Data, Models and Decisions:

the Fundamentals of Management Science

数据、模型与决策

管理科学基础

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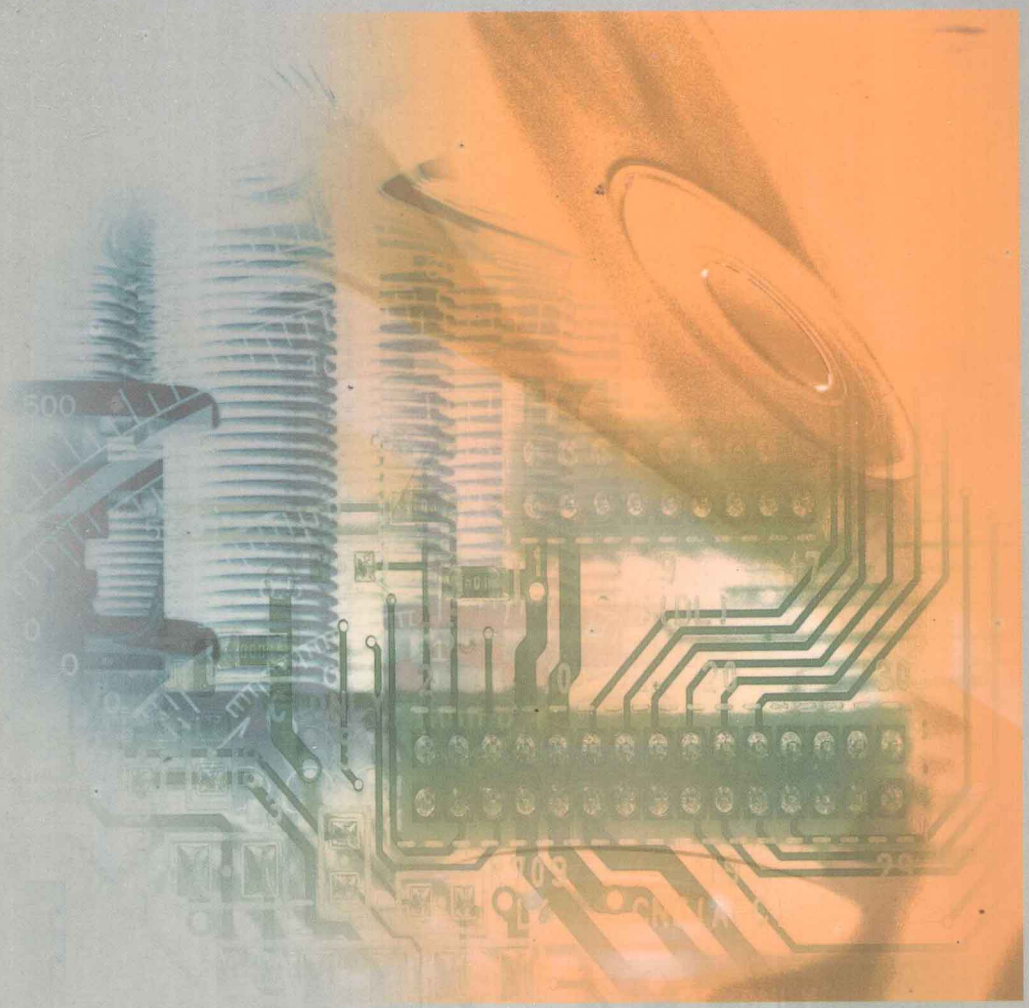

