

Introduction to operation research hillier and liberman



ADVANCE PRAISE FOR INTRODUCTION TO OPERATIONS RESEARCH, SEVENTH EDITION Reviewers seem to agree that this is clearly the best edition yet.

Here is a sampling of comments: " The new edition seems to contain the most current information available. " " The new edition of Hillier/Lieberman is very well done and greatly enhances this classic text. " " The authors have done an admirable job of rewriting and reorganizing to reflect modern management practices and the latest software developments. " " It is a complete package. " " Hillier/Lieberman has recaptured any advantage it may have lost (to other competitors) in the past. " " The changes in this new edition make Hillier/Lieberman the preeminent book for operations research and I would highly recommend it. " INTRODUCTION TO OPERATIONS

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www. mhhe. com ABOUT THE AUTHORS Frederick S. Hillier was born and

raised in Aberdeen, Washington, where he was an award winner in statewide high school contests in essay writing, mathematics, debate, and music. As an

undergraduate at Stanford University he ranked first in his engineering class of over 300 students. He also won the McKinsey Prize for technical writing,

won the Outstanding Sophomore Debater award, played in the Stanford

Woodwind Quintet, and won the Hamilton Award for combining excellence in engineering with notable achievements in the humanities and social

sciences. Upon his graduation with a B. S. degree in Industrial Engineering,

he was awarded three national fellowships (National Science Foundation, Tau Beta Pi, and Danforth) for graduate study at Stanford with specialization in

operations research. After receiving his Ph. D. degree, he joined the faculty

of Stanford University, and also received visiting appointments at Cornell

University, Carnegie-Mellon University, the Technical University of Denmark,

the University of Canterbury (New Zealand), and the University of Cambridge

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(England). After 35 years on the Stanford faculty, he took early retirement from his faculty responsibilities in 1996 in order to focus full time on textbook writing, and so now is Professor Emeritus of Operations Research at Stanford. Dr. Hillier's research has extended into a variety of areas, including integer programming, queueing theory and its application, statistical quality control, and the application of operations research to the design of production systems and to capital budgeting. He has published widely, and his seminal papers have been selected for republication in books of selected readings at least ten times. He was the first-prize winner of a research contest on "Capital Budgeting of Interrelated Projects" sponsored by The Institute of Management Sciences (TIMS) and the U. S. Office of Naval Research. He and Dr. Lieberman also received the honorable mention award for the 1995 Lanchester Prize (best English-language publication of any kind in the field of operations research), which was awarded by the Institute of Operations Research and the Management Sciences (INFORMS) for the 6th edition of this book. Dr. Hillier has held many leadership positions with the professional societies in his field. For example, he has served as Treasurer of the Operations Research Society of America (ORSA), Vice President for Meetings of TIMS, Co-General Chairman of the 1989 TIMS International Meeting in Osaka, Japan, Chair of the TIMS Publications Committee, Chair of the ORSA Search Committee for Editor of Operations Research, Chair of the ORSA Resources Planning Committee, Chair of the ORSA/TIMS Combined Meetings Committee, and Chair of the John von Neumann Theory Prize Selection Committee for INFORMS. vii viii ABOUT THE AUTHORS He currently is serving as the Series Editor for the International Series in Operations

Publishers. In addition to Introduction to Operations Research and the two companion volumes, Introduction to Mathematical Programming and Introduction to Stochastic Models in Operations Research, his books are The Evaluation of Risky Interrelated Investments (NorthHolland, 1969), Queueing Tables and Graphs (Elsevier North-Holland, 1981, co-authored by O. S. Yu, with D. M. Avis, L. D. Fossett, F. D. Lo, and M. I. Reiman), and Introduction to Management Science: A Modeling and Case Studies Approach with Spreadsheets (Irwin/McGraw-Hill, co-authored by M. S. Hillier and G. J. Lieberman). The late Gerald J. Lieberman sadly passed away shortly before the completion of this edition. He had been Professor Emeritus of Operations Research and Statistics at Stanford University, where he was the founding chair of the Department of Operations Research. He was both an engineer (having received an undergraduate degree in mechanical engineering from Cooper Union) and an operations research statistician (with an A. M. from Columbia University in mathematical statistics, and a Ph. D. from Stanford University in statistics). Dr. Lieberman was one of Stanford's most eminent leaders in recent decades. After chairing the Department of Operations Research, he served as Associate Dean of the School of Humanities and Sciences, Vice Provost and Dean of Research, Vice Provost and Dean of Graduate Studies, Chair of the Faculty Senate, member of the University Advisory Board, and Chair of the Centennial Celebration Committee. He also served as Provost or Acting Provost under three different Stanford presidents. Throughout these years of university leadership, he also remained active professionally. His research was in the stochastic areas of operations research, often at the interface of applied probability and statistics. He published extensively in the areas of reliability and quality

