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**A Modeling and Case Studies Approach with Spreadsheets**

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# Introduction to Management Science

**A Modeling and Case Studies Approach  
with Spreadsheets**

Third Edition

**Frederick S. Hillier**

*Stanford University*

**Mark S. Hillier**

*University of Washington*

*Cases developed by*

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*Northwestern University*

**Molly Stephens**

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INTRODUCTION TO MANAGEMENT SCIENCE: A MODELING AND CASE STUDIES APPROACH WITH SPREADSHEETS

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To our wives—Ann and Christine—for their  
steadfast support and to the memory of a beloved  
mentor, Gerald J. Lieberman, who was one of the  
true giants of our field

Frederick S. Hillier  
Mark S. Hillier

# About the Authors

**Frederick S. Hillier** is professor emeritus of operations research at Stanford University. Dr. Hillier is especially known for his classic, award-winning text, *Introduction to Operations Research*, co-authored with the late Gerald J. Lieberman, which has been translated into well over a dozen languages and is currently in its 8th edition. The 6th edition won honorable mention for the 1995 Lanchester Prize (best English-language publication of any kind in the field) and Dr. Hillier also was awarded the 2004 INFORMS Expository Writing Award for the 8th edition. His other books include *The Evaluation of Risky Interrelated Investments*, *Queueing Tables and Graphs*, *Introduction to Stochastic Models in Operations Research*, and *Introduction to Mathematical Programming*. He received his BS in industrial engineering and doctorate specializing in operations research and management science from Stanford University. The winner of many awards in high school and college for writing, mathematics, debate, and music, he ranked first in his undergraduate engineering class and was awarded three national fellowships (National Science Foundation, Tau Beta Pi, and Danforth) for graduate study. Dr. Hillier's research has extended into a variety of areas, including integer programming, queueing theory and its application, statistical quality control, and production and operations management. He also has won a major prize for research in capital budgeting. Twice elected a national officer of professional societies, he has served in many important professional and editorial capacities. For example, he served The Institute of Management Sciences as vice president for meetings, chairman of the publications committee, associate editor of *Management Science*, and co-general chairman of an international meeting. He currently is continuing to serve as the founding series editor for the International Series in Operations Research and Management Science for Springer Science + Business Media. He has had visiting appointments at Cornell University, the Graduate School of Industrial Administration of Carnegie-Mellon University, the Technical University of Denmark, the University of Canterbury (New Zealand), and the Judge Institute of Management Studies at the University of Cambridge (England).

**Mark S. Hillier**, son of Fred Hillier, is associate professor of quantitative methods at the School of Business at the University of Washington. Dr. Hillier received his BS in engineering (plus a concentration in computer science) from Swarthmore College, and he received his MS with distinction in operations research and PhD in industrial engineering and engineering management from Stanford University. As an undergraduate, he won the McCabe Award for ranking first in his engineering class, won election to Phi Beta Kappa based on his work in mathematics, set school records on the men's swim team, and was awarded two national fellowships (National Science Foundation and Tau Beta Pi) for graduate study. During that time, he also developed a comprehensive software tutorial package, *OR Courseware*, for the Hillier-Lieberman textbook, *Introduction to Operations Research*. As a graduate student, he taught a PhD-level seminar in operations management at Stanford and won a national prize for work based on his PhD dissertation. At the University of Washington, he currently teaches courses in management science and spreadsheet modeling. He has won several MBA teaching awards for the core course in management science and his elective course in spreadsheet modeling, as well as a universitywide teaching award for his work in teaching undergraduate classes in operations management. He also has been awarded an appointment to the Evert McCabe Endowed Faculty Fellowship. His research interests include issues in component commonality, inventory, manufacturing, and the design of production systems. A paper by Dr. Hillier on component commonality won an award for best paper of 2000–2001 in *IIE Transactions*.

# About the Case Writers

**Karl Schmedders** is an associate professor with tenure in the Department of Managerial Economics and Decision Sciences at the Kellogg School of Management at Northwestern University, where he teaches quantitative methods for managerial decision making. His research interests include applications of management science in economic theory, general equilibrium theory with incomplete markets, asset pricing, portfolio choice, and computational economics. Dr. Schmedders received his doctorate in operations research from Stanford University, where he taught both undergraduate and graduate classes in management science. Among the classes taught was a case studies course in management science and he subsequently was invited to speak at a conference sponsored by the Institute of Operations Research and Management Sciences (INFORMS) about his successful experience with this course. He received several teaching awards at Stanford, including the university's prestigious Walter J. Gores Teaching Award. He also has received several awards at both the Kellogg School of Management and the WHU Koblenz (a leading business school in Germany).

