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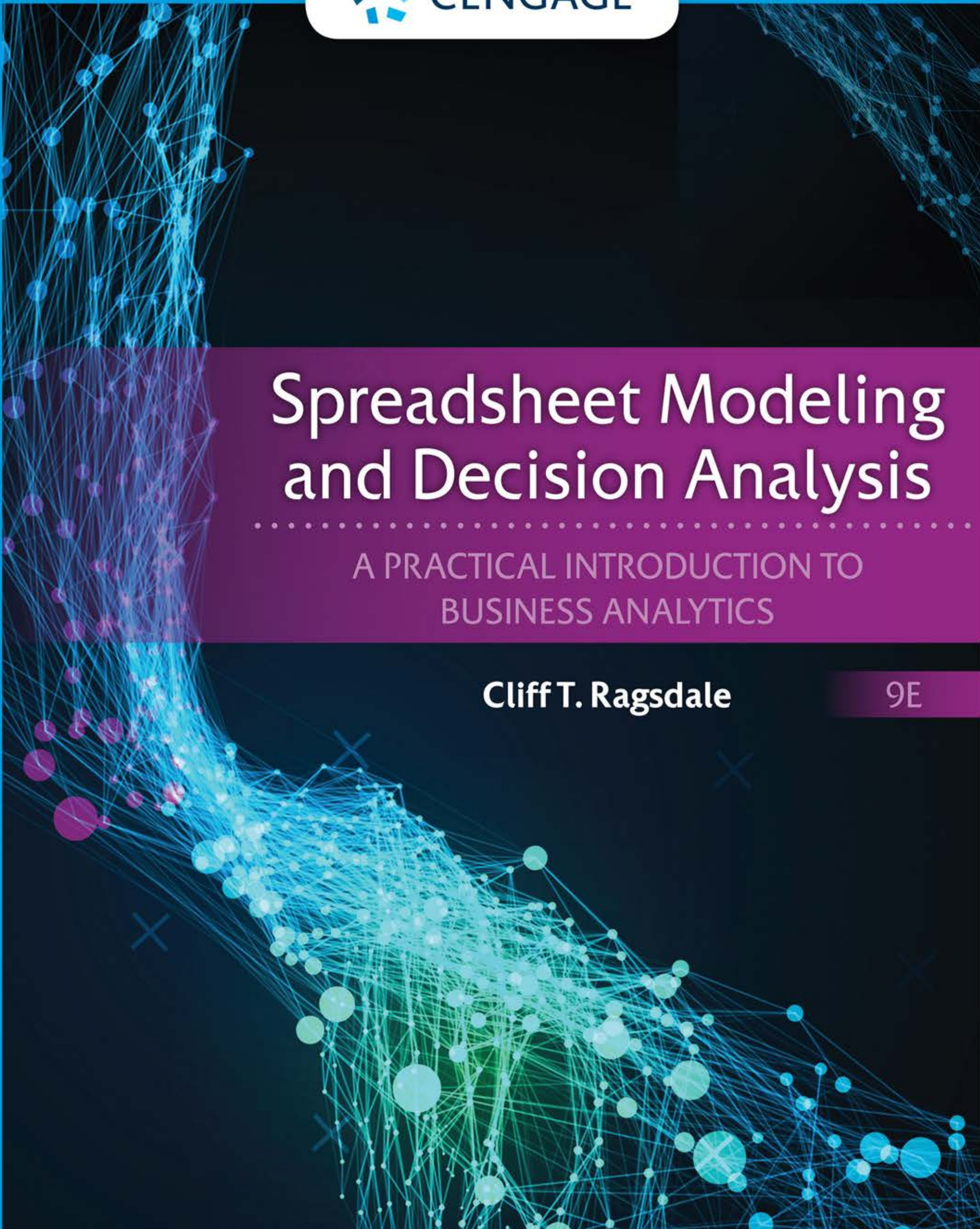

Spreadsheet Modeling and Decision Analysis

A PRACTICAL INTRODUCTION TO BUSINESS ANALYTICS

Cliff T. Ragsdale

9E

NINTH EDITION

Spreadsheet Modeling and Decision Analysis

A Practical Introduction to Business Analytics

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A Practical Introduction to Business Analytics

Cliff T. Ragsdale

Virginia Polytechnic Institute
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Cliff T. 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 Ninth Edition?

The ninth edition introduces a brand new WebAssign product. WebAssign provides students with electronic access to the book as well as online homework assignments, author videos, and exam questions for each chapter.