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control, and in the modeling of complex systems, including their optimal design, when resources are limited. Highly respected as a senior statesman of the field of operations research, Dr. Lieberman served in numerous leadership roles, including as the elected President of The Institute of Management Sciences. His professional honors included being elected to the National Academy of Engineering, receiving the Shewhart Medal of the American Society for Quality Control, receiving the Cuthbertson Award for exceptional service to Stanford University, and serving as a fellow at the Center for Advanced Study in the Behavioral Sciences. In addition, the Institute of Operations Research and the Management Sciences (INFORMS) awarded him and Dr. Hillier the honorable mention award for the 1995 Lanchester Prize for the 6th edition of this book. In 1996, INFORMS also awarded him the prestigious Kimball Medal for his exceptional contributions to the field of operations research and management science. In addition to Introduction to Operations Research and the two companion volumes, Introduction to Mathematical Programming and Introduction to Stochastic Models in Operations Research, his books are Handbook of Industrial Statistics (Prentice-Hall, 1955, co-authored by A. H. Bowker), Tables of the Non-Central t-Distribution (Stanford University Press, 1957, co-authored by G. J. Resnikoff), Tables of the Hypergeometric Probability Distribution (Stanford University Press, 1961, co-authored by D. Owen), Engineering Statistics, Second Edition (Prentice-Hall, 1972, co-authored by A. H. Bowker), and Introduction to Management Science: A Modeling and Case Studies Approach with Spreadsheets (Irwin/McGraw-Hill, 2000, co-authored by F. S. Hillier and M. S. Hillier). ABOUT THE CASE WRITERS Karl Schmedders is assistant professor in the Department of Managerial Economics and Decision

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Sciences at the Kellogg Graduate School of Management (Northwestern University), where he teaches quantitative methods for managerial decision making. His research interests include applications of operations research in economic theory, general equilibrium theory with incomplete markets, asset pricing, and computational economics. Dr. Schmedders received his doctorate in operations research from Stanford University, where he taught both undergraduate and graduate classes in operations research. Among the classes taught was a case studies course in operations research, and he subsequently was invited to speak at a conference sponsored by the Institute of Operations Research and the 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. Molly Stephens is currently pursuing a J. D. degree with a concentration in technology and law. She graduated from Stanford University with a B. S. in Industrial Engineering and an M. S. in Operations Research. A champion debater in both high school and college, and president of the Stanford Debating Society, Ms. Stephens taught public speaking in Stanford's School of Engineering and served as a teaching assistant for a case studies course in operations research. As a teaching assistant, she analyzed operations research problems encountered in the real world and the transformation of these problems 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 an INFORMS conference 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 resuming <https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/>

her graduate studies. ix DEDICATION To the memory of our parents and To the memory of one of the true giants of our field, Jerry Lieberman, whose recent passing prevented him from seeing the publication of this edition xi

PREFACE It now is 33 years since the first edition of this book was published in 1967. We have been humbled by having had both the privilege and the responsibility of introducing so many students around the world to our field over such a long span of time. With each new edition, we have worked toward the goal of meeting the changing needs of new generations of students by helping to define the modern approach to teaching the current status of operations research effectively at the introductory level. Over 33 years, much has changed in both the field and the pedagogical needs of the students being introduced to the field. These changes have been reflected in the substantial revisions of successive editions of this book. We believe that this is true for the current 7th edition as well. The enthusiastic response to our first six 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 Englishlanguage 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

