

PREFACE

When Jerry Lieberman and I started working on the first edition of this book 40 years ago, our goal was to develop a pathbreaking textbook that would help establish the future direction of education in what was then the emerging field of operations research. Following publication, it was unclear how well this particular goal was met, but what did become clear was that the demand for the book was far larger than either of us had anticipated. Neither of us could have imagined that this extensive worldwide demand would continue at such a high level for such an extended period of time.

The enthusiastic response to our first seven editions has been most gratifying. It was a particular pleasure to have the 6th edition receive honorable mention for the 1995 INFORMS Lanchester Prize (the prize awarded for the year's most outstanding English-language publication of any kind in the field of operations research), including receiving the following citation. "This is the latest edition of the textbook that has introduced approximately one-half million students to the methods and models of Operations Research. While adding material on a variety of new topics, the sixth edition maintains the high standard of clarity and expository excellence for which the authors have long been known. In honoring this work, the prize committee noted the enormous cumulative impact that the Hillier-Lieberman text has had on the development of our field, not only in the United States but also around the world through its many foreign-language editions."

When we began work on the book 40 years ago, Jerry already was a prominent member of the field, a successful textbook writer, and the chairman of a renowned operations research program at Stanford University. I was a very young assistant professor just starting my career. It was a wonderful opportunity for me to work with and to learn from the master. I will be forever indebted to Jerry for giving me this opportunity.

Now, sadly, Jerry is no longer with us. During the progressive illness that led to his death nearly five years ago, I resolved that I would pick up the torch and devote myself to subsequent editions of this book, maintaining a standard that would fully honor Jerry. Therefore, I took early retirement from my faculty responsibilities at Stanford in order to work full time on textbook writing for the foreseeable future. This has enabled me to spend far more than the usual amount of time in preparing this new edition. It also has enabled me to closely monitor new trends and developments in the field in order to bring this edition completely up to date. This monitoring has led to the choice of the new topics outlined below.

NEW TO THIS EDITION

A special goal for this edition has been to add substantial coverage of dramatic, recent developments that are beginning to revolutionize how certain areas of operations research are being practiced. These recent developments include (1) the use of *metaheuristics* to solve large, complex problems, (2) the integration of *constraint programming* with mathematical programming (especially integer programming) to greatly expand our ability to formulate complicated problems, and (3) the use of *multiechelon inventory models* to aid supply chain management. Although these topics traditionally have not been covered in introductory survey

courses, their dramatically increased importance for future practitioners of operations research now demands their inclusion in a modern introductory OR textbook, so I have added the following material.

- New Chapter 13: *Metaheuristics*.
- New Section 11.9: *The Incorporation of Constraint Programming*.
- New Section 18.5: *Multiechelon Inventory Models for Supply Chain Management*.

Another dramatic development in recent years has been an explosion in the use of spreadsheets and spreadsheet software to formulate and solve OR models, including especially mathematical programming models and simulation models. Therefore, I have added the following spreadsheet material.

- Expansion of Section 3.6: *Formulating and Solving Linear Programming Models on a Spreadsheet*.
- New Section 6.8: *Performing Sensitivity Analysis on a Spreadsheet*.
- New Section 12.10: *Nonconvex Programming (with Spreadsheets)*.
- New Section 15.5: *Using Spreadsheets to Perform Sensitivity Analysis on Decision Trees*.
- Complete rewrite of Section 20.6: *Performing Simulations on Spreadsheets*.
- New Section 20.7: *Optimizing with OptQuest*.
- New Chapter 21 (on CD-ROM and website): *The Art of Modeling with Spreadsheets*.
- New Section 27.7 (on CD-ROM and website): *Time Series Forecasting with CB Predictor*.
- New Chapter 28 (on CD-ROM and website): *Examples of Performing Simulations with Crystal Ball*.
- New Supplement to Chapter 8 (on CD-ROM and website): *A Case Study with Many Transportation Problems*.