**Molly Stephens** is an associate in the Los Angeles office of Quinn, Emanuel, Urquhart, Oliver & Hedges, LLP. She graduated from Stanford with a BS in industrial engineering and an MS in operations research. Ms. Stephens taught public speaking in Stanford's School of Engineering and served as a teaching assistant for a case studies course in management science. As a teaching assistant, she analyzed management science problems encountered in the real world and transformed these into classroom case studies. Her research was rewarded when she won an undergraduate research grant from Stanford to continue her work and was invited to speak at INFORMS to present her conclusions regarding successful classroom case studies. Following graduation, Ms. Stephens worked at Andersen Consulting as a systems integrator, experiencing real cases from the inside, before receiving her JD degree from the University of Texas School of Law.

# Preface

We have long been concerned that traditional management science textbooks have not taken the best approach in introducing business students to this exciting field. Our goal when developing this book was to break out of the old mold and present new and innovative ways of teaching management science more effectively. We have been gratified by the favorable response to our efforts. Many reviewers and other users of the first two editions of the book have expressed appreciation for its various distinctive features, as well as for its clear presentation at just the right level for their business students.

Our goal for this third edition has been to build on the strengths of the first two editions. Co-author Mark Hillier has won several schoolwide teaching awards for his spreadsheet modeling and management science courses at the University of Washington while using the first two editions, and this experience has led to many improvements in the current edition. We also incorporated many user comments and suggestions. Throughout this process, we took painstaking care to enhance the quality of the preceding edition while maintaining the distinctive orientation of the book.

This distinctive orientation is one that closely follows the recommendations in the 1996 report of the operating subcommittee of the INFORMS Business School Education Task Force, including the following extract.

There is clear evidence that there must be a major change in the character of the (introductory management science) course in this environment. There is little patience with courses centered on algorithms. Instead, the demand is for courses that focus on business situations, include prominent non-mathematical issues, use spreadsheets, and involve model formulation and assessment more than model structuring. Such a course requires new teaching materials.

This book is designed to provide the teaching materials for such a course.

In line with the recommendations of this task force, we believe that a modern introductory management science textbook should have three key elements. As summarized in the subtitle of this book, these elements are a *modeling* and *case studies* approach with *spreadsheets*.

## SPREADSHEETS

The modern approach to the teaching of management science clearly is to use spreadsheets as a primary medium of instruction. Both business students and managers now live with spreadsheets, so they provide a comfortable and enjoyable learning environment. Modern spreadsheet software, including Microsoft Excel used in this book, now can be used to do real management science. For student-scale models (which include many practical real-world models), spreadsheets are a much better way of implementing management science models than traditional algebraic solvers. This means that the algebraic curtain that was so prevalent in traditional management science courses and textbooks now can be lifted.

However, with the new enthusiasm for spreadsheets, there is a danger of going overboard. Spreadsheets are not the only useful tool for performing management science analyses. Occasional modest use of algebraic and graphical analyses still have their place and we would be doing a disservice to the students by not developing their skills in these areas when appropriate. Furthermore, the book should not be mainly a spreadsheet cookbook that focuses largely on spreadsheet mechanics. Spreadsheets are a means to an end, not an end in themselves.

## A MODELING APPROACH

This brings us to the second key feature of the book, a *modeling approach*. Model formulation lies at the heart of management science methodology. Therefore, we heavily emphasize the art of model formulation, the role of a model, and the analysis of model results. We primarily (but not exclusively) use a spreadsheet format rather than algebra for formulating and presenting a model.

Some instructors have many years of experience in teaching modeling in terms of formulating algebraic models (or what the INFORMS Task Force called “model structuring”). Some of these instructors feel that students should do their modeling in this way and then transfer the model to a spreadsheet simply to use the Excel Solver to solve the model. We disagree with this approach. Our experience (and the experience reported by many others) is that most business students find it more natural and comfortable to do their modeling directly in a spreadsheet. Furthermore, by using the best spreadsheet modeling techniques (as presented in this edition), formulating a spreadsheet model tends to be considerably more efficient and transparent than formulating an algebraic model.