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many foreign-language editions. " As we enter a new millennium, the particular challenge for this new edition was to revise a book with deep roots in the 20th century so thoroughly that it would become fully suited for the 21st century. We made a special effort to meet this challenge, especially in regard to the software and pedagogy in the book. A WEALTH OF SOFTWARE OPTIONS The new CD-ROM that accompanies the book provides an exciting array of software options that reflect current practice. One option is to use the increasingly popular spreadsheet approach with Excel and its Solver. Using spreadsheets as a key medium of instruction clearly is one new wave in xxiii xxiv PREFACE the teaching of operations research. The new Sec. 3. 6 describes and illustrates how to use Excel and its Solver to formulate and solve linear programming models on a spreadsheet. Similar discussions and examples also are included in several subsequent chapters for other kinds of models. In addition, the CD-ROM provides an Excel file for many of the chapters that displays the spreadsheet formulation and solution for the relevant examples in the chapter. Several of the Excel files also include a number of Excel templates for solving the models in the chapter. Another key resource is a collection of Excel add-ins on the CD-ROM (Premium Solver, TreePlan, SensIt, and RiskSim) that are integrated into the corresponding chapters. In addition, Sec. 22. 6 describes how some simulations can be performed efficiently on spreadsheets by using another popular Excel add-in (@RISK) that can be downloaded temporarily from a website. Practitioners of operations research now usually use a modeling language to formulate and manage models of the very large size commonly encountered in practice. A modeling language system also will support one or more sophisticated software packages that can be called to solve a model once it has been

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formulated appropriately. The new Sec. 3. 7 discusses the application of modeling languages and illustrates it with one modeling language (MPL) that is relatively amenable to student use. The student version of MPL is provided on the CD-ROM, along with an extensive MPL tutorial. Accompanying MPL as its primary solver is the student version of the renowned state-of-the-art software package, CPLEX. The student version of CONOPT also is provided as the solver for nonlinear programming. We are extremely pleased to be able to provide such powerful and popular software to students using this book. To further assist students, many of the chapters include an MPL/CPLEX file (or MPL/CPLEX/CONOPT file in the case of the nonlinear programming chapter) on the CD-ROM that shows how MPL and CPLEX would formulate and solve the relevant examples in the chapter. These files also illustrate how MPL and CPLEX can be integrated with spreadsheets. As described in the appendix to Chaps. 3 and 4, a third attractive option is to employ the student version of the popular and student-friendly software package LINDO and its modeling language companion LINGO. Both packages can be downloaded free from the LINDO Systems website. Associated tutorial material is included on the CD-ROM, along with a LINDO/LINGO file for many of the chapters showing how LINDO and LINGO would formulate and solve the relevant examples in the chapter. Once again, integration with spreadsheets also is illustrated. Complementing all these options on the CD-ROM is an updated version of the tutorial software that many instructors have found so useful for their students with the 5th and 6th editions. A program called OR Tutor provides 16 demonstration examples from the 6th edition, but now with an attractive new design based on JavaScript. These demos vividly demonstrate the evolution of an algorithm in ways that cannot

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be duplicated on the printed page. Most of the interactive routines from the 6th edition also are included on the CD-ROM, but again with an attractive new design. This design features a spreadsheet format based on VisualBasic. Each of the interactive routines enables the student to interactively execute one of the algorithms of operations research, making the needed decision at each step while the computer does the needed arithmetic. By enabling the student to focus on concepts rather than mindless number crunching when doing homework to learn an algorithm, we have found that these interactive routines make the learning process far more efficient and effective as well as more stimulating. In addition to these PREFACE xxv routines, the CD-ROM includes a few of the automatic routines from the 6th edition (again redesigned with VisualBasic) for those cases that are not covered by the software options described above. We were very fortunate to have the services of Michael O'Sullivan, a talented programmer and an advanced Ph. D. student in operations research at Stanford, to do all this updating of the software that had been developed by Mark S. Hillier for the 5th and 6th editions. Microsoft Project is introduced in Chap. 10 as a useful tool for project management. This software package also is included on the CD-ROM.

NEW EMPHASES Today's students in introductory operations research courses tend to be very interested in learning more about the relevance of the material being covered, including how it is actually being used in practice. Therefore, without diluting any of the features of the 6th edition, the focus of the revision for this edition has been on increasing the motivation and excitement of the students by making the book considerably more "real world" oriented and accessible. The new emphasis on the kinds of software that practitioners use is one thrust in this direction. Other major