However, some instructors prefer to have their students use convenient traditional software (LINDO and LINGO) or state-of-the-art OR software (MPL and CPLEX) instead of spreadsheets. I have retained the philosophy of the 7th edition of providing enough introduction in the book to enable the use of any of the three options (plus OR Tutor and IOR Tutorial to help learn algorithms efficiently) without distracting those using another of the options (while also providing ample supporting material for each option on the CD-ROM). Therefore, this new spreadsheet material always is near or at the end of a chapter (or on the CD-ROM and website) so that it can easily be passed over by those using another software option. At the same time, I have updated the LINDO/LINGO and MPL/CPLEX material, including some expansion of Sec. 3.7 (Formulating Very Large Linear Programming Models) that features MPL.

We solicited extensive feedback from many instructors to guide the planning of this new edition. In response to a significant number of requests, we have added the following traditional topics.

- New Section 8.4: *A Special Algorithm for the Assignment Problem*, presenting the Hungarian algorithm.
- Addition to Sections 12.4 and 12.5: Newton's method for unconstrained optimization.

You also will find a number of smaller additions in various parts of the book.

Reduced Size of the Book

Over the years, new editions of introductory OR textbooks (including ours) have tended to grow substantially larger. For example, one such textbook (not ours) now has 1,418 pages! We have received extensive feedback in recent years decrying this unfortunate trend to provide much more material than is appropriate for an introductory textbook. Textbooks have become increasingly expensive and students don't like to pay so much for an oversized book when so much of it will never be covered in their course, and many instructors don't like to impose this on their students. It also is much less convenient to use a textbook that provides much more material than can be covered in the course.

With apologies for providing a 7th edition that was larger than intended, I have listened to this feedback and taken it to heart. Therefore, a special goal for this new edition has been to substantially reduce its size, despite the addition of all the key new topics. Although we would have liked to have gone further, we are pleased to have achieved a major reduction in the 1,214 pages of the 7th edition.

This major pruning was achieved partially by shifting a substantial amount of little-used material to both the CD-ROM and the Online Learning Center (OLC) on the book's website, <http://highered.mcgraw-gill.com/sites/0070600929>. We first obtained the advice of many reviewers on what should be shifted in this way, and we also collected their syllabi to determine what topics they currently cover in their introductory OR courses. There was a surprising amount of consensus on the topics that are no longer being covered, sometimes because they now are being picked up in other courses. Based on this input, the decision was made to shift the following material.

Material Shifted to the CD-ROM and OLC:

- The section on *Linear Goal Programming and Its Solution Procedures*.
- The chapter on *Project Management with PERT/CPM* (but with a section, *A Network Model for Optimizing a Project's Time-Cost Trade-Off*, added at the end of the book chapter on *Network Optimization Models*).
- The chapter on *The Application of Queueing Theory* (but with an introductory section with this same title added at the end of the book chapter on *Queueing Theory*).
- The section on *Stochastic Periodic-Review Models*.
- The chapter on *Forecasting*.
- The section on *Variance-Reducing Techniques*.
- The section on *Regenerative Method of Statistical Analysis*.

Therefore, all this material and much more (including five other chapters) now are readily available on both the CD-ROM and OLC for the occasional instructor who wants to cover any of these topics without needlessly lengthening the book for all others.

A popular feature of the 7th edition has been the inclusion of many (32) cases that complement the end-of-chapter problems by requiring a more challenging and comprehensive analysis with substantial use of the computer. Embedded in a realistic setting and employing a stimulating storytelling approach, most of these elaborate cases were developed by two talented case writers, Karl Schmedders (a faculty member at the Kellogg Graduate School of Management at Northwestern University) and Molly Stephens (formerly an operations research consultant with Andersen Consulting). However, the drawback was that all these cases added nearly 100 pages to the size of the book. An instructor normally has time in a course to assign only very few (if any) of the cases and not more than one case for any particular chapter. Therefore, based on the nearly unanimous recommendation of reviewers who used the 7th edition, we have retained only 12 cases within the book, which amounts to at most one case per chapter (with one exception). All the other cases have been shifted to the CD-ROM, but with one-paragraph previews within the book. We also have added 8 new cases, so a total of 28 cases now are readily available both on the CD-ROM and OLC without adding precious pages to the size of the book.

