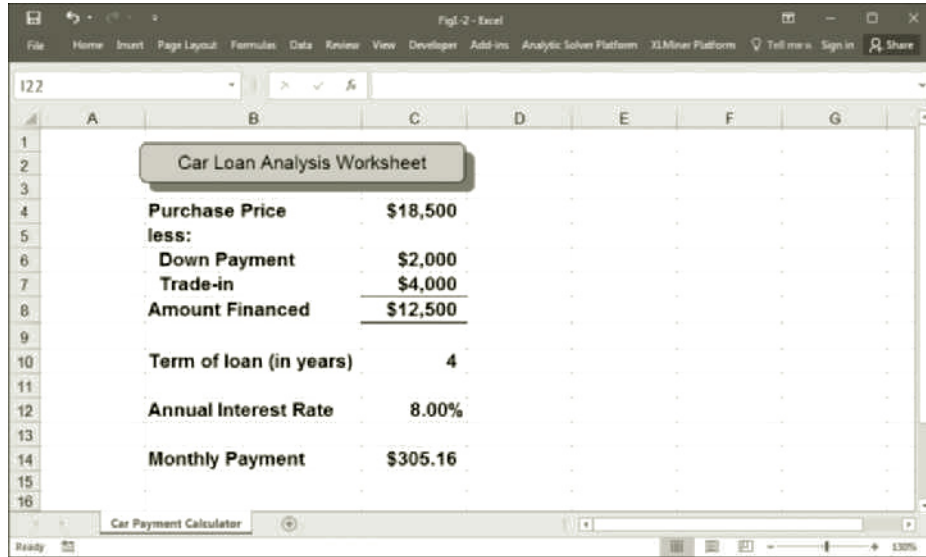
In equation 1.4, the dependent variable Y represents some bottom-line performance measure of the problem we are modeling. The terms X_1, X_2, \dots, X_k represent the different independent variables that play some role or have some impact in determining the value of Y. Again, $f(\cdot)$ is the function (possibly quite complex) that specifies or describes the relationship between the dependent and independent variables.

The relationship expressed in equation 1.4 is very similar to what occurs in most spreadsheet models. Consider a simple spreadsheet model to calculate the monthly payment for a car loan, as shown in Figure 1.2.

The spreadsheet in Figure 1.2 contains a variety of **input** cells (e.g., purchase price, down payment, trade-in, term of loan, annual interest rate) that correspond conceptually to the independent variables X_1, X_2, \dots, X_k in equation 1.4. Similarly, a variety of mathematical operations are performed using these input cells in a manner analogous to the function $f(\cdot)$ in equation 1.4. The results of these mathematical operations determine the value of some **output** cell in the spreadsheet (e.g., monthly payment) that corresponds to the dependent variable Y in equation 1.4. Thus, there is a direct correspondence between equation 1.4 and the spreadsheet in Figure 1.2. This type of correspondence exists for most of the spreadsheet models in this book.

FIGURE 1.2

Example of a simple spreadsheet model



1.4 Categories of Mathematical Models

Not only does equation 1.4 describe the major elements of mathematical or spreadsheet models, but it also provides a convenient means for comparing and contrasting the three categories of modeling techniques presented in this book—Prescriptive Models, Predictive Models, and Descriptive Models. Figure 1.3 summarizes the characteristics and some of the techniques associated with each of these categories.

In some situations, a manager might face a decision problem involving a very precise, well-defined functional relationship $f(\cdot)$ between the independent variables X_1, X_2, \dots, X_k and the dependent variable Y . If the values for the independent variables are under the decision maker’s control, the decision problem in these types of situations boils down

FIGURE 1.3

Categories and characteristics of business analytics modeling techniques

Category	Model Characteristics:		
	Form of $f(\cdot)$	Values of Independent Variables	Business Analytics Techniques
Prescriptive Models	known, well-defined	known or under decision maker’s control	Linear Programming, Networks, Integer Programming, CPM, Goal Programming, EOQ, Nonlinear Programming
Predictive Models	unknown, ill-defined	known or under decision maker’s control	Regression Analysis, Time Series Analysis, Discriminant Analysis, Neural Networks, Logistic Regression, Affinity Analysis, Cluster Analysis
Descriptive Models	known, well-defined	unknown or uncertain	Simulation, Queuing, PERT, Inventory Models

to determining the values of the independent variables X_1, X_2, \dots, X_k that produce the best possible value for the dependent variable Y . These types of models are called **prescriptive models** because their solutions tell the decision maker what actions to take. For example, you might be interested in determining how a given sum of money should be allocated to different investments (represented by the independent variables) to maximize the return on a portfolio without exceeding a certain level of risk.

