

Spreadsheet Modeling & Decision Analysis

Edition: 6



Category	Quantity	Unit Price	Subtotal	Quantity	Unit Price	Subtotal	Comments
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Product AH	34000	\$ 175.00	\$ 5,950,000	17000	\$ 87.50	\$ 1,487,500	Product AH - Phase 1
Product AI	35000	\$ 180.00	\$ 6,300,000	17500	\$ 90.00	\$ 1,575,000	Product AI - Phase 1
Product AJ	36000	\$ 185.00	\$ 6,660,000	18000	\$ 92.50	\$ 1,665,000	Product AJ - Phase 1
Product AK	37000	\$ 190.00	\$ 7,030,000	18500	\$ 95.00	\$ 1,757,500	Product AK - Phase 1
Product AL	38000	\$ 195.00	\$ 7,410,000	19000	\$ 97.50	\$ 1,852,500	Product AL - Phase 1
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Product AQ	43000	\$ 220.00	\$ 9,460,000	21500	\$ 110.00	\$ 2,365,000	Product AQ - Phase 1
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Product AS	45000	\$ 230.00	\$ 10,350,000	22500	\$ 115.00	\$ 2,587,500	Product AS - Phase 1
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Product BU	73000	\$ 370.00	\$ 27,010,000	36500	\$ 185.00	\$ 6,730,000	Product BU - Phase 1
Product BV	74000	\$ 375.00	\$ 27,750,000	37000	\$ 187.50	\$ 6,912,500	Product BV - Phase 1
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Product BX	76000	\$ 385.00	\$ 29,260,000	38000	\$ 192.50	\$ 7,290,000	Product BX - Phase 1
Product BY	77000	\$ 390.00	\$ 30,030,000	38500	\$ 195.00	\$ 7,482,500	Product BY - Phase 1
Product BZ	78000	\$ 395.00	\$ 30,810,000	39000	\$ 197.50	\$ 7,677,500	Product BZ - Phase 1
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Product CG	85000	\$ 430.00	\$ 36,550,000	42500	\$ 215.00	\$ 9,112,500	Product CG - Phase 1
Product CH	86000	\$ 435.00	\$ 37,410,000	43000	\$ 217.50	\$ 9,327,500	Product CH - Phase 1
Product CI	87000	\$ 440.00	\$ 38,280,000	43500	\$ 220.00	\$ 9,545,000	Product CI - Phase 1
Product CJ	88000	\$ 445.00	\$ 39,160,000	44000	\$ 222.50	\$ 9,765,000	Product CJ - Phase 1
Product CK	89000	\$ 450.00	\$ 40,050,000	44500	\$ 225.00	\$ 9,987,500	Product CK - Phase 1
Product CL	90000	\$ 455.00	\$ 40,950,000	45000	\$ 227.50	\$ 10,212,500	Product CL - Phase 1
Product CM	91000	\$ 460.00	\$ 41,860,000	45500	\$ 230.00	\$ 10,440,000	Product CM - Phase 1
Product CN	92000	\$ 465.00	\$ 42,780,000	46000	\$ 232.50	\$ 10,670,000	Product CN - Phase 1
Product CO	93000	\$ 470.00	\$ 43,710,000	46500	\$ 235.00	\$ 10,902,500	Product CO - Phase 1
Product CP	94000	\$ 475.00	\$ 44,650,000	47000	\$ 237.50	\$ 11,137,500	Product CP - Phase 1
Product CQ	95000	\$ 480.00	\$ 45,600,000	47500	\$ 240.00	\$ 11,375,000	Product CQ - Phase 1
Product CR	96000	\$ 485.00	\$ 46,560,000	48000	\$ 242.50	\$ 11,615,000	Product CR - Phase 1
Product CS	97000	\$ 490.00	\$ 47,530,000	48500	\$ 245.00	\$ 11,857,500	Product CS - Phase 1