An abundance of good problems often has been cited as one of the strengths of the book. With each new edition (including this one), we have added a substantial number of new problems. However, this led to devoting nearly 200 pages to problems in the 7th edition, including an excessive redundancy of problems of some types. Therefore, a significant number of pages has been saved in this new edition by doing some modest pruning of overly redundant problems.

Text material also has been trimmed a little whenever feasible. Although each individual trim has little effect, combining all these methods of saving pages in a disciplined way throughout the book has helped considerably in reducing its size to a more appropriate level for an introductory textbook.

Wider Software Options

The 7th edition provided a wealth of software options. Nearly all of these options have been retained, as outlined below.

Software Options Retained:

- Excel spreadsheets: state-of-the-art spreadsheet formulations are displayed on the CD-ROM for all relevant examples throughout the book.
- Several Excel add-ins, including Premium Solver for Education (an enhancement of the basic Excel Solver), TreePlan (for decision analysis), SensIt (for probabilistic sensitivity analysis), and RiskSim (for simulation).
- A number of Excel templates for solving basic models.
- Student versions of MPL (a leading algebraic modeling language) and its prime solver CPLEX (the most widely used state-of-the-art optimizer), along with an MPL Tutorial and MPL/CPLEX formulations and solutions for all relevant examples throughout the book.
- A student version of CONOPT (for convex programming) as an additional MPL solver.
- Formulations and solutions with both LINDO (a traditional optimizer) and LINGO (an algebraic modeling language) are displayed on the CD-ROM for all relevant examples throughout the book.
- Queueing Simulator (for the simulation of queueing systems).
- OR Tutor for illustrating various algorithms in action.
- Interactive Operations Research (IOR) Tutorial for efficiently learning and executing algorithms interactively, implemented in Java 2 in order to be platform independent. (IOR Tutorial also is available on the Online Learning Center.)

This new edition also provides various enhancements of the software options, as listed below.

New Enhancements:

- Student versions of LINDO and LINGO now are provided on the CD-ROM rather than requiring free downloads from the vendor.
- The student versions of MPL and CPLEX on the CD-ROM are both very recent major upgrades (releases 5.0 and 9.0, respectively).
- A student version of LGO (for both global optimization and convex programming) is provided as an additional MPL solver.
- Revised state-of-the-art spreadsheet formulations are provided on the CD-ROM for all relevant examples throughout the book.
- A new Excel add-in called *Solver Table* is being provided to automate sensitivity analysis in optimization problems.
- A major new software package on the CD-ROM (on a 140-day trial basis) is Crystal Ball Professional Edition 2000.5 (version 5.5) Student Edition, a powerful Excel add-in for performing risk analysis (especially with simulation) which also includes an OptQuest module for optimizing simulations and a CB Predictor module for performing time series forecasting within a spreadsheet environment.
- IOR Tutorial has been substantially enhanced by adding a considerable number of both interactive and automatic procedures.

I am grateful to the McGraw-Hill editorial team for giving the support needed to provide such a great wealth of software options.

OTHER FEATURES

In addition to all the improvements already described, this edition also received the major enhancements listed below.

- Several new examples for nearly every book chapter have been added in a *new Worked Examples section* of the CD-ROM to provide additional help to occasional students who need it without disrupting the flow of the text and adding unneeded pages for others. (The book does mention whenever an additional example on the current topic is available.) All these examples also are included in the Online Learning Center (OLC) on the book's website.
- A new *glossary* for every book chapter also has been added to both the CD-ROM and OLC.
- *Data files* for various cases have been added to both the CD-ROM and OLC to enable students to focus on analysis rather than inputting large data sets.
- An abundance of supplementary textual material (including eight complete chapters) now is conveniently available for everybody on both the CD-ROM and OLC instead of being mostly password protected on the book's website.
- All textual material in either the book or the CD-ROM and OLC (as well as in the Hillier-Hillier textbook, *Introduction to Management Science: A Modeling and Case Studies Approach with Spreadsheets*) is available on the publisher's PRIMIS system, which enables interested instructors to pick and choose which material to include in a custom-designed book. (See www.mhhe.com/primis/online/ for further information.)
- The Selected References at the end of each chapter have been carefully updated to provide the best current references.
- Many footnotes have been added or updated to provide the most up-to-date references on current research trends.
- The various sections describing real-world applications of operations research have been further enhanced by adding a considerable number of very recent applications, including some award-winning applications.
- Many other small updates and refinements have been added throughout the book.
- A new *test bank* featuring moderately difficult questions that require students to show their work is being provided to instructors. Most of the questions in this test bank have previously been used successfully as test questions by the authors.