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new features are outlined below. Twenty-five elaborate new cases, embedded in a realistic setting and employing a stimulating storytelling approach, have been added at the end of the problem sections. All but one of these cases were developed jointly by two talented case writers, Karl Schmedders (a faculty member at the Kellogg Graduate School of Management at Northwestern University) and Molly Stephens (recently an operations research consultant with Andersen Consulting). We also have further fleshed out six cases that were in the 6th edition. The cases generally require relatively challenging and comprehensive analyses with substantial use of the computer. Therefore, they are suitable for student projects, working either individually or in teams, and can then lead to class discussion of the analysis. A complementary new feature is that many new problems embedded in a realistic setting have been added to the problem section of many chapters. Some of the current problems also have been fleshed out in a more interesting way. This edition also places much more emphasis on providing perspective in terms of what is actually happening in the practice of operations research. What kinds of applications are occurring? What sizes of problems are being solved? Which models and techniques are being used most widely? What are their shortcomings and what new developments are beginning to address these shortcomings? These kinds of questions are being addressed to convey the relevance of the techniques under discussion. Eight new sections (Secs. 10. 7, 12. 2, 15. 6, 18. 5, 19. 8, 20. 1, 20. 10, and 22. 2) are fully devoted to discussing the practice of operations research in such ways, along with briefer mentions elsewhere. The new emphases described above benefited greatly from our work in developing our recent new textbook with Mark S. Hillier (Introduction to Management Science: A <https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/>

Modeling and Case Studies Approach with Spreadsheets, Irwin/McGraw-Hill, 2000). That book has a very different orientation from this one. It is aimed directly at business students rather than students who may be in engineering and the mathematical sciences, and it provides almost no coverage of the mathematics and algorithms of operations research. Nevertheless, its applied orientation enabled us to adapt some excellent material developed for that book to provide a more well-rounded coverage in this edition. xxvi PREFACE OTHER FEATURES In addition to all the new software and new emphases just described, this edition received a considerable number of other enhancements as well. The previous section on project planning and control with PERT/CPM has been replaced by a complete new chapter (Chap. 10) with an applied orientation. Using the activity-on-node (AON) convention, this chapter provides an extensive modern treatment of the topic in a very accessible way. Other new topics not yet mentioned include the SOB mnemonic device for determining the form of constraints in the dual problem (in Sec. 6. 4), 100 percent rules for simultaneous changes when conducting sensitivity analysis (in Sec. 6. 7), sensitivity analysis with Bayes' decision rule (in Sec. 15. 2), a probability tree diagram for calculating posterior probabilities (in Sec. 15. 3), a single-server variation of the nonpreemptive priorities model where the service for different priority classes of customers now have different mean service rates (in Sec. 17. 8), a new simpler analysis of a stochastic continuous-review inventory model (Sec. 19. 5), the mean absolute deviation as a measure of performance for forecasting methods (in Sec. 20. 7), and the elements of a major simulation study (Sec. 22. 5). We also have added much

supplementary text material on the book's new website, [www. mhhe. https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/](http://www.mhhe.com/assignbuster.com/introduction-to-operation-research-hillier-and-liberman/)

com/hillier. Some of these supplements are password protected, but are available to all instructors who adopt this textbook. For the most part, this material appeared in previous editions of this book and then was subsequently deleted (for space reasons), to the disappointment of some instructors. Some also appeared in our Introduction to Mathematical Programming textbook. As delineated in the table of contents, this supplementary material includes a chapter on additional special types of linear programming problems, a review or primer chapter on probability theory, and a chapter on reliability, along with supplements to a few chapters in the book. In addition to providing this supplementary text material, the website will give updates about the book, including an errata, as the need arises. We made two changes in the order of the chapters. The decision analysis chapter has been moved forward to Chap. 15 in front of the stochastic chapters. The game theory chapter has been moved backward to Chap. 14 to place it next to the related decision analysis chapter. We believe that these changes provide a better transition from topics that are mainly deterministic to those that are mainly stochastic. Every chapter has received significant revision and updating, ranging from modest refining to extensive rewriting. Chapters receiving a particularly major revision and reorganization included Chaps. 15 (Decision Analysis), 19 (Inventory Theory), 20 (Forecasting), and 22 (Simulation). Many sections in the linear programming and mathematical programming chapters also received major revisions and updating. The overall thrust of all the revision efforts has been to build upon the strengths of previous editions while thoroughly updating and clarifying the material in a contemporary setting to fully meet the needs of today's students. We think that the net effect has been to make this edition even <https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/>

