Practical Management Science

SECOND EDITION

WINSTON • ALBRIGHT

2ND EDITION

Practical Management Science

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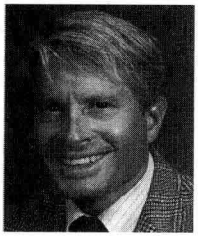
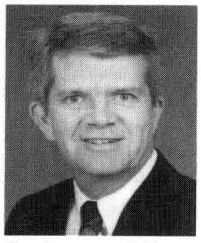


Wayne L. Winston is Professor of Operations & Decision Technologies in the Kelley School of Business at Indiana University, where he has taught since 1975. Wayne received his B.S. degree in mathematics from MIT and his Ph.D. degree in operations research from Yale. He has written the successful textbooks *Operations Research: Applications and Algorithms*, *Mathematical Programming: Applications and Algorithms*, *Simulation Modeling Using @RISK*, *Data Analysis and Decision Making*, and *Financial Models Using Simulation and Optimization*. Wayne has published over 20 articles in leading journals and has won many teaching awards, including the schoolwide MBA award four times. He has taught classes at Microsoft, GM, Ford, Eli Lilly, Bristol-Myers Squibb, Arthur Andersen, Roche, PriceWaterhouseCoopers, and NCR. His current interest is in showing how spreadsheet models can be used to solve business problems in all disciplines, particularly in finance and marketing.

Wayne enjoys swimming and basketball, and his passion for trivia won him an appearance several years ago on the television game show *Jeopardy*, where he won two games. He is married to the lovely and talented Vivian. They have two children, Gregory and Jennifer.

S. Christian Albright



Chris Albright got his B.S. degree in Mathematics from Stanford in 1968 and his Ph.D. in Operations Research from Stanford in 1972. Since then he has been teaching in the Operations & Decision Technologies Department in the Kelley School of Business at Indiana University. He has taught courses in management science, computer simulation, and statistics to all levels of business students: undergraduates, MBAs, and doctoral students. In addition, he has recently taught simulation modeling at General Motors and Whirlpool. He has published over 20 articles in leading operations research journals in the area of applied probability, and he has authored the books *Statistics for Business and Economics*, *Student Execustat 3.0 MiniGuide*, *VBA for Modelers*, and *Data Analysis and Decision Making*. He also is working with the Palisade Corporation on a statistical software package. His current interests are in spreadsheet modeling and the development of VBA applications in Microsoft® Excel and Access.

On the personal side, Chris has been married for 28 years to his wonderful wife, Mary, who has somehow endured teaching 7th graders all of that time. They have one son, Sam, who is currently working in New York City in the music business and is playing saxophone with a rock band on the side. Chris has many interests outside the academic area. They include activities with his family (especially traveling with Mary), going to cultural events at Indiana University, playing golf and tennis, running and power walking, and reading. And, although he earns his livelihood from statistics and management science, his *real* passion is for playing the piano and listening to classical music.

DEDICATION

TO MY WONDERFUL FAMILY

Vivian, Jennifer, Gregory

W. L. W

TO MY MAIN SUPPORTERS

Mary, Sam, Tami, Ruth, and, of course, Charlie. And to Sam Senior, who is up there watching it all.

S. C. A.

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PREFACE

Practical Management Science, Second Edition, provides a spreadsheet-based, example-driven approach to management science. Our initial objective in writing the book was to reverse negative attitudes about the course by making the subject relevant to students. We intended to do this by imparting valuable modeling skills that students can appreciate and take with them into their careers. We are very gratified by the success of the first edition. The book has done a lot to meet our initial objectives in our own courses. We are especially pleased to hear about the success of the book at many other colleges and universities around the world. The latest information is that over 200 schools are using the book in the United States alone. This has motivated us to revise the book and make it even better, by incorporating our own teaching experience and many user comments and suggestions. We believe this second edition is a significant improvement over the first. We hope you agree.

When we wrote the first edition, management science courses were regarded as irrelevant or uninteresting to many business students, and the use of spreadsheets in management science was in its first stages of development. Much has changed since the first edition was published in 1996, and we believe that these changes are for the better. We have learned a lot about the "best practices" of spreadsheet modeling for clarity and communication. We have also developed better ways of teaching the materials, and we understand more about where students tend to have difficulty with the concepts. Finally, we have had the opportunity to teach this material at several Fortune 500 companies (including Eli Lilly, Price Waterhouse Coopers, General Motors, Microsoft, and Intel). These companies, through their enthusiastic support, have further enhanced the realism of the models included in this book.