Another break from tradition in this book (and several contemporary textbooks) is to virtually ignore the algorithms that are used to solve the models. We feel that there is no good reason why typical business students should learn the details of algorithms executed by computers. Within the time constraints of a one-term management science course, there are far more important lessons to be learned. Therefore, the focus in this book is on what we believe are these far more important lessons. High on this list is the art of modeling managerial problems on a spreadsheet.

Formulating a spreadsheet model of a real problem typically involves much more than designing the spreadsheet and entering the data. Therefore, we work through the process step by step: understand the unstructured problem, verbally develop some structure for the problem, gather the data, express the relationships in quantitative terms, and then lay out the spreadsheet model. The structured approach highlights the typical components of the model (the data, the decisions to be made, the constraints, and the measure of performance) and the different types of spreadsheet cells used for each. Consequently, the emphasis is on the modeling rather than spreadsheet mechanics.

## A CASE STUDIES APPROACH

However, all this still would be quite sterile if we simply presented a long series of brief examples with their spreadsheet formulations. This leads to the third key feature of this book—a *case studies* approach. In addition to examples, essentially every chapter includes one or two case studies patterned after actual applications to convey the whole process of applying management science. In a few instances, the entire chapter revolves around a case study. By drawing the student into the story, we have designed each case study to bring that chapter’s technique to life in a context that vividly illustrates the relevance of the technique for aiding managerial decision making. This storytelling, case-centered approach should make the material more enjoyable and stimulating while also conveying the practical considerations that are key factors in applying management science.

We have been pleased to have several reviewers of the first two editions express particular appreciation for our case study approach. Even though this approach has received little use in other management science textbooks, we feel that it is a real key to preparing students for the practical application of management science in all its aspects. Some of the reviewers have highlighted the effectiveness of the dialogue/scenario enactment approach used in some of the case studies. Although unconventional, this approach provides a way of demonstrating the process of managerial decision making with the help of management science. It also enables previewing some key concepts in the language of management.

Except for Chapter 1, every chapter also contains full-fledged cases following the problems at the end of the chapter. These cases usually continue to employ a stimulating storytelling approach, so they can be assigned as interesting and challenging projects. Most of these cases were developed jointly by two talented case writers, Karl Schmedders (a faculty member at the Kellogg School of Management at Northwestern University) and Molly Stephens (formerly a management science consultant with Andersen Consulting). The authors also have added some cases, including several shorter ones.

We are, of course, not the first to incorporate any of these key features into a management science textbook. However, we believe that the book currently is unique in the way that it fully incorporates all three key features together.

## OTHER SPECIAL FEATURES

We also should mention some additional special features of the book that are continued from the second edition.

- Diverse examples, problems, and cases convey the pervasive relevance of management science.
- A strong managerial perspective.
- Learning objectives at the beginning of each chapter.
- Numerous margin notes that clarify and highlight key points.
- Excel tips interspersed among the margin notes.
- Review questions at the end of each section.
- A glossary at the end of each chapter.
- Partial answers to selected problems in the back of the book.
- Supplementary text material on the CD-ROM (as identified in the table of contents).
- An Excel-based software package (MS Courseware) on the CD-ROM that includes many add-ins, templates, and files (described below).
- Other helpful supplements on both the student's CD-ROM and the instructor's CD-ROM (described later).

## SOFTWARE

The second edition provided a comprehensive Excel-based software package called *MS Courseware* on the student's CD-ROM. The most current version of virtually this entire package is being provided again with the current edition.

This package includes Excel files that provide the live spreadsheets for all the various examples and case studies throughout the book. In addition to further investigating the examples and case studies, these spreadsheets can be used by either the student or instructor as templates to formulate and solve similar problems. The package also includes dozens of Excel templates for solving various models in the book.

Another key resource in the MS Courseware is a collection of Excel add-ins that are integrated into the corresponding chapters.

- **Solver Table** for automating sensitivity analysis in optimization problems (used in several chapters, including especially Chapter 5).
- **Premium Solver for Education**, including its powerful Evolutionary Solver for solving difficult optimization problems (featured in Section 8.5).
- **TreePlan** for generating and analyzing decision trees for decision analysis (used throughout Chapter 9).
- **SensIt** for performing sensitivity analysis with probabilistic systems (used mainly in Chapter 9).
- **RiskSim** for performing basic computer simulations (introduced in Chapter 12).
- **Crystal Ball Professional Edition** for performing a variety of computer simulations (used throughout Chapter 13).
- **CB Predictor** (a module of Crystal Ball) for applying various time-series forecasting methods (featured in the supplement to Chapter 10).
- **OptQuest** (a module of Crystal Ball Professional Edition) for combining computer simulation with an advanced optimization technique (featured in the supplement to Chapter 13).