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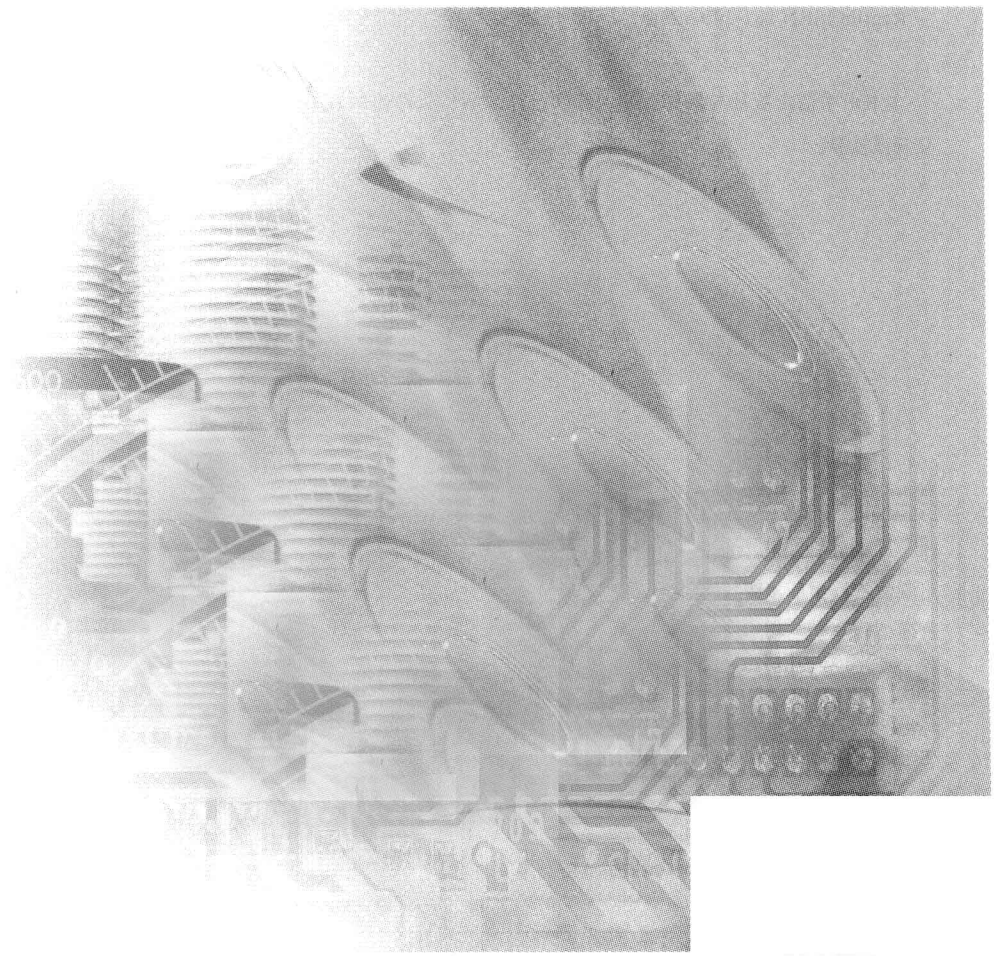

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Preface

MANY MANAGERIAL DECISIONS—REGARDLESS OF THEIR FUNCTIONAL ORIENTATION—are increasingly being based on analysis using quantitative models from the discipline of management science. Management science tools, techniques, and concepts (decision trees, probability and statistics, simulation, regression, linear optimization, and nonlinear and discrete optimization) have dramatically changed the way business operates in finance, service operations, manufacturing, marketing, and consulting. When used wisely, management science models and tools have enormous power to enhance the competitiveness of almost any company or enterprise.

This book is designed to introduce management students—from a wide variety of backgrounds—to the fundamental techniques of using data and management science tools and models to think structurally about decision problems, make more informed management decisions, and ultimately enhance decision-making skills.

EDUCATIONAL PHILOSOPHY

We believe that the use of management science tools and models represents the future of best-practices for tomorrow's successful companies. It is therefore imperative that tomorrow's business leaders be well-versed in the underlying concepts and modeling tools of management science, broadly defined. George Dantzig, a founding father of modern management science, wrote, "The final test of any theory is its capacity to solve the problems which originated it."[1] It is our objective in this book to contribute to preparing today's management students to become tomorrow's business leaders, and thereby demonstrate that the tools and models of management science pass Dantzig's test.

This book is designed with the following three principles in mind:

- **Rigor.** In order to become tomorrow's business leaders, today's managers need to know the fundamental quantitative concepts, tools, and modeling methods. The focus here is on *fundamental concepts*. While management students should not be expected to remember specific formulas, spreadsheet commands, or technical

[1] *Linear Programming and Extensions* by George B. Dantzig, Princeton University Press, Princeton, New Jersey, 1963.

details after they graduate, it is important for them to retain fundamental concepts necessary for managing in an increasingly technically-oriented business environment. Simply teaching students to plug numbers into black-box models is not relevant to a student's education. This book emphasizes how, what, and why certain tools and models are useful, and what their ramifications would be when used in practice. In recognition of the wide variety of backgrounds of readers of this book, however, we have indicated with a star (*) some sections that contain more advanced material, and their reading can be omitted without loss of continuity.

- **Relevance.** All of the material presented in the book is immediately applied to realistic and representative business scenarios. Because students recognize a spreadsheet as a standard business environment, the spreadsheet is the basic template for almost every model that is presented in the book. Furthermore, the book features over thirty business cases that are drawn from our own consulting experience or the experience of our students and cover a wide spectrum of industries, management functions, and modeling tools.
- **Readability.** We have deliberately written the book in a style that is engaging, informative, informal, conversational in tone, and imbued with a touch of humor from time to time. Many students and colleagues have praised the book's engaging writing style. Most of the chapters and cases have been pre-tested in classrooms at MIT Sloan, Harvard Business School, Wharton, Columbia University, University of British Columbia, Ohio State University, Northwestern University, and McGill University, plus several universities overseas.

