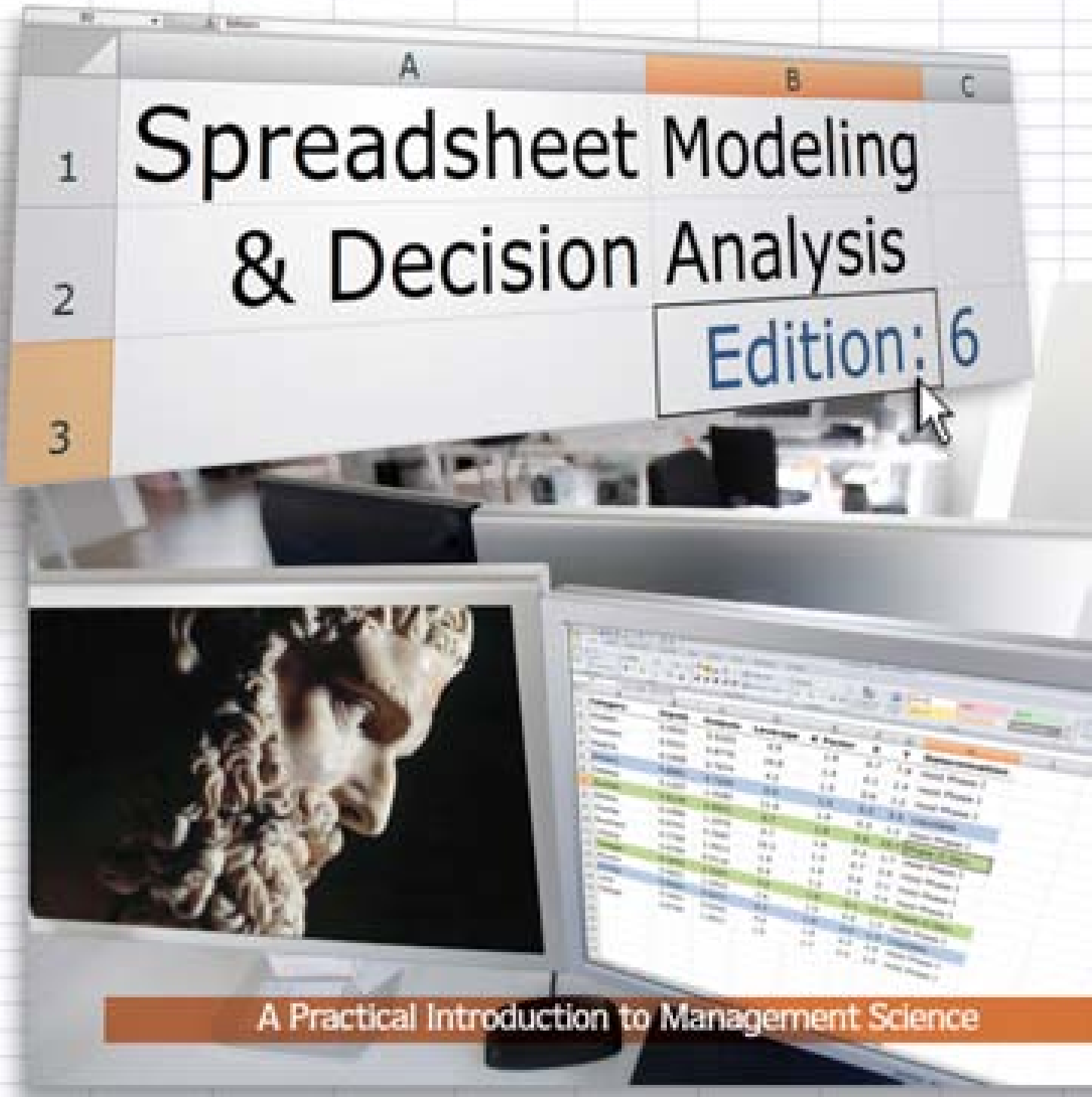

Cliff T.
Ragsdale

Spreadsheet Modeling & Decision Analysis 6e

A Practical Introduction to Management Science

Cliff 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 & Decision Analysis, Sixth Edition

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 operations research/management science (OR/MS) course. This simultaneously develops students' skills with a standard tool of today's business world and opens their eyes to how a variety of OR/MS techniques can be used in this modeling environment. Spreadsheets also capture students' interest and add a new relevance to OR/MS 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 OR/MS 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 screenshots are provided for each example, and software tips are included throughout the text as needed.