The success of the book outside of the classroom motivated our approach in the second edition. While we have retained many of the features that have made this book a best-seller, we have enhanced the coverage to make it more relevant and more accessible to students of varying backgrounds. Throughout the book, you will find many new models that are based on real problems, and you will find a much clearer presentation of the modeling, solution, and interpretation of the problems. Indeed, we have found that professionals, like students, have differing backgrounds in terms of mathematics and Excel, yet they both desire skills and knowledge that they can immediately apply to their own real problems. Those of you who are sympathetic to this approach will find this second edition better suited to these needs.

Why We Wrote This Book

Our initial objectives in writing the first edition were very simple. We wanted to make management science relevant and practical to students and professionals. There are four fundamental ways in which this book distinguishes itself relative to other texts.

- **Teach by Example.** We believe that the best way to learn modeling concepts is by working through examples and completing plenty of problems. This active learning approach is not new, but we believe this book has more fully developed this approach than any book in the field. The feedback we have received from many of you has appeared to confirm the success of this pedagogical approach for management science.
- **Integrate Modeling with Finance, Marketing, and Operations Management.** We integrate modeling into all functional areas of business. This is an important feature because the majority of students are majoring in finance and marketing. Almost all competing textbooks emphasize operations-management-related examples. While these examples are important, and many are included in the book, the application of modeling to problems in finance and marketing is too important to ignore. Throughout the book, we use real examples from all functional areas of business to illustrate the power of spreadsheet modeling to all of these areas. At our school, this has led to the development of special team-taught advanced electives in finance and marketing that build upon the content in this book. The inside front cover of the book illustrates the integrative applications contained in the book.

- **Teach Modeling and Not Just Models.** Poor attitudes among students in past management science courses can be attributed to the way in which they were taught: emphasis on algebraic formulations and memorization of models. (In fact, we hear of courses that continue to use this approach.) We believe that students gain more insight into the power of management science by developing skills in modeling. Throughout the book, we stress the logic associated with model development and formulation, and we discuss the solution in this context. Because real problems and real models often include limitations or alternatives, we include many "Modeling Issues" sections to discuss these important matters. Finally, we have included "Modeling Problems" in most chapters to help develop these skills.
- **Provide Numerous Problems and Cases.** While all textbooks contain problem sets for students to practice, we have spent an enormous amount of time crafting the problems and cases contained in this book. This new edition contains many new problems and cases. Each chapter contains four types of problems: Skill-Building Problems, Skill-Extending Problems, Modeling Problems, and Cases. We have attempted to grade these problems carefully within each section and at the conclusion of each chapter. Selected solutions appear on the accompanying CD-ROM and are denoted in the book by the color numbering of the problem. Solutions for all of the problems and cases are provided to adopting instructors. In addition, shell files (templates) are available for most of the problems (again, to adopting instructors). The shell files contain the basic structure of the problem with the relevant formulas omitted. By adding or omitting hints in individual solutions, instructors can tailor these shell files for their own purposes.

Enhancements to the Second Edition

Our experience over the past four years has taught us much about teaching a spreadsheet-based course in management science, and we have incorporated many suggestions from users of the first edition to improve the book. In addition, there have been several advances in spreadsheet-based technology in recent years. The accompanying software includes the most extensive and valuable suite of tools ever available in a management science textbook. The significant changes to the Second Edition include the following.

- **Improved Spreadsheet Readability and Documentation.** Many professionals we have taught instinctively document their spreadsheet models for the purpose of sharing them with colleagues or communicating them in presentations and reports. We believe this is an important element of good spreadsheet modeling, and the second edition does much more to emphasize this.

  Furthermore, grading homework assignments and exams can be a very time-consuming chore if students are permitted to construct their models in any form. Therefore, we place early and consistent emphasis on good spreadsheet habits. This should benefit both students and instructors. Although we try not to force any one approach on everyone, we do suggest some good habits that should lead to better spreadsheet models.