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 PREFACE xxvii 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. 13 (Nonlinear Programming) and in one example in Chap. 11 (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. 13, but the only background needed for this is presented in Appendix 4. For Chaps. 15 to 22 (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 22 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 <https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/>

mathematical programming) may essentially be covered independently of Chaps. 15 to 22 (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 22, 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, 19, 20, and 22, along with parts of Chaps. 9, 11, 12, and 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 21. 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 22 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 the graduate level at Stanford University, and <https://assignbuster.com/introduction-to-operation-research-hillier-and-liberman/>

this text has been used in the manner suggested. To assist the instructor who will be covering only a portion of the chapters and who prefers a slimmer book containing only those chapters, all the material (including the supplementary text material on the book's website) has been placed in McGraw-Hill's PRIMIS xxviii PREFACE system. This system enables an instructor to pick and choose precisely which material to include in a self-designed book, and then to order copies for the students at an economical price. For example, this enables instructors who previously used our Introduction to Mathematical Programming or Introduction to Stochastic Models in Operations Research textbooks to obtain updated versions of the same material from the PRIMIS system. For this reason, we will not be publishing new separate editions of these other books. Again, as in previous editions, we thank our wives, Ann and Helen, for their encouragement and support during the long process of preparing this 7th edition. Our children, David, John, and Mark Hillier, Janet Lieberman Argyres, and Joanne, Michael, and Diana Lieberman, have literally grown up with the book and our periodic hibernations to prepare a new edition. Now, most of them have used the book as a text in their own college courses, given considerable advice, and even (in the case of Mark Hillier) become a software collaborator. It is a joy to see them and (we trust) the book reach maturity together. And now I must add a very sad note. My close friend and co-author, Jerry Lieberman, passed away on May 18, 1999, while this edition was in preparation, so I am writing this preface on behalf of both of us. Jerry was one of the great leaders of our field and he had a profound influence on my life. More than a third of a century ago, we embarked on a mission together to attempt to develop a path-breaking book for teaching operations research at the introductory

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level. Ever since, we have striven to meet and extend the same high standards for each new edition. Having worked so closely with Jerry for so many years, I believe I understand well how he would want the book to evolve to meet the needs of each new generation of students. As the substantially younger co-author, I am grateful that I am able to carry on our joint mission to continue to update and improve the book, both with this edition and with future editions as well. It is the least I can do to honor Jerry. I welcome your comments, suggestions, and errata to help me improve the book in the future.

ACKNOWLEDGMENTS We are indebted to an excellent group of reviewers who provided sage advice throughout the revision process. This group included Jeffery Cochran, Arizona State University; Yahya Fathi, North Carolina State University; Yasser Hosni and Charles Reilly, University of Central Florida; Cerry Klein, University of Missouri–Columbia; Robert Lipset, Ohio University; Mark Parker, United States Air Force Academy; Christopher Rump, State University of New York at Buffalo; and Ahmad Seifoddini, California Polytechnic State University–San Luis Obispo. We also received helpful advice from Judith Liebman, Siegfried Schaible, David Sloan, and Arthur F. Veinott, Jr., as well as many instructors who sent us letters or e-mail messages. In addition, we also thank many dozens of Stanford students and many students at other universities who gave us helpful written suggestions. This edition was very much of a team effort. Our case writers, Karl Schmedders and Molly Stephens (both graduates of our department), made a vital contribution. One of our department's current Ph. D. students, Roberto Szechtman, did an excellent job in preparing the solutions manual. Another Ph. D. student, Michael O'Sullivan, was very skillful in updating the software that Mark Hillier had developed for the 5th

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and 6th editions. Mark PREFACE xxix (who was born the same year as the first edition and now is a tenured faculty member in the Management Science Department at the University of Washington) helped to oversee this updating and also provided both the spreadsheets and the Excel files (including many Excel templates) for this edition. Linus Schrage of the University of Chicago and LINDO Systems (and who took an introductory operations research course from me 37 years ago) supervised the 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, and OptiMax 2000 for the CD-ROM. One of our department's Ph. D. graduates, Irv Lustig, was the ILOG project manager for providing CPLEX. Linus, Bjarni, and Irv all were helpful in checking material going into this edition regarding their software. Ann Hillier devoted numerous long days and nights to sitting with a Macintosh, doing word processing and constructing many figures and tables, in addition to endless cutting and pasting, photocopying, and FedExing of material. Helen Lieberman also carried a heavy burden in supporting Jerry. They all were vital members of the team. The inside back cover 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 Eric Munson (executive editor), Maja Lorkovic (developmental editor), and Christine Vaughan (project manager). Frederick S. Hillier