What's New in the Sixth Edition?

The most significant change in the sixth edition of *Spreadsheet Modeling & Decision Analysis* is its extensive coverage and use of Risk Solver Platform™ for Education by Frontline Systems, Inc. Risk Solver Platform for Education is a new add-in for Excel that provides access to analytical tools for performing optimization, simulation, sensitivity analysis, and discriminant analysis, as well as the ability to create decision trees. Risk 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. Risk 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, Risk Solver Platform provides students with more than 100 customized dialogs that provide diagnoses of various model conditions and explain the steps involved in solving problems. Risk Solver Platform offers numerous other features and will transform the way we approach OR/MS education now and in the future.

Additional changes in the revised sixth edition of *Spreadsheet Modeling & Decision Analysis* from the fifth edition include the following:

- Microsoft® Office 2010 is featured throughout.
- Data files and software to accompany the book are now available for download online.
- Chapter 1 features a new way of characterizing the quality and outcomes of decisions.

- Chapter 3 introduces Risk Solver Platform's ability to perform multiple optimizations in the context of Data Envelopment Analysis (DEA).
- Chapter 4 features new coverage of using multiple optimizations for sensitivity analysis and a new section on robust optimization.
- Chapters 8, 10, and 11 feature new coverage of Excel's AVERAGEIF( ) function.
- Chapter 12 features the interactive simulation capabilities of Risk Solver Platform, including the use of Value at Risk constraints and simulation optimization.
- Chapter 14 (formerly Chapter 15) now covers Decision Analysis featuring Risk Solver Platform's decision tree and sensitivity analysis tools.
- Chapter 15 (formerly Chapter 14) is now available exclusively online and covers project management, including Microsoft Project 2010.
- Several new and revised end-of-chapter problems have been added throughout.

Innovative Features

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

- Algebraic formulations and spreadsheets are used side by side to help develop conceptual thinking skills.
- Step-by-step instructions and numerous annotated screenshots 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.
- A unique and accessible chapter covering discriminant analysis is provided.
- Sections entitled "The World of Management Science" 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 OR/MS in Chapter 1. Chapters 2 through 8 cover various topics in deterministic 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, discriminant analysis, and time series analysis.

Chapters 12 and 13 cover stochastic modeling techniques: simulation and queuing theory. Coverage of simulation using the inherent capabilities of Excel alone is available on the textbook's website (for more information, visit **www.cengage.com/decisionsciences/ragsdale.** Chapter 14 covers decision analysis, and Chapter 15 (available online) 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 on the website. Following this, an instructor could cover the material on optimization, forecasting, 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 the revised edition of *Spreadsheet Modeling & Decision Analysis*. All instructor ancillaries are provided online at the textbook's website. Included in this convenient format are the following:

- **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 of the University of Wisconsin-Whitewater, includes multiple-choice, true/false, and short answer problems for each text chapter. It also includes mini-projects that may be assigned as take-home assignments. The Test Bank is included as Microsoft Word files. The Test Bank also comes separately in a computerized ExamView™ format that allows instructors to use or modify the questions and create original questions.
- **PowerPoint Presentation Slides.** Microsoft PowerPoint presentation slides, prepared by the author, provide ready-made lecture material for each chapter in the book.

Instructors who adopt the text for their classes may contact their Cengage Learning Representative to request the Instructor's Resource CD (ISBN 1-111-56841-3).

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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 Learning: Charles McCormick, Jr., Senior Acquisitions Editor; Maggie Kubale, Developmental Editor; Holly Henjum, Senior Content Project Manager; Chris Valentine, Media Editor; and Adam Marsh, Marketing Manager. I feel very fortunate and privileged to work with each of you.