  To achieve this goal of better readability and documentation, we have completely reworked the examples in the chapters, and we have incorporated our new habits in the many new examples. This is especially important because this edition continues to be example-oriented; its most important feature is the set of examples. For users of the first edition, the changes will sometimes appear quite subtle, but we believe they will make a significant difference pedagogically. Improved readability and documentation are reflected in the following changes to the new edition.
- **Range Names.** We use range names in place of cell references whenever possible. We believe that nothing makes a formula more readable than the use of range names. The formula =SUMPRODUCT(Flows,UnitCosts) is certainly much easier to read (and grade) than =SUMPRODUCT(C15:C30,E15:E30). Range names are particularly helpful in Solver models. If the Solver dialog box has changing cells like AmtSold and constraints like Used<= Available, rather than obscure cell addresses, your grading will be much easier. Of course, naming ranges can be overdone, and it takes time. Arguably, we have possibly overdone it in some of our examples, and you might want to caution students not to name every single cell or range used in a model. However, in our experience, students *like* to name ranges, and they pick up on the habit very quickly.
- **Lists of Range Names.** We always list the range names and corresponding addresses we have used in a text box. This is a pedagogical tool used to make the *book* more readable. However, it is also a good practice for you and your students to use. (Alternatively, you can let Excel do it for you, by selecting the Insert/Names/Paste menu item and clicking on the Paste List button.)
- **Labels, Comments, Text Boxes.** We use labels, cell comments, and text boxes to document the logic behind the models wherever it is appropriate. One short sentence can be all it takes to let the reader know how or why you have done something in a certain way. There is no sense in keeping your logic a mystery to others.
- **Color Coding.** While it might not be apparent from the two-color format of the book, the accompanying example files contain color-coding that helps clarify the models. All decision variable cells (changing cells for Solver models) are in a red border, all input cells are in a blue border and shaded, and the target cell for Solver models is in a double-black border. The designation of input cells, whether in a blue border with shading or by some other means, is particularly important. When you look at someone else's model, you want to know immediately which cells are the inputs and which are calculated from them.
- **New Introductory Modeling Chapter 2.** Although students entering this course are becoming increasingly proficient in their Excel skills, many still need a "jump start" in the spreadsheet modeling process. Therefore, we have included a new introductory chapter that walks them through this process with relatively simple, but far from trivial, business examples. Important Excel tools

included in this chapter include data tables for sensitivity analysis, trend lines on scatterplots, Goal Seek, the auditing toolbar, conditional formatting, and various "advanced" Excel functions, such as IF, SUMPRODUCT, VLOOKUP, and NPV. This chapter provides a "gentle" introduction to spreadsheet modeling, so that students will be better prepared for the Solver optimization chapters, beginning with Chapter 3. For those who are relatively new to Excel, we have also included an Excel tutorial file that can be used to get up to speed in basic Excel proficiency.