Product CT	98000	\$ 495.00	\$ 48,510,000	49000	\$ 247.50	\$ 12,102,500	Product CT - Phase 1
Product CU	99000	\$ 500.00	\$ 49,500,000	49500	\$ 250.00	\$ 12,350,000	Product CU - Phase 1
Product CV	100000	\$ 505.00	\$ 50,500,000	50000	\$ 252.50	\$ 12,600,000	Product CV - Phase 1
Product CW	101000	\$ 510.00	\$ 51,510,000	50500	\$ 255.00	\$ 12,852,500	Product CW - Phase 1
Product CX	102000	\$ 515.00	\$ 52,530,000	51000	\$ 257.50	\$ 13,107,500	Product CX - Phase 1
Product CY	103000	\$ 520.00	\$ 53,560,000	51500	\$ 260.00	\$ 13,365,000	Product CY - Phase 1
Product CZ	104000	\$ 525.00	\$ 54,600,000	52000	\$ 262.50	\$ 13,625,000	Product CZ - Phase 1
Product DA	105000	\$ 530.00	\$ 55,650,000	52500	\$ 265.00	\$ 13,887,500	Product DA - Phase 1
Product DB	106000	\$ 535.00	\$ 56,710,000	53000	\$ 267.50	\$ 14,152,500	Product DB - Phase 1
Product DC	107000	\$ 540.00	\$ 57,780,000	53500	\$ 270.00	\$ 14,420,000	Product DC - Phase 1
Product DD	108000	\$ 545.00	\$ 58,860,000	54000	\$ 272.50	\$ 14,690,000	Product DD - Phase 1
Product DE	109000	\$ 550.00	\$ 59,950,000	54500	\$ 275.00	\$ 14,962,500	Product DE - Phase 1
Product DF	110000	\$ 555.00	\$ 61,050,000	55000	\$ 277.50	\$ 15,237,500	Product DF - Phase 1
Product DG	111000	\$ 560.00	\$ 62,160,000	55500	\$ 280.00	\$ 15,515,000	Product DG - Phase 1
Product DH	112000	\$ 565.00	\$ 63,280,000	56000	\$ 282.50	\$ 15,795,000	Product DH - Phase 1
Product DI	113000	\$ 570.00	\$ 64,410,000	56500	\$ 285.00	\$ 16,077,500	Product DI - Phase 1
Product DJ	114000	\$ 575.00	\$ 65,550,000	57000	\$ 287.50	\$ 16,362,500	Product DJ - Phase 1
Product DK	115000	\$ 580.00	\$ 66,700,000	57500	\$ 290.00	\$ 16,650,000	Product DK - Phase 1
Product DL	116000	\$ 585.00	\$ 67,860,000	58000	\$ 292.50	\$ 16,940,000	Product DL - Phase 1
Product DM	117000	\$ 590.00	\$ 69,030,000	58500	\$ 295.00	\$ 17,232,500	Product DM - Phase 1
Product DN	118000	\$ 595.00	\$ 70,210,000	59000	\$ 297.50	\$ 17,527,500	Product DN - Phase 1
Product DO	119000	\$ 600.00	\$ 71,400,000	59500	\$ 300.00	\$ 17,825,000	Product DO - Phase 1
Product DP	120000	\$ 605.00	\$ 72,600,000	60000	\$ 302.50	\$ 18,125,000	Product DP - Phase 1
Product DQ	121000	\$ 610.00	\$ 73,810,000	60500	\$ 305.00	\$ 18,427,500	Product DQ - Phase 1
Product DR	122000	\$ 615.00	\$ 75,030,000	61000	\$ 307.50	\$ 18,732,500	Product DR - Phase 1
Product DS	123000	\$ 620.00	\$ 76,260,000	61500	\$ 310.00	\$ 19,040,000	Product DS - Phase 1
Product DT	124000	\$ 625.00	\$ 77,500,000	62000	\$ 312.50	\$ 19,350,000	Product DT - Phase 1
Product DU	125000	\$ 630.00	\$ 78,750,000	62500	\$ 315.00	\$ 19,662,500	Product DU - Phase 1
Product DV	126000	\$ 635.00	\$ 79,990,000	63000	\$ 317.50	\$ 19,977,500	Product DV - Phase 1
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Spreadsheet Modeling & Decision Analysis 6e