MS Courseware includes additional software as well.

- **Interactive Management Science Modules** for interactively exploring certain management science techniques in depth (including techniques presented in Chapters 1, 2, 5, 10, 11, 12, and 18).
- **Queueing Simulator** for performing computer simulations of queueing systems (used in Chapter 12).

## NEW FEATURES IN THIS EDITION

We have made many important enhancements to the third edition.

- **A Major Streamlining of the Book.** The 870 pages of the second edition provided a considerably more comprehensive introduction to management science than could be covered well in the usual one-term course. Therefore, we have very substantially reduced the size of this new edition to better fit the usual course. This was achieved largely by eliminating three chapters that feedback indicated were seldom being used, namely, the chapters on (1) PERT/CPM Models for Project Management (now commonly covered in an operations management course instead), (2) Goal Programming (seldom covered), and (3) Transportation and Assignment Problems (seldom covered in this depth so a far briefer introduction has been added to another chapter). The danger with eliminating any chapter of course is that it may be one of the favorite chapters of some instructor somewhere, so all three of these chapters are still being made available on the CD-ROM. Considerably more streamlining was achieved by eliminating over a dozen relatively unimportant sections in other chapters (but most of this material also is still available on the CD-ROM). In addition, the material in certain other sections (including some managerial dialogues) has been condensed. We think that the net effect of all this streamlining has been to bring a sharper focus on the essentials of management science.
- **A Modest Reorganization.** We have reversed the order of the previous Chapter 3 (The Art of Modeling with Spreadsheets) and Chapter 4 (Linear Programming: Formulation and Applications) so that Chapter 2 (Linear Programming: Basic Concepts) could flow directly into its companion chapter. Because the previous Chapter 6 (Transportation and Assignment Problems) now has been transferred to the CD-ROM, we also have added both a section on transportation problems and a section on assignment problems to the new Chapter 3. Otherwise, the ordering of the chapters remaining in the book is the same as in the second edition.
- **Integration of the New Excel 2007.** The new Excel 2007 represents by far the most major revision of Excel and its user interface in many, many years. Therefore, to avoid being immediately outdated, we delayed the publication of this edition for several months in order to fully integrate Excel 2007. Since some users will continue to use older versions of Excel for awhile, we also point out the differences.
- **A Complete Revision of Integer Programming Material.** The previous Chapter 9 (Integer Programming) has been transformed into the new Chapter 7 (Using Binary Integer Programming to Deal with Yes-or-No Decisions). Previous material on general integer programming has been integrated into the second chapter on linear programming (because the formulations are so similar) so the new chapter can focus solely on binary integer programming and its applications. This new chapter includes new sections on project selection, site selection, crew scheduling, and dealing with setup costs for initiating production. Advanced formulation techniques for binary integer programming presented in the second edition now has been shifted to the CD-ROM.
- **A New Overview of Forecasting Techniques.** Chapter 10 (Forecasting) has a new initial section that presents an overview of forecasting techniques. Since many courses provide only a very brief introduction to forecasting, this section provides the needed textual material for such a course. For courses that cover forecasting in greater depth, this section eases the way into the in-depth coverage in the remainder of the chapter.
- **New Application Vignettes.** Twenty application vignettes have been added throughout the book. These vignettes succinctly describe recent actual applications of management science that had a dramatic impact on their companies by using techniques similar to those currently being covered in the book. To avoid disrupting the flow of textual material while also highlighting the application, these vignettes are enclosed in shaded boxes.
- **New Solved Problems.** One or more solved problems now have been added to every chapter in the book. The solved problems for each chapter are presented just before the Problems section for that chapter and then the complete solutions are spelled out on the CD-ROM.

Since these solved problems are typical of the problems in the Problems section, these solutions will help guide students through their homework.

- **Supplementary Cases from the Ivey School.** The University of Western Ontario Ivey School of Business (the second-largest producer of teaching cases in the world) now has specially selected cases from their case collection that match the chapters in this textbook. These cases are available on the Ivey Web site, [www.cases.ivey.uwo.ca/case](http://www.cases.ivey.uwo.ca/case), in the segment of the CaseMate area designated for this book. These cases supplement the dozens of cases already provided in this book.
- **A New Appendix on Using Microsoft Excel.** We have added a new appendix (Tips for Using Microsoft Excel for Modeling) to highlight some features of Excel that are particularly useful for modeling.
- **A New Appendix on Using the Solver Table.** The Solver Table is used extensively in Chapter 5 and also comes up in certain other chapters. To provide a central reference on the Solver Table, we have added a new appendix that describes how to use this Excel add-in.