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1176 1105 1 Introduction 1. 1 THE ORIGINS OF OPERATIONS RESEARCH

Since the advent of the industrial revolution, the world has seen a remarkable growth in the size and complexity of organizations. The artisans' small shops of an earlier era have evolved into the billion-dollar corporations of today. An integral part of this revolutionary change has been a tremendous increase in the division of labor and segmentation of management responsibilities in these organizations. The results have been spectacular. However, along with its blessings, this increasing specialization has created new problems, problems that are still occurring in many organizations. One problem is a tendency for the many components of an organization to grow into relatively autonomous empires with their own goals and value systems, thereby losing sight of how their activities and objectives mesh with those of the overall organization. What is best for one component frequently is detrimental to another, so the components may end up working at cross purposes. A related problem is that as the complexity and specialization in an organization increase, it becomes more and more difficult to allocate the available resources to the various activities in a way that is most effective for the organization as a whole. These kinds of problems and the need to find a better way to solve them provided the environment for the emergence of operations research (commonly referred to as OR). The roots of OR can be traced back many decades, when early attempts were made to use a scientific approach in the management of organizations. However, the beginning of the activity called operations
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research has generally been attributed to the military services early in World War II. Because of the war effort, there was an urgent need to allocate scarce resources to the various military operations and to the activities within each operation in an effective manner. Therefore, the British and then the U. S. military management called upon a large number of scientists to apply a scientific approach to dealing with this and other strategic and tactical problems. In effect, they were asked to do research on (military) operations. These teams of scientists were the first OR teams. By developing effective methods of using the new tool of radar, these teams were instrumental in winning the Air Battle of Britain. Through their research on how to better manage convoy and antisubmarine operations, they also played a major role in winning the Battle of the North Atlantic. Similar efforts assisted the Island Campaign in the Pacific. When the war ended, the success of OR in the war effort spurred interest in applying OR outside the military as well. As the industrial boom following the war was run1 2 1

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ning its course, the problems caused by the increasing complexity and specialization in organizations were again coming to the forefront. It was becoming apparent to a growing number of people, including business consultants who had served on or with the OR teams during the war, that these were basically the same problems that had been faced by the military but in a different context. By the early 1950s, these individuals had introduced the use of OR to a variety of organizations in business, industry, and government. The rapid spread of OR soon followed. At least two other factors that played a key role in the rapid growth of OR during this period can be identified. One was the substantial progress that was made early in improving the techniques of OR. After the war, many of

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the scientists who had participated on OR teams or who had heard about this work were motivated to pursue research relevant to the field; important advancements in the state of the art resulted. A prime example is the simplex method for solving linear programming problems, developed by George Dantzig in 1947. Many of the standard tools of OR, such as linear programming, dynamic programming, queueing theory, and inventory theory, were relatively well developed before the end of the 1950s. A second factor that gave great impetus to the growth of the field was the onslaught of the computer revolution. A large amount of computation is usually required to deal most effectively with the complex problems typically considered by OR. Doing this by hand would often be out of the question. Therefore, the development of electronic digital computers, with their ability to perform arithmetic calculations thousands or even millions of times faster than a human being can, was a tremendous boon to OR. A further boost came in the 1980s with the development of increasingly powerful personal computers accompanied by good software packages for doing OR. This brought the use of OR within the easy reach of much larger numbers of people. Today, literally millions of individuals have ready access to OR software. Consequently, a whole range of computers from mainframes to laptops now are being routinely used to solve OR problems.

1. 2 THE NATURE OF OPERATIONS RESEARCH

As its name implies, operations research involves “research on operations.” Thus, operations research is applied to problems that concern how to conduct and coordinate the operations (i. e., the activities) within an organization. The nature of the organization is essentially immaterial, and, in fact, OR has been applied extensively in such diverse areas as manufacturing, transportation, construction,