A second category of decision problems is one in which the objective is to predict or estimate what value the dependent variable Y will take on when the independent variables X_1, X_2, \dots, X_k take on specific values. If the function $f(\cdot)$ relating the dependent and independent variables is known, this is a very simple task—simply enter the specified values for X_1, X_2, \dots, X_k into the function $f(\cdot)$ and compute Y . In some cases, however, the functional form of $f(\cdot)$ might be unknown and must be estimated in order for the decision maker to make predictions about the dependent variable Y . These types of models are called **predictive models**. For example, a real estate appraiser might know that the value of a commercial property (Y) is influenced by its total square footage (X_1) and age (X_2), among other things. However, the functional relationship $f(\cdot)$ that relates these variables to one another might be unknown. By analyzing the relationship between the selling price, total square footage, and age of other commercial properties, the appraiser might be able to identify a function $f(\cdot)$ that relates these variables in a reasonably accurate manner.

The third category of models you are likely to encounter in the business world is called **descriptive models**. In these situations, a manager might face a decision problem that has a very precise, well-defined functional relationship $f(\cdot)$ between the independent variables X_1, X_2, \dots, X_k and the dependent variable Y . However, there might be great uncertainty as to the exact values that will be assumed by one or more of the independent variables X_1, X_2, \dots, X_k . In these types of problems, the objective is to describe the outcome or behavior of a given operation or system. For example, suppose a company is building a new manufacturing facility and has several choices about the type of machines to put in the new plant, as well as various options for arranging the machines. Management might be interested in studying how the various plant configurations would affect on-time shipments of orders (Y), given the uncertain number of orders that might be received (X_1) and the uncertain due dates (X_2) that might be required by these orders.

1.5 Business Analytics and the Problem-Solving Process

Business analytics focuses on identifying and leveraging business opportunities. But business *opportunities* can often be viewed or formulated as decision *problems* that need to be solved. As a result, the words “opportunity” and “problem” are used somewhat synonymously throughout this book. Indeed, some use the phrase “probortunity” to denote that every problem is also an opportunity.

Throughout our discussion, we have said that the ultimate goal in building models is to assist managers in making decisions that solve problems. The modeling techniques we will study represent a small but important part of the total problem-solving process. The “problem-solving process” discussed here is usually focused on leveraging a business opportunity of one sort or another. To become an effective modeler, it is important to understand how modeling fits into the entire problem-solving process. Because a model can be used to represent a decision problem or phenomenon, we

FIGURE 1.4

A visual model of the problem-solving process



might be able to create a visual model of the phenomenon that occurs when people solve problems—what we call the problem-solving process. Although a variety of models could be equally valid, the one in Figure 1.4 summarizes the key elements of the problem-solving process and is sufficient for our purposes.

The first step of the problem-solving process, identifying the problem (or ‘probortunity’), is also the most important. If we do not identify the correct decision problem associated with the business opportunity at hand, all the work that follows will amount to nothing more than wasted effort, time, and money. Unfortunately, identifying the problem to solve is often not as easy as it seems. We know that a problem exists when there is a gap or disparity between the present situation and some desired state of affairs. However, we usually are not faced with a neat, well-defined problem. Instead, we often find ourselves facing a “mess”!² Identifying the real problem involves gathering a lot of information and talking with many people to increase our understanding of the mess. We must then sift through all this information and try to identify the root problem or problems causing the mess. Thus, identifying the real problem (and not just the symptoms of the problem) requires insight, some imagination, time, and a good bit of detective work.