- **New Evolutionary Solver Chapter 8.** If you have ever used Excel's Solver for optimization, you realize that it cannot handle certain types of nonlinearities, at least not without tricks that are difficult to teach. This is particularly true for problems that are modeled most naturally with IF, MAX, MIN, ABS, and several other functions. Fortunately, genetic algorithms are often able to solve these models with ease, provided that the software is available. It is *not* available with the standard Solver that ships with Excel, but we have been able to include a special version of the Solver developed by Frontline System (the developer of Excel's Solver) on the CD-ROM that accompanies the book. This version, called Premium Solver for Education, performs genetic algorithms with its "Evolutionary Solver." We exploit its capabilities in a new chapter to solve a number of interesting problems that could not, at least not easily, be solved with the standard Solver. By the way, the Premium Solver is easy to install, and, with a simple toggle, can be made to behave exactly like the Solver you are used to. We explain this in an appendix to Chapter 3.
- **Improved Sensitivity Analysis.** Sensitivity analysis for optimization models is limited in Excel. To address this problem, we have included a unique new add-in called SolverTable that makes this important component of optimization much more intuitive. SolverTable is introduced in Chapter 3 and is used in succeeding optimization chapters. It makes Excel a much more powerful tool for sensitivity analysis.
- **Reorganized and Streamlined Coverage.** After using the book for four years, we found that there was room for improvement in organization and coverage of the book. Specifically, several revisions were made to improve the focus of certain chapters and to provide additional discussions and practical examples where necessary.
- **Simulation.** We were never satisfied with the organization of the two simulation chapters in the first edition. They were organized around the idea that some users have the @Risk add-in and others do not. This led us to write a chapter for each audience. In this edition we have included @Risk on the accompanying CD-ROM (as part of the Palisade Decision Tools suite), so we now know that *everyone* who uses this book has @Risk. This has allowed us to reorganize the two simulation chapters (Chapters 11 and 12) in a much more natural way. Chapter 11 introduces the basic concepts of simulation, and it illustrates how to use @Risk to create and run simulation models. Given this basic knowledge, Chapter 12 then presents a wide variety of simulation examples from different business areas. All of these take advantage of @Risk. In fact, they use the newest version of @Risk, version 4.0, which was just released as we were writing this edition. This version takes some getting used to if you are an experienced @Risk user, but we believe you will appreciate its features very quickly.
- **Inventory Models.** We have reorganized the inventory models so that they now appear in a single chapter. Most of the material from the first edition is still included, but because this chapter follows the simulation chapters, we are now able to include examples of inventory simulation models. This chapter also includes a new example of a supply chain model, currently one of the hottest topics in management science and in business.
- **Queueing Models.** The queueing chapter (Chapter 14) now has less coverage of analytical models and more coverage of queueing simulation models. We have tried to make this chapter less mathematical, and we have placed more emphasis on the *insights* that can be obtained from a queueing model—either analytical or simulation.
- **Regression and Forecasting.** Based on suggestions from several users, we have split the regression and forecasting chapter into two separate chapters, one on regression and one on time series analysis and forecasting. These chapters contain more material than in the first edition, particularly in the regression chapter.
- **New Modeling Approaches.** There are at least two places where we have changed our approach to modeling certain problems. The first is in general network flow models in Chapter 5. We now develop virtually all network models in a standard way, using one range for information about arcs and another range for the node balance constraints. (We thank Cliff Ragsdale for this idea. We assume he was the first to develop it.) This approach appears to be more natural (for example, it does not require the obscure dummy nodes), and it is efficient in the sense of using the least number of changing cells. The second change is in the examples of project scheduling. In the first edition, we used an activity-on-arc approach in one chapter and an activity-on-node approach in another. While we still get arguments as to which approach is better or easier to teach, we believe it is better to be consistent. Therefore, we now use an activity-on-arc approach throughout.
- **New Models and Problems.** Throughout the book we have added many new example models. These include pricing models, a supply chain model, break-even analysis, a hedging model with put options, and others. We have also added many new problems. These include the problems in the new Chapters 2 and 8, many problems that deal with SolverTable, and others throughout the book. As before, there is a CD-ROM available to all adopting instructors that contains solutions to all of the problems and cases in Excel format. (Many of these have been reworked, either because of bugs in the original solutions or because we discovered better solution methods.) In addition, because we have gotten numerous requests from nonacademic readers for problem solutions, we have included solutions to a few designated problems in the CD-ROM that accompanies this book. (These problems are designated by problem numbers printed in color in the chapters themselves.)

Contents of the Accompanying CD-ROM

We are very excited about offering the most comprehensive suite of software ever available with a management science textbook. The commercial value of the enclosed software exceeds $1000 if purchased directly. This software is for students only, and requires online registration within 30 days of installing it to activate the software for its full one-year license. Professionals may use the software for 30 days but will need to contact the software vendors directly to obtain licensed versions. The following software is included on the accompanying CD-ROM.

Palisade's **DecisionTools™ Suite,** including the award-winning **@Risk, PrecisionTree, BestFit, TopRank,** and **RiskView.** This software is not available with any competing textbook. Although @Risk was featured in the first edition of the text, the software was not included. The addition of the software in this edition makes the simulation chapters (Chapters 11 and 12) very useful without having to obtain a special license for the software. The PrecisionTree is used extensively for decision making under uncertainty in Chapter 10. It replaces the TreePlan add-in that was used for decision trees in the first edition. For more information about the Palisade Corporation and the DecisionTools Suite, visit Palisade's Web site at www.palisade.com.

Frontline Systems' **Premium Solver™ for Education** is included in the second edition and is utilized in the new Chapter 8 on Evolutionary Solvers. Premium Solver uses genetic algorithms to solve nonlinear optimization problems. For more information on Premium Solver or Frontline Systems, visit Frontline's Web site at www.frontsys.com.

Also available from Palisade Corporation is **StatPro™**, an Excel add-in for data analysis. StatPro is featured in the regression and forecasting chapters (Chapters 15 and 16). It performs many useful statistical operations, from creating simple charts and calculating basic summary measures to more complex techniques such as discriminant analysis and logistic regression. Much of this add-in is not necessary for this book, but the regression and forecasting tools are very useful in the final two chapters.

To make sensitivity analysis useful and intuitive, we provide **SolverTable**, which we have developed. SolverTable provides data-table-like output that is easy to interpret. In the first edition we tried our best to skirt around the difficult issue of interpreting the Solver's sensitivity reports for linear programming models. We believed then, and we believe even more strongly now, that these reports are too confusing to incorporate into a spreadsheet-based course. Admittedly, they sometimes provide useful information, but many times the information they provide is virtually impossible to untangle. The SolverTable add-in works much like Excel's data tables. You specify one or two input cells, a range of values for these cells that you want to test, and one or more output cells that you want to keep track of. Then SolverTable runs Solver repeatedly with your varying inputs and reports the corresponding outputs. It is the most intuitive way we have found of conducting sensitivity analysis in optimization models, and students can learn it almost immediately.