## CHANGES IN INDIVIDUAL CHAPTERS

Each chapter in the second edition has been carefully examined and revised as needed to update the material and (when appropriate) to streamline the presentation. The more significant changes are mentioned below.

- **Chapter 1 (Introduction).** In addition to deleting one section, the presentation of the break-even analysis example has been revised by moving the spreadsheet modeling in front of the algebraic modeling.
- **Chapter 2 (Linear Programming: Basic Concepts).** In addition to deleting one section, the presentation of the graphical method has been substantially condensed (but with a full presentation available on the CD-ROM).
- **Chapter 3 (Linear Programming: Formulation and Applications).** This chapter has been substantially condensed and reorganized. The category of distribution-network problems has been replaced by the categories of transportation problems and assignment problems. The relatively complicated example on the management of solid wastes has been converted into an end-of-chapter case.
- **Chapter 4 (The Art of Modeling with Spreadsheets).** No major changes except for integrating Excel 2007.
- **Chapter 5 (What-If Analysis for Linear Programming).** In addition to adding an appendix on installing and using the Solver Table, a chapter supplement on reduced costs now is available on the CD-ROM.
- **Chapter 6 (Network Optimization Problems).** The section on minimum spanning-tree problems has been shifted to the CD-ROM as a chapter supplement.
- **Chapter 7 (Using Binary Integer Programming to Deal with Yes-or-No Decisions).** This chapter has been extensively revised as described in the previous section.
- **Chapter 8 (Nonlinear Programming).** We have added a subsection on applying Evolutionary Solver to a traveling salesman problem.
- **Chapter 9 (Decision Analysis).** We have added the expected value of sample information and simplified the treatment of utilities, including the lottery method for determining utilities. We also added two end-of-chapter cases that are less involved than the two cases that already are there.
- **Chapter 10 (Forecasting).** Three sections have been deleted (including the section on time-series forecasting with CB Predictor that has been shifted to the CD-ROM as a chapter supplement), but with an overview of forecasting techniques added as the initial section (as described above).
- **Chapter 11 (Queueing Models).** In addition to deleting one section, the Erlang models have been shifted to the CD-ROM as part of a chapter supplement.

- **Chapter 12 (Computer Simulation: Basic Concepts).** In addition to deleting one section, the section describing the outline of a major computer simulation study has been substantially condensed. The inverse transformation method has been shifted to the CD-ROM as a chapter supplement. One minor addition is the concept of a seed value for pseudo-random numbers.
- **Chapter 13 (Computer Simulation with Crystal Ball).** Crystal Ball has evolved substantially since the publication of the second edition, so many changes were needed to incorporate the current version of Crystal Ball Professional Edition. The organization of the chapter has remained the same with one exception. Because the new substantially updated version of OptQuest will not be available for another several months at the time of this writing, we will update the section on Optimizing with OptQuest later and transfer it to the book's web site as a chapter supplement.

## OTHER SUPPLEMENTS

An instructor's CD-ROM is being provided with this edition. This CD-ROM includes complete solutions to all problems and cases, which will be handy for cutting and pasting homework solutions. Also included is a test bank with computest that includes hundreds of multiple-choice and true-false questions. Presentation materials on PowerPoint slides also are provided. These slides include both lecture materials for nearly every chapter and nearly all the figures (including all the spreadsheets) in the book.

The student's CD-ROM bundled with the book provides the entire MS Courseware package. It also includes a tutorial with sample test questions (different from those in the instructor's test bank) for self-testing quizzes on the various chapters.

A Web page will provide updates about the book, including an errata. To access this site, visit [www.mhhe.com/hillier3e](http://www.mhhe.com/hillier3e). In addition, the publisher's operations management supersite at [www.mhhe.com/pom/](http://www.mhhe.com/pom/) links to many resources on the Internet that you might find pertinent to this book.

We invite your comments, suggestions, and errata. You can contact either one of us at the e-mail addresses given below. While giving these addresses, let us also assure instructors that we will continue our policy of not providing solutions to problems and cases in the book to anybody (including your students) who contacts us. We hope that you enjoy the book.

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