The end result of the problem-identification step is a well-defined statement of the problem. Simply defining a problem well will often make it much easier to solve. There is much truth in the saying, “A problem clearly stated is a problem half solved.” Having identified the problem, we turn our attention to creating or formulating a model of the problem. Depending on the nature of the problem, we might use a mental model, a visual model, a scale model, or a mathematical model. Although this book focuses on mathematical models, this does not mean that mathematical models are always applicable or best. In most situations, the best model is the simplest model that accurately reflects the relevant characteristic or essence of the problem being studied.

We will discuss several different business analytics techniques in this book. It is important that you not develop too strong a preference for any one technique. Some people want to formulate every problem they face as something that can be solved by their favorite modeling technique. This simply will not work.

As indicated earlier in Figure 1.3, there are fundamental differences in the types of problems a manager might face. Sometimes, the values of the independent variables affecting a problem are under the manager’s control; sometimes they are not. Sometimes, the form of the functional relationship $f(\cdot)$ relating the dependent and independent variables is well-defined, and sometimes it is not. These fundamental characteristics of the problem should guide your selection of an appropriate business analytics modeling technique. Your goal at the model-formulation stage is to select a modeling technique that fits your problem, rather than trying to fit your problem into the required format of a preselected modeling technique.

After you select an appropriate representation or formulation of your problem, the next step is to implement this formulation as a spreadsheet model. We will not dwell on the implementation process now because that is the focus of the remainder of this

²This characterization is borrowed from James R. Evans, *Creative Thinking in the Decision and Management Sciences* (Cincinnati, Ohio: South-Western Publishing, 1991), 89–115.

book. After you verify that your spreadsheet model has been implemented accurately, the next step in the problem-solving process is to use the model to analyze the problem it represents. The main focus of this step is to generate and evaluate alternatives that might lead to a solution of the problem. This often involves playing out a number of scenarios or asking several “What if?” questions. Spreadsheets are particularly helpful in analyzing mathematical models in this manner. In a well-designed spreadsheet model, it should be fairly simple to change some of the assumptions in the model to see what might happen in different situations. As we proceed, we will highlight some techniques for designing spreadsheet models that facilitate this type of “What if” analysis. “What if” analysis is also very appropriate and useful when working with nonmathematical models.

The end result of analyzing a model does not always provide a solution to the actual problem being studied. As we analyze a model by asking various “What if?” questions, it is important to test the feasibility and quality of each potential solution. The blueprints Frank Brock showed to his production employees represented the end result of his analysis of the problem he faced. He wisely tested the feasibility and quality of this alternative before implementing it, and discovered an important flaw in his plans. Thus, the testing process can give important new insights into the nature of a problem. The testing process is also important because it provides the opportunity to double check the validity of the model. At times, we might discover an alternative that appears to be too good to be true. This could lead us to find that some important assumption has been left out of the model. Testing the results of the model against known results (and simple common sense) helps ensure the structural integrity and validity of the model. After analyzing the model, we might discover that we need to go back and modify it.

The last step of the problem-solving process, implementation, is often the most difficult. Implementation begins by deriving managerial insights from our modeling efforts, framed in the context of the real-world problem we are solving, and communicating those insights to influence actions that affect the business situation. This requires crafting a message that is understood by various stakeholders in an organization and persuading them to take a particular course of action. (See Grossman *et al.*, 2008 for numerous helpful suggestions on this process.) It has been said that managers would rather live with problems they cannot solve than accept solutions they cannot understand. Making solutions understandable and acceptable is the heart of the implementation process.

By their very nature, solutions to problems involve people and change. For better or for worse, most people resist change. However, there are ways to minimize the seemingly inevitable resistance to change. For example, it is wise, if possible, to involve anyone who will be affected by the decision in all steps of the problem-solving process. This not only helps develop a sense of ownership and understanding of the ultimate solution, but it also can be the source of important information throughout the problem-solving process. As the Brock Candy story illustrates, even if it is impossible to include those affected by the solution in all steps, their input should be solicited and considered before a solution is accepted for implementation. Resistance to change and new systems can also be eased by creating flexible, user-friendly interfaces for the mathematical models that are often developed in the problem-solving process.

Throughout this book, we focus mostly on the model formulation, implementation, analysis, and testing steps of the problem-solving process, summarized previously in Figure 1.4. Again, this does not imply that these steps are more important than the others. If we do not identify the correct problem, the best we can hope for from our modeling effort is “the right answer to the wrong question,” which does not solve