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telecommunications, financial planning, health care, the military, and public services, to name just a few. Therefore, the breadth of application is unusually wide. The research part of the name means that operations research uses an approach that resembles the way research is conducted in established scientific fields. To a considerable extent, the scientific method is used to investigate the problem of concern. (In fact, the term management science sometimes is used as a synonym for operations research.) In particular, the process begins by carefully observing and formulating the problem, including gathering all relevant data. The next step is to construct a scientific (typically mathematical) model that attempts to abstract the essence of the real problem. It is then hypothesized that this model is a sufficiently precise representation of the essential features of the situation that the conclusions (solutions) obtained from the model are also valid for the real problem. Next, suitable experiments are conducted to test this hypothesis, modify it as needed, and eventually verify some form of the hypothesis. (This step is frequently referred to as model validation.) Thus, in a certain sense, operations research involves creative scientific research into the fundamental properties of operations. However, there is more to it than this. Specifically, OR is also concerned with the practical management of the organization. Therefore, to be successful, OR must also provide positive, understandable conclusions to the decision maker(s) when they are needed. Still another characteristic of OR is its broad viewpoint. As implied in the preceding section, OR adopts an organizational point of view. Thus, it attempts to resolve the conflicts of interest among the components of the organization in a way that is best for the organization as a whole. This does

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not imply that the study of each problem must give explicit consideration to all aspects of the organization; rather, the objectives being sought must be consistent with those of the overall organization. An additional characteristic is that OR frequently attempts to find a best solution (referred to as an optimal solution) for the problem under consideration. (We say a best instead of the best solution because there may be multiple solutions tied as best.) Rather than simply improving the status quo, the goal is to identify a best possible course of action. Although it must be interpreted carefully in terms of the practical needs of management, this “search for optimality” is an important theme in OR. All these characteristics lead quite naturally to still another one. It is evident that no single individual should be expected to be an expert on all the many aspects of OR work or the problems typically considered; this would require a group of individuals having diverse backgrounds and skills. Therefore, when a full-fledged OR study of a new problem is undertaken, it is usually necessary to use a team approach. Such an OR team typically needs to include individuals who collectively are highly trained in mathematics, statistics and probability theory, economics, business administration, computer science, engineering and the physical sciences, the behavioral sciences, and the special techniques of OR. The team also needs to have the necessary experience and variety of skills to give appropriate consideration to the many ramifications of the problem throughout the organization.

1. 3 THE IMPACT OF OPERATIONS RESEARCH

Operations research has had an impressive impact on improving the efficiency of numerous organizations around the world. In the process, OR has made a significant contribution to increasing the productivity of the economies of various countries. There now are a few dozen member

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countries in the International Federation of Operational Research Societies (IFORS), with each country having a national OR society. Both Europe and Asia have federations of OR societies to coordinate holding international conferences and publishing international journals in those continents. It appears that the impact of OR will continue to grow. For example, according to the U. S. Bureau of Labor Statistics, OR currently is one of the fastest-growing career areas for U. S. college graduates. To give you a better notion of the wide applicability of OR, we list some actual awardwinning applications in Table 1. 1. Note the diversity of organizations and applications in the first two columns. The curious reader can find a complete article describing each application in the January—February issue of Interfaces for the year cited in the third col-

4 1 INTRODUCTION TABLE 1. 1

Some applications of operations research	Organization	Nature of Application
The Netherlands Rijkswaterstaat	Develop national water management policy, including mix of new facilities, operating procedures, and pricing.	Optimize production operations in chemical plants to meet production targets with minimum cost.
Schedule shift work at reservation offices and airports to meet customer needs with minimum cost.	Optimize refinery operations and the supply, distribution, and marketing of products.	Optimally schedule and deploy police patrol officers with a computerized system.
Optimally blend available ingredients into gasoline products to meet quality and sales requirements.	Integrate a national network of spare parts inventories to improve service support.	Monsanto Corp.
United Airlines	Citgo Petroleum Corp.	San Francisco Police Department
Texaco, Inc.	IBM Yellow Freight System, Inc.	New Haven Health Department
AT&T	Delta Airlines	Digital Equipment Corp.
China	South African defense force	Proctor and Gamble
Taco		