A substantial effort has gone into developing all these additional and updated educational resources. We hope that you find them helpful.

THE USE OF THE BOOK

The overall thrust of all the revision efforts has been to build upon the strengths of previous editions to more fully meet the needs of today's students. Both the new topics and the extensive updates make the book even more suitable for use in a modern course that reflects contemporary practice in the field. The reduction in the size of the book makes it more useful as a textbook for an introductory survey course. The use of software is integral to the practice of operations research, so the wealth of software options accompanying the book provides great flexibility to the instructor in choosing the preferred types of software for student use. All the educational resources accompanying the book further enhance the learning experience. Therefore, the book and its CD-ROM should fit a course where the instructor wants the students to have a single self-contained textbook that complements and supports what happens in the classroom.

The McGraw-Hill editorial team and I think that the net effect of the revision has been to make this edition even more of a “student’s book”—clear, interesting, and well-organized with lots of helpful examples and illustrations, good motivation and perspective, easy-to-find important material, and enjoyable homework, without too much notation, terminology, and dense mathematics. We believe and trust that the numerous instructors who have used previous editions will agree that this is the best edition yet. This feeling has been reinforced by the generally enthusiastic reviews of drafts of this edition.

The prerequisites for a course using this book can be relatively modest. As with previous editions, the mathematics has been kept at a relatively elementary level. Most of Chaps. 1 to 14 (introduction, linear programming, and mathematical programming) require no mathematics beyond high school algebra. Calculus is used only in Chaps. 12 (Nonlinear Programming) and in one example in Chap. 10 (Dynamic Programming). Matrix notation is used in Chap. 5 (The Theory of the Simplex Method), Chap. 6 (Duality Theory and Sensitivity Analysis), Sec. 7.4 (An Interior-Point Algorithm), and Chap. 12, but the only background needed for this is presented in Appendix 4. For Chaps. 15 to 20 (probabilistic models), a previous introduction to probability theory is assumed, and calculus is used in a few places. In general terms, the mathematical maturity that a student achieves through taking an elementary calculus course is useful throughout Chaps. 15 to 20 and for the more advanced material in the preceding chapters.

The content of the book is aimed largely at the upper-division undergraduate level (including well-prepared sophomores) and at first-year (master’s level) graduate students. Because of the book’s great flexibility, there are many ways to package the material into a course. Chapters 1 and 2 give an introduction to the subject of operations research. Chapters 3 to 14 (on linear programming and on mathematical programming) may essentially be covered independently of Chaps. 15 to 20 (on probabilistic models), and vice-versa. Furthermore, the individual chapters among Chaps. 3 to 14 are almost independent, except that they all use basic material presented in Chap. 3 and perhaps in Chap. 4. Chapter 6 and Sec. 7.2 also draw upon Chap. 5. Sections 7.1 and 7.2 use parts of Chap. 6. Section 9.6 assumes an acquaintance with the problem formulations in Secs. 8.1 and 8.3, while prior exposure to Secs. 7.3 and 8.2 is helpful (but not essential) in Sec. 9.7. Within Chaps. 15 to 20, there is considerable flexibility of coverage, although some integration of the material is available.