A very special word of thanks to my friend Dan Fylstra and the crew at Frontline Systems (**www.solver.com**) for conceiving and creating Risk Solver Platform and supporting me so graciously and quickly throughout my revision work on this book. In my opinion, Risk Solver Platform is the most significant development in OR/MS 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. (You will always be the one.) This book is dedicated to our sons, Thomas, Patrick, and Daniel. I am proud of each one of you and will always be so glad that God let me be your daddy and the leader of the Ragsdale ragamuffin band.

Final Thoughts

I hope you enjoy the spreadsheet approach to teaching OR/MS 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

Contents

Chapter 1

Introduction to Modeling and Decision Analysis

1.0 Introduction

This book is titled *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Management Science*, 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, 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.

During the past decade, millions of business people discovered that one of the most effective ways to analyze and evaluate decision alternatives involves using electronic spreadsheets to build computer models of the 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 businessperson 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 management science that can be applied in spreadsheet models to assist in the decision-analysis process. For our purposes, we will define **management science** as a field of study that uses computers, statistics, and mathematics to solve business problems. It involves applying the methods and tools of science to management and decision making. It is the science of making better decisions. Management science is also sometimes referred to as operations research or decision science. See Figure 1.1 for a summary of how management science has been applied successfully in a number of real-world situations.

In the not-too-distant past, management science 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 and computer programming languages. However, the proliferation of powerful PCs and the development of easy-to-use electronic spreadsheets have made the tools of management science far more practical and available to a much larger audience. Virtually everyone who uses a

FIGURE 1.1

Examples of successful management science applications

Over the past decade, scores of operations research and management science projects saved companies millions of dollars. 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 OR/MS projects during the past year. Here are some of the "home runs" from the 2008 Edelman Awards (described in *Interfaces*, Vol. 39, No. 1, January-February, 2009).

- **Xerox** has invented, tested, and implemented an innovative group of productivity-improvement solutions, trademarked LDP Lean Document Production® solutions, for the $100 billion printing industry in the United States. These solutions have provided dramatic productivity and cost improvements for both print shops and document-manufacturing facilities. These solutions have extended the use of operations research to small- and medium-sized print shops, while increasing the scope of applications in large document-production facilities. **Benefits:** LDP solutions have generated approximately $200 million of incremental profit across the Xerox customer value chain since their initial introduction in 2000 and improved productivity by 20–40%.
- The network for transport of natural gas on the Norwegian Continental Shelf is the world's largest offshore pipeline network. The gas flowing through this network represents approximately 15% of European consumption. In a network of interconnected pipelines, system effects are prevalent, and the network must be analyzed as a whole to determine the optimal operation. The main Norwegian shipper of natural gas, **StatoilHydro**, uses a tool called GassOpt that allows users to graphically model their network and run optimizations to find the best network configuration and routing for transporting gas. **Benefits:** The company estimates that its accumulated savings related to the use of GassOpt were approximately US $2 billion as of 2008.
- In the United States, the **Federal Aviation Administration** (FAA) is responsible for providing air traffic management services and frequently faces situations where a large-scale weather system reduces airspace capacity. In June 2006, the FAA began using a tool known as Airspace Flow Programs that gave the FAA the ability to control activity in congested airspaces by issuing ground delays customized for each individual flight when large-scale thunderstorms block major flight routes. **Benefits:** During its first two years of use, the system saved aircraft operators an estimated $190 million.
- In 2006, **Netherlands Railways** introduced a new timetable designed to support the growth of passenger and freight transport on a highly used railway network and to reduce the number of train delays. Constructing a railway timetable from scratch for about 5,500 daily trains is a complex challenge. To meet this challenge, techniques were used to generate several timetables, one of which was finally selected and implemented. Additionally, because rolling stock and crew costs are the most significant expenses for a railway operator, OR (operations research) tools were used to design efficient schedules for these two resources. **Benefits:** The more efficient resource schedules and the increased number of passengers have increased annual profit by 40 million Euros (US $60 million). Moreover, the trains are transporting more passengers on the same railway infrastructure with more on-time arrivals than ever before.

spreadsheet today for model building and decision making is a practitioner of management science—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 really 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 decision problems, 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 in order 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.

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