A Practical Introduction to Management Science

Cliff Ragsdale

Virginia Polytechnic Institute
and State University

In memory of those
who were killed and injured
in the noble pursuit of education
here at Virginia Tech on April 16, 2007



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**Spreadsheet Modeling & Decision
Analysis, Sixth Edition**

Cliff T. Ragsdale

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Preface

Spreadsheets are one of the most popular and ubiquitous software packages on the planet. Every day, millions of business people use spreadsheet programs to build models of the decision problems they face as a regular part of their work activities. As a result, employers look for experience and ability with spreadsheets in the people they recruit.

Spreadsheets have also become the standard vehicle for introducing undergraduate and graduate students in business and engineering to the concepts and tools covered in the introductory operations research/management science (OR/MS) course. This simultaneously develops students' skills with a standard tool of today's business world and opens their eyes to how a variety of OR/MS techniques can be used in this modeling environment. Spreadsheets also capture students' interest and add a new relevance to OR/MS as they see how it can be applied with popular commercial software being used in the business world.

Spreadsheet Modeling & Decision Analysis provides an introduction to the most commonly used OR/MS techniques and shows how these tools can be implemented using Microsoft® Excel. Prior experience with Excel is certainly helpful but is not a requirement for using this text. In general, a student familiar with computers and the spreadsheet concepts presented in most introductory computer courses should have no trouble using this text. Step-by-step instructions and screenshots are provided for each example, and software tips are included throughout the text as needed.

What's New in the Sixth Edition?

The most significant change in the sixth edition of *Spreadsheet Modeling & Decision Analysis* is its extensive coverage and use of Risk Solver Platform™ for Education by Frontline Systems, Inc. Risk Solver Platform for Education is a new add-in for Excel that provides access to analytical tools for performing optimization, simulation, sensitivity analysis, and discriminant analysis, as well as the ability to create decision trees. Risk Solver Platform for Education makes it easy to run multiple parameterized optimizations and simulations and apply optimization techniques to simulation models in one integrated, coherent interface. Risk Solver Platform also offers amazing interactive simulation features in which simulation results are automatically updated in real time whenever a manual change is made to a spreadsheet. Additionally, when run in its optional Guided Mode, Risk Solver Platform provides students with more than 100 customized dialogs that provide diagnoses of various model conditions and explain the steps involved in solving problems. Risk Solver Platform offers numerous other features and will transform the way we approach OR/MS education now and in the future.

Additional changes in the revised sixth edition of *Spreadsheet Modeling & Decision Analysis* from the fifth edition include the following:

- Microsoft® Office 2010 is featured throughout.
- Data files and software to accompany the book are now available for download online.
- Chapter 1 features a new way of characterizing the quality and outcomes of decisions.

- Chapter 3 introduces Risk Solver Platform's ability to perform multiple optimizations in the context of Data Envelopment Analysis (DEA).
- Chapter 4 features new coverage of using multiple optimizations for sensitivity analysis and a new section on robust optimization.
- Chapters 8, 10, and 11 feature new coverage of Excel's AVERAGEIF() function.
- Chapter 12 features the interactive simulation capabilities of Risk Solver Platform, including the use of Value at Risk constraints and simulation optimization.
- Chapter 14 (formerly Chapter 15) now covers Decision Analysis featuring Risk Solver Platform's decision tree and sensitivity analysis tools.
- Chapter 15 (formerly Chapter 14) is now available exclusively online and covers project management, including Microsoft Project 2010.
- Several new and revised end-of-chapter problems have been added throughout.

Innovative Features

Aside from its strong spreadsheet orientation, the sixth edition of *Spreadsheet Modeling & Decision Analysis* contains several other unique features that distinguish it from traditional OR/MS texts.

- Algebraic formulations and spreadsheets are used side by side to help develop conceptual thinking skills.
- Step-by-step instructions and numerous annotated screenshots make examples easy to follow and understand.
- Emphasis is placed on model formulation and interpretation rather than on algorithms.
- Realistic examples motivate the discussion of each topic.
- Solutions to example problems are analyzed from a managerial perspective.
- A unique and accessible chapter covering discriminant analysis is provided.
- Sections entitled "The World of Management Science" show how each topic has been applied in a real company.

Organization

The table of contents for *Spreadsheet Modeling & Decision Analysis* is laid out in a fairly traditional format, but topics may be covered in a variety of ways. The text begins with an overview of OR/MS in Chapter 1. Chapters 2 through 8 cover various topics in deterministic modeling techniques: linear programming, sensitivity analysis, networks, integer programming, goal programming and multiple objective optimization, and nonlinear and evolutionary programming. Chapters 9 through 11 cover predictive modeling and forecasting techniques: regression analysis, discriminant analysis, and time series analysis.

Chapters 12 and 13 cover stochastic modeling techniques: simulation and queuing theory. Coverage of simulation using the inherent capabilities of Excel alone is available on the textbook's website (for more information, visit www.cengage.com/decisionsciences/ragsdale). Chapter 14 covers decision analysis, and Chapter 15 (available online) provides an introduction to project management.

After completing Chapter 1, a quick refresher on spreadsheet fundamentals (entering and copying formulas, basic formatting and editing, etc.) is always a good idea. Suggestions for the Excel review may be found on the website. Following this, an instructor could cover the material on optimization, forecasting, or simulation, depending on personal preferences. The chapters on queuing and project management make general references to simulation and, therefore, should follow the discussion of that topic.

Ancillary Materials

Several excellent ancillaries for the instructor accompany the revised edition of *Spreadsheet Modeling & Decision Analysis*. All instructor ancillaries are provided online at the textbook's website. Included in this convenient format