An elementary survey course covering linear programming, mathematical programming, and some probabilistic models can be presented in a quarter (40 hours) or semester by selectively drawing from material throughout the book. For example, a good survey of the field can be obtained from Chaps. 1, 2, 3, 4, 15, 17, 18, and 20, along with parts of Chaps. 9–13. A more extensive elementary survey course can be completed in two quarters (60 to 80 hours) by excluding just a few chapters, for example, Chaps. 7, 14, and 19. Chapters 1 to 8 (and perhaps part of Chap. 9) form an excellent basis for a (one-quarter) course in linear programming. The material in Chaps. 9 to 14 covers topics for another (one-quarter) course in other deterministic models. Finally, the material in Chaps. 15 to 20 covers the probabilistic (stochastic) models of operations research suitable for presentation in a (one-quarter) course. In fact, these latter three courses (the material in the entire text) can be viewed as a basic one-year sequence in the techniques of operations research, forming the core of a master’s degree program. Each course outlined has been presented at either the undergraduate or graduate level at Stanford University, and this text has been used in the manner suggested.

ACKNOWLEDGMENTS

I am grateful to Irv Lustig, Fred Glover, and Sven Axsäter for their expert feedback on drafts of the new section or chapter on constraint programming, metaheuristics, and multiechelon inventory models, respectively. Ed Rothberg provided up-to-date information on the sizes of problems being solved successfully by the latest optimization software. In addition, thanks go to many instructors and students who sent email messages to provide their feedback on the 7th edition.

This edition was very much of a team effort. Our case writers, Karl Schmedders and Molly Stephens (both graduates of our department), wrote 24 elaborate cases for the 7th edition, and all of these cases continue to accompany this new edition. One of our department's current Ph.D. students, Che-Lin Su, did an excellent job in preparing the solutions manual. He also prepared the data files for the cases and drafted both the new Worked Examples section of the CD-ROM and the test bank. One of our former Ph.D. students, Michael O'Sullivan, developed OR Tutor for the 7th edition (and continued here), based on part of the software that my son Mark Hillier had developed for the 5th and 6th editions. Mark (who was born the same year as the first edition, earned his Ph.D. at Stanford, and now is a tenured faculty member in the Management Science Department at the University of Washington) provided both the spreadsheets and the Excel files (including many Excel templates) for this edition, as well as the Solver Table and Queueing Simulator. He also gave helpful advice on both the new textual material and new software for this edition, and contributed greatly to Chapters 21 and 28 on the CD-ROM. Another Stanford Ph.D. graduate, William Sun (CEO of the software company Acelet Corporation), and his team did a brilliant job of starting with much of Mark's earlier software and implementing it anew in Java 2 as IOR Tutorial for the 7th edition. They again did a masterful job of further enhancing IOR Tutorial for this new edition. Linus Schrage of the University of Chicago and LINDO Systems (and who took an introductory operations research course from me 41 years ago) provided LINGO, LINDO, and What's Best for the CD-ROM. He also supervised the further development of LINGO/LINDO files for the various chapters as well as providing tutorial material for the CD-ROM. Another long-time friend, Bjarni Kristjansson (who heads Maximal Software), did the same thing for the MPL/CPLEX files and MPL tutorial material, as well as arranging to provide student versions of MPL, CPLEX, CONOPT, LGO, and OptiMax 2000 Component Library for the CD-ROM. My wife, Ann Hillier, devoted numerous long days and nights to sitting with a Macintosh, doing word processing and constructing many figures and tables. They all were vital members of the team.

The back page lists the various companies and individuals who have provided software for the CD-ROM. We greatly appreciate their key contributions.

It was a real pleasure working with McGraw-Hill's thoroughly professional editorial and production staff, including Suzanne Jeans (Senior Sponsoring Editor), Lisa Kalner Williams (Developmental Editor), Debra Matteson (Managing Developmental Editor), Katie White (Developmental Editor), and Mary Powers (Senior Project Manager).

Just as so many individuals made important contributions to this edition, I would like to invite each of you to start contributing to the next edition by using my email address below to send me your comments, suggestions, and errata to help me improve the book in the future. In giving my email address, let me also assure instructors that I will continue to follow the policy of not providing solutions to problems and cases in the book to anybody (including your students) who contacts me.

Enjoy the book.

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