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Bell Hewlett-Packard Optimize the design of a national trucking network and the routing of shipments. Design an effective needle exchange program to combat the spread of HIV/AIDS. Develop a PC-based system to guide business customers in designing their call centers. Maximize the profit from assigning airplane types to over 2500 domestic flights. Restructure the global supply chain of suppliers, plants, distribution centers, potential sites, and market areas. Optimally select and schedule massive projects for meeting the country's future energy needs. Optimally redesign the size and shape of the defense force and its weapons systems. Redesign the North American production and distribution system to reduce costs and improve speed to market. Optimally schedule employees to provide desired customer service at a minimum cost. Redesign the sizes and locations of buffers in a printer production line to meet production goals. Year of Publication* Related Chaptersâ€ 1985 2—8, 13, 22 \$15 million 1985 2, 12 \$2 million 1986 2—9, 12, 17, 18, 20 \$6 million 1987 2—9, 20 \$70 million 1989 2—4, 12, 20 \$11 million 1989 2, 13 \$30 million 1990 2, 19, 22 1992 1993 2, 9, 13, 20, 22 2 \$20 million \$250 million less inventory \$17. 3 million 1993 17, 18, 22 33% less HIV/AIDS \$750 million 1994 12 \$100 million 1995 12 \$800 million 1995 12 \$425 million 1997 12 \$1. 1 billion 1997 8 \$200 million 1998 12, 20, 22 \$13 million 1998 17, 18 \$280 million more revenue *Pertains to a January—February issue of Interfaces in which a complete article can be found describing the application. â€ Refers to chapters in this book that describe the kinds of OR techniques used in the application. Annual Savings 1. 4

ALGORITHMS AND OR COURSEWARE 5 umn of the table. The fourth column lists the chapters in this book that describe the kinds of OR techniques that were used in the application. (Note that many of the applications combine a

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variety of techniques.) The last column indicates that these applications typically resulted in annual savings in the millions (or even tens of millions) of dollars. Furthermore, additional benefits not recorded in the table (e. g., improved service to customers and better managerial control) sometimes were considered to be even more important than these financial benefits. (You will have an opportunity to investigate these less tangible benefits further in Probs. 1. 3-1 and 1. 3-2.) Although most routine OR studies provide considerably more modest benefits than these award-winning applications, the figures in the rightmost column of Table 1. 1 do accurately reflect the dramatic impact that large, well-designed OR studies occasionally can have. We will briefly describe some of these applications in the next chapter, and then we present two in greater detail as case studies in Sec. 3. 5. 1. 4

ALGORITHMS AND OR COURSEWARE An important part of this book is the presentation of the major algorithms (systematic solution procedures) of OR for solving certain types of problems. Some of these algorithms are amazingly efficient and are routinely used on problems involving hundreds or thousands of variables. You will be introduced to how these algorithms work and what makes them so efficient. You then will use these algorithms to solve a variety of problems on a computer. The CD-ROM called OR Courseware that accompanies the book will be a key tool for doing all this. One special feature in your OR Courseware is a program called OR Tutor. This program is intended to be your personal tutor to help you learn the algorithms. It consists of many demonstration examples that display and explain the algorithms in action. These “ demos” supplement the examples in the book. In addition, your OR Courseware includes many interactive routines for executing the algorithms interactively in a convenient

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spreadsheet format. The computer does all the routine calculations while you focus on learning and executing the logic of the algorithm. You should find these interactive routines a very efficient and enlightening way of doing many of your homework problems. In practice, the algorithms normally are executed by commercial software packages. We feel that it is important to acquaint students with the nature of these packages that they will be using after graduation. Therefore, your OR Courseware includes a wealth of material to introduce you to three particularly popular software packages described below. Together, these packages will enable you to solve nearly all the OR models encountered in this book very efficiently. We have added our own automatic routines to the OR Courseware only in a few cases where these packages are not applicable. A very popular approach now is to use today's premier spreadsheet package, Microsoft Excel, to formulate small OR models in a spreadsheet format. The Excel Solver then is used to solve the models. Your OR Courseware includes a separate Excel file for nearly every chapter in this book. Each time a chapter presents an example that can be solved using Excel, the complete spreadsheet formulation and solution is given in that chapter's Excel file. For many of the models in the book, an Excel template also is provided that already includes all the equations necessary to solve the model. Some Excel add-ins also are included on the CD-ROM. After many years, LINDO (and its companion modeling language LINGO) continues to be a dominant OR software package. Student versions of LINDO and LINGO now can be downloaded free from the Web. As for Excel, each time an example can be solved with this package, all the details are given in a LINGO/LINDO file for that chapter in your OR Courseware. CPLEX is an elite state-of-the-art software package that is

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widely used for solving large and challenging OR problems. When dealing with such problems, it is common to also use a modeling system to efficiently formulate the mathematical model and enter it into the computer. MPL is a user-friendly modeling system that uses CPLEX as its main solver. A student versio