DISTINGUISHING CHARACTERISTICS OF THIS BOOK

Unified Treatment of Quantitative Methods. The book combines topics from two traditionally distinct quantitative subjects: probability/statistics, and optimization models, into one unified treatment of quantitative methods and models for management and business. The book stresses those fundamental concepts that we believe are most important for the practical analysis of management decisions. Consequently, it focuses on modeling and evaluating uncertainty explicitly, understanding the dynamic nature of decision-making, using historical data and limited information effectively, simulating complex systems, and allocating scarce resources optimally.

Concise Writing. Despite its wide coverage, the book is designed to be more concise than most existing textbooks. That is, the relevant points are made in the book once or twice, with appropriate examples, and then reinforced in the exercises and in the case modules. There is no excess repetition of material.

Appropriate Use of Spreadsheets. Because students recognize a spreadsheet as a standard business environment, the spreadsheet is the basic template for almost every model presented in the book. In addition, for simulation modeling, linear regression, and linear, nonlinear and discrete optimization, we present command instructions on how to construct and run these models in a spreadsheet environment. However, the book presumes that students already have a basic familiarity with spreadsheets, and so the book is not a spreadsheet user's manual. Unlike many existing textbooks, the use of spreadsheets in our book is designed not to interfere with the development of key concepts. For example, in Chapters 7–9, which cover optimization models, we introduce and develop the concept of an optimization model by defining decision variables and by explicitly constructing the relevant constraints

and objective function. Only then do we translate the problem into a spreadsheet for solution by appropriate software. In context, spreadsheets are a vehicle for working with models, but are not a substitute for thinking through the construction of models and analyzing modeling-related issues.

Case Material for Tomorrow's Managers. The book features over thirty business cases that are rich in context, realistic, and are often designed with the protagonist being a relatively young MBA graduate facing a difficult management decision. They cover a wide spectrum of industries, functional areas of management, and modeling tools.

A Capstone Chapter on Integration in the Art of Decision Modeling. Chapter 10, which is the last chapter in the book, illustrates the integrated use of decision modeling in three sectors: the airline industry, the investment management industry, and the manufacturing sector. This chapter contains much material to motivate students about the power of using management science tools and models in their careers.

AUXILIARY MATERIAL

The book is accompanied by a Student Resource CD-ROM that contains:

1. Spreadsheet data and partially- and/or fully-constructed spreadsheet models for many of the cases in the book.
2. Crystal Ball® simulation software, which is a Microsoft Excel® add-on, for use in the construction and use of the simulation case models in Chapter 5.
3. Answers to half of the exercises in each chapter.

For instructors, there is an Instructor's Resource CD-ROM that contains the Solutions Manual, Microsoft PowerPoint® Presentation Slides, Test Bank, and Thomson Learning Testing Tools™ Testing Software. The Solutions Manual provides answers to all the exercises and cases in the book. PowerPoint Slides detail the concepts presented in each chapter and are designed to enhance lecture presentations. A comprehensive test bank comes in two formats: Microsoft Word® document files, and Testing Tools, which allows easy selection and arrangement of only the chosen questions.

In addition to the auxiliary material listed above, resources for both students and instructors are available on the text web site: bertsimas.swcollege.com.

A TOUR OF THE BOOK

Chapter 1: Decision Analysis. This chapter starts right out by introducing decision trees and the decision tree methodology. This material is developed from an intuitive point of view without any formal theory of probability. Students immediately see the value of an easy-to-grasp model that helps them to structure a decision problem, and they also see the need for a theory of probability to model uncertainty, which is developed in the next chapter.

Chapter 2: Fundamentals of Discrete Probability. This chapter covers the laws of probability, including conditional probability. We cover the arithmetic of conditional probability by using probability tables instead of a "Bayes' Theorem" formula in order to keep the concepts as intuitive as possible. We then cover discrete random variables and probability distributions, including the binomial distribution. As preparation for finance, we cover linear functions of a random variable, covariance and correlation of two random variables, and sums of random variables.

Chapter 3: Continuous Probability Distributions and their Applications. This chapter introduces continuous random variables, the probability density function, and the cumulative distribution function. We cover the continuous uniform distribution and the Normal distribution in detail, showing how the Normal distribution arises in models of many management problems. We then cover sums of Normally distributed random variables and the Central Limit Theorem. The Central Limit Theorem points the way to statistical inference, which is covered in the next chapter.

Chapter 4: Statistical Sampling. This chapter covers the basics of statistical sampling: collecting random samples, statistics of a random sample, confidence intervals for the mean of a distribution and for the sample proportion, experimental design, and confidence intervals for the mean of the difference of two random variables.

Chapter 5: Simulation Modeling: Concepts and Practice. In this chapter, we return to constructing and using models, in this case simulation models based on random number generators. We develop the key ideas of simulation with a prototypical management decision problem involving the combination of different random variables. We show how simulation models are constructed, used, and analyzed in a management context.