The CD-ROM also contains the **Excel workbooks** that are used in the examples, the **data files** required for a number of problems and cases, and the **solutions** to selected problems in the book. The problems with solutions on the enclosed CD-ROM are denoted with color numbering in the chapters. These are the only solutions that are available to students and professionals.

Companion VBA Book

Soon after the first edition appeared, we began using Visual Basic for Applications (VBA), the programming language for Excel, in our management science courses. VBA allows us to develop decision support systems around the spreadsheet models. (An example appears at the end of Chapter 3.) This use of VBA has been popular with our students, and many instructors have expressed interest in learning how to do it. Therefore, one of the authors (Albright) has written a companion book, *VBA for Modelers*. It assumes no prior experience in computer programming, but it progresses rather quickly to the development of interesting and nontrivial applications. The second edition of *Practical Management Science* depends in no way on this companion VBA book, but we expect that many instructors will want to incorporate some VBA into their management science courses.

Ancillary Materials

Besides the CD-ROM that accompanies this disk, the following materials are available.

For Instructors:

- **The Instructor's Suite** CD-ROM contains the solutions in Excel format for every problem and case study throughout the book. In addition, the CD-ROM contains shell files for every problem and case study. Shell files are partially completed solutions with formulas and other information removed. We have used these shell files in large classes where students might benefit from additional help.
- **PowerPoint presentation files** for all of the examples in the book.
- **A Test Items file** is under development. In teaching a spreadsheet-based management course, we have found testing and assessment to be the most challenging aspects of delivering a successful course. We are pleased that Christopher Zappe of Bucknell University is preparing a test item file that is especially suited to our approach.

For Students:

- **A Study Guide** for students assists them in successfully mastering the art of spreadsheet modeling by working through the examples from the textbook.
- ***VBA for Modelers*** is a stand-alone book, as previously described.

Acknowledgments

The authors would like to thank those people who helped make this book a reality. We are indebted to Mark Broadie of the Graduate School of Business, Columbia University, for

contributing the excellent Case Studies that appear throughout the book. Our special thanks to Jim Orlin of MIT for his vital ideas and suggestions regarding SolverTable.

This book has gone through several stages of reviews, and it is a much better product because of them. The majority of the reviewers' suggestions were very good ones, and we have attempted to incorporate them. Thanks to Sudhakar D. Deshmukh, Kellogg School of Management, Northwestern University; James Morris, University of Wisconsin; Stephen Powell, Tuck School, Dartmouth College; and Thomas J. Schriber, University of Michigan. Our thanks to the first-edition reviewers, whose suggestions helped lead this book to success: Aaron Paul Blossom, Grand Valley State University; Richard E. Crandall, Appalachian State University; Roger B. Grinde, University of New Hampshire; Jerrold H. May, University of Pittsburgh; James G. Morris, University of Wisconsin–Madison; Danny Myers, Bowling Green State University; James B. Orlin, Massachusetts Institute of Technology; Gary Reeves, University of South Carolina; Timothy A. Riggle, Baldwin-Wallace College; and David Schilling, Ohio State University. We thank also the first-edition adopters who have added so much to the second edition through their suggestions.

We would also like to thank two special people. First, we want to thank our editor Curt Hinrichs for continuing to be the guiding light on this project. Throughout the development of both editions, Curt has kept up incredible enthusiasm for this new approach to teaching management science. He is truly a visionary in this area, and his ideas have shaped much of what we have done here. If the new edition continues to be a success, it is due in large part to Curt's efforts. We also want to thank our production editor, Susan Reiland. She has been wonderful to work with. Any management science book is bound to contain a lot of details, and one based on spreadsheets has even more details. Trying to get all of these details correct is a difficult task—to say the least—and Susan has had the patience and the perfectionist attitude to help us "get it right."

In addition, we would like to thank Peter Vacek and William Baxter for their devoted work in the production of the book. Few people know how much work it takes to make a book *look* good, with tables placed properly, headings sized correctly, and numerous other details. Peter and William have been invaluable in this task.

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We would also enjoy hearing from you—we can be reached by e-mail. And please visit our Web site at www.duxbury.com and go to the online Book Companion link for more information and occasional updates.

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