The most significant feature in the ninth edition of *Spreadsheet Modeling & Decision Analysis* is its focus on business analytics and extensive coverage and use of Analytic Solver for Education by Frontline Systems, Inc. Analytic Solver 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 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 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 also includes Frontline's Data Mining 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, affinity analysis, and more. Analytic Solver 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 ninth edition of *Spreadsheet Modeling & Decision Analysis* from the eighth edition include:

- Microsoft® Office 365 is featured throughout.
- Learning objectives have been included for every chapter.
- Chapter 1 includes new material on the interrelationship between descriptive, predictive, and prescriptive analytics techniques.
- Chapter 2 provides a new emphasis on the centrality of optimization across decision making and all analytics techniques.
- Chapter 10 has undergone extensive revision to reflect changes in Analytic Solver's Data Mining tool.
- Chapter 9 includes a new feature providing a more intuitive understanding of measuring goodness of fit via the R^2 statistic.
- Chapter 13 provides a new description of balking computations.
- Several new and revised end-of-chapter problems are included throughout.

Innovative Features

Aside from its strong spreadsheet orientation, the ninth 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 nonlinear 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 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. Sign up or sign in at www.cengage.com to search for and access this product and its online resources. 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.

WebAssign

Prepare for class with confidence using WebAssign from Cengage. This online learning platform fuels practice, so students can truly absorb what you learn—and are better prepared come test time. You can easily help your students master course concepts with this powerful digital platform and its content specific to business analytics. WebAssign provides students with electronic access to the book as well as online homework assignments, author videos, and exam questions for each chapter. You can customize assignment settings, add your own content, and easily access student and course analytics and communication tools.

Instructor and Student Resources

Additional instructor and student resources for this product are available online. Sign up or sign in at www.cengage.com to search for and access this product and its online resources. Instructor assets include:

- **Instructor's Manual.** The Instructor's Manual, prepared by the author, contains solutions to all the text problems and cases.
- **Test Bank.** Powered by Cognero®. Cognero® is a flexible, online system that allows you to author, edit, and manage test bank content from multiple Cengage solutions. Create multiple test versions in an instant, and deliver tests from your Learning Management System (LMS), your classroom, or wherever you want.
- **PowerPoint® Slides.** PowerPoint presentation slides, prepared by Kevin Scheibe, provide ready-made lecture material for each chapter in the book.

Student assets include:

- **Datasets.** Sign up or sign in at www.cengage.com to search for and access this product and its online resources.

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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; Renee Schnee, Content Manager; and Nancy Marchant, Subject Matter Expert. I feel very fortunate and privileged to work with them.

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 and supporting me so graciously and quickly throughout my revision work on this book. In my opinion, Analytic Solver 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 our sons, Thomas, Patrick, and Daniel, who have all grown into fine young men of whom we are exceedingly proud.

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.

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Brief Contents

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Chapter 1

Introduction to Modeling and Decision Analysis

Learning Objectives

After reading this chapter students should be able to:

1. Define the terms *computer model* and *spreadsheet model*.
2. Define the term *business analytics*.
3. Describe various ways models are used in decision making.
4. Describe the benefits of using models in decision making.
5. Define the components of a mathematical model.
6. Describe the relation between mathematical models and spreadsheet models.
7. Differentiate between descriptive, predictive, and prescriptive models.
8. Describe the problem-solving process.
9. Describe anchoring and framing effects.
10. Describe the relationship between good decisions and good outcomes.

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, 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, flexible, 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.

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 recent "home runs" from the Edelman Awards.

- 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.

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 high-speed computers and who possessed an advanced knowledge of mathematics, computer programming languages, and specialized software packages. However, the proliferation of powerful 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 several 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. 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 non-mathematical 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.

"All Models Are Wrong, But Some Are Useful."

Professor George E.P. Box (1919–2013) was a British statistician, often described as one of the great statistical minds of the 20th century who famously opined that "All models are wrong, but some are useful." Since all models are wrong, Box thought it pointless to try to obtain a correct one by "excessive elaboration." Instead, he regarded the ability to devise simple but useful models as the signature of a great analytical mind and overelaboration as often the mark of mediocrity.

[1] Colson, Charles and Jack Eckerd. *Why America Doesn't Work.* Denver, CO: Word Publishing, 1991, pp. 146–147.

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:

$$\text{PROFIT} = \text{REVENUE} - \text{EXPENSES} \tag{1.1}$$

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:

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

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:

$$Y = f(X_1, X_2) \tag{1.3}$$

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 $f(\cdot)$ would be 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:

$$Y = f(X_1, X_2, \ldots, X_k) \tag{1.4}$$

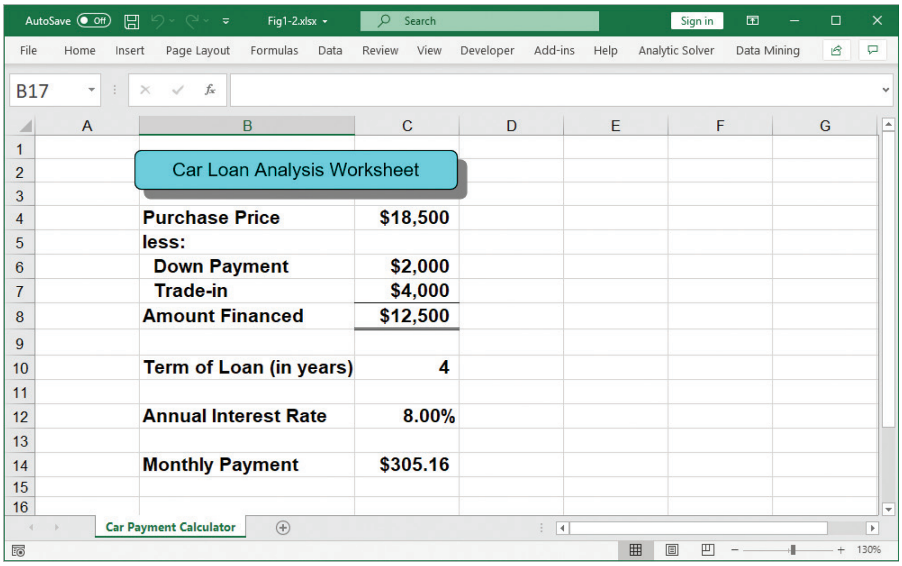
In equation 1.4, the dependent variable Y represents some bottom-line performance measure of the problem we are modeling. The terms $X_1, X_2, \ldots, X_k$ represent the different independent variables that play some role or have some impact in determining the value of Y. Again, $f(\cdot)$ is the function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

FIGURE 1.2

Example of a simple spreadsheet model



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 and probably most spreadsheet models created in the business world too.

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 major categories of modeling (or analytics) techniques presented in this book—descriptive models, predictive models, and prescriptive models. Figure 1.3 summarizes the characteristics and some of the techniques associated with each of these categories.

FIGURE 1.3

Categories and characteristics of business analytics modeling techniques

	Model Characteristics		
Category	**Form of $f(\cdot)$**	**Values of the Independent Variables**	**Example Analytics Techniques**
Descriptive Models	Known, well-defined	Known, unknown, or uncertain	Basic Statistics, Simulation, Queuing Analysis
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
Prescriptive Models	Known, well-defined	Known or under decision maker's control	Linear Programming, Networks, Integer Programming, Goal Programming, Economic Order Quantity, Nonlinear Programming

The first 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 $X1_1$, X_2, …, X_k and the dependent variable Y. In some cases, historical values of the independent variables will be known and our task is simply to summarize them by running them through functions that compute descriptive statistics like averages, maximums, minimums, and variances. However, in other cases, 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, …, X_k. In these types of problems, the goal 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.

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, …, 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, …, X_k into the function $f(\cdot)$ and compute Y. In many 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 decision models a manager might face involves a very precise, well-defined functional relationship $f(\cdot)$ between the independent variables X_1, X_2, …, 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 to determining the values of the independent variables X_1, X_2, …, 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.

As illustrated in Figure 1.4, these categories of mathematical models are not independent of one another and can interact in various ways. For example, predictive and prescriptive models often use numbers calculated by descriptive models. Similarly, predictive models can be fit to historical data that are descriptive in nature and then produce forecasts that become inputs for prescriptive models. Finally, prescriptive modeling techniques are often used to optimize the performance of predictive and descriptive models. Just as a good basketball player must master the disciplines of dribbling, passing, and shooting, and seamlessly integrate those skills to win games, a skilled business analytics professional must master the techniques of descriptive, predictive, and prescriptive modeling and integrate them as needed to solve problems.

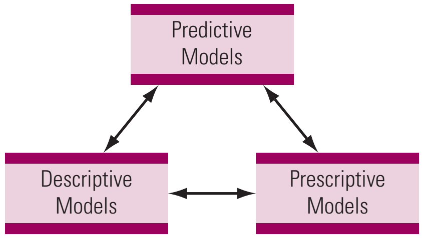


FIGURE 1.4

Interactions of different modeling techniques

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 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 model in Figure 1.5 summarizes the key elements of the problem-solving process and is sufficient for our purposes.

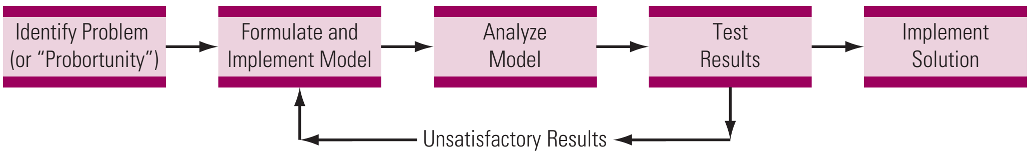


FIGURE 1.5

A visual model of the problem-solving process

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 identify the various **stakeholders** for the problem, identify what they value, and understand what a successful solution looks like from their various perspectives. 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

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

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.

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. 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.

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 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 motivate actions that affect the business situation. This requires crafting a message that is understood by the 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