Chapter 6: Regression Models: Concepts and Practice. This chapter introduces linear regression as a method of prediction. We cover all of the basics of multiple linear regression. Particular care is taken to ensure that students learn how to evaluate and validate a regression model. We also discuss warnings and issues that arise in using linear regression, and we cover extended regression modeling techniques such as nonlinear transformations and dummy variables. We present instructional material on constructing, solving, and interpreting regression models using spreadsheet software.

Chapter 7: Linear Optimization. In this chapter, we develop the basic concepts for constructing, solving, and interpreting the solution of a linear optimization model. We present instructional material on using linear optimization in a spreadsheet. In addition to standard topics, we also focus on shadow prices and the importance of sensitivity analysis of a linear optimization model as an adjunct to informed decision-making. As an optional topic, we show how to model uncertainty in linear optimization using two-stage linear optimization under uncertainty.

Chapter 8: Nonlinear Optimization. This chapter focuses on the extension of the linear optimization model to nonlinear optimization, stressing the key similarities and differences between linear and nonlinear optimization models. We present instructional material on solving a nonlinear optimization model in a spreadsheet. We also focus on portfolio optimization as an important application of nonlinear optimization modeling in management.

Chapter 9: Discrete Optimization. In this chapter, we show how discrete optimization arises in the modeling of many management problems. We focus on binary optimization, integer optimization, and mixed-integer optimization models. We present instructional material on solving a discrete optimization model in a spreadsheet. We also illustrate how discrete optimization problems are solved, to give students a feel for the potential pros and cons of constructing large scale models.

Chapter 10: Integration in the Art of Decision Modeling. This is the "capstone" chapter of the book, which illustrates how management science models and tools are used in an integrative way in today's successful enterprises. This is accomplished by focusing on three sectors: the airline industry, the investment management industry,

and the manufacturing sector. This chapter contains much material to motivate students about the power of using management science tools and models in their careers.

USING THE BOOK IN COURSE DESIGN

This book can be used to teach several different types of courses to management students. For a one-semester course in all of management science, we recommend using all of Chapters 1–10 in order. For a half-semester course focusing only on the most basic material, we recommend Chapters 1–3, 6, and 7. Alternatively, Chapters 1–6 can be used in their entirety as part of a course on the fundamentals of probability and statistical modeling, including regression. Yet a fourth alternative is to use Chapters 1 and 7–10 for a half-semester course on optimization modeling for managers.

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Finally, and perhaps most importantly, we are grateful to our families and our friends, but especially to our wives, Georgia and Sandy, for their love and support in the course of this extensive project.

Dimitris Bertsimas
Robert M. Freund
Cambridge, December 1999

About the Authors

Dimitris Bertsimas is the Boeing Professor of Management Science and Operations Research at the MIT Sloan School of Management, where he has been teaching quantitative methods to management students for over twelve years. He has won numerous scholarly awards for his research in combinatorial optimization, stochastic processes, and applied modeling, including the SIAM Optimization Prize and the Erlang Prize in probabilistic methods. He serves on the editorial boards of several journals. Professor Bertsimas is also the co-author, together with John Tsitsiklis, of the textbook *Introduction to Linear Optimization*, published by Athena Scientific in 1997.

Robert M. Freund is the Theresa Seley Professor of Management Science and Operations Research at the MIT Sloan School of Management. He has also been responsible for the design, development, and delivery of the quantitative methods curriculum at the Harvard Business School. He has been teaching quantitative methods to management students for over sixteen years. He has won a variety of teaching awards, including being named the Teacher of the Year for the Sloan School three times. His research is in the areas of linear and nonlinear optimization, and in applied modeling. Professor Freund is also a co-editor of the journal *Mathematical Programming*.

DEDICATION

To my parents Aspa and John Bertsimas, and to Georgia.
DB

To the memory of my mother Esta, to my father Richard Freund, and to Sandy.
RMF

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CHARTER 1

Decision Analysis

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PERHAPS THE MOST FUNDAMENTAL AND IMPORTANT TASK THAT A MANAGER FACES is to make decisions in an uncertain environment. For example, a manufacturing manager must decide how much capital to invest in new plant capacity, when future demand for products is uncertain. A marketing manager must decide among a variety of different marketing strategies for a new product, when consumer response to these different marketing strategies is uncertain. An investment manager must decide whether or not to invest in a new venture, or whether or not to merge with another firm in another country, in the face of an uncertain economic and political environment.

In this chapter, we introduce a very important method for structuring and analyzing managerial decision problems in the face of uncertainty, in a systematic and rational manner. The method goes by the name **decision analysis.** The analytical model that is used in decision analysis is called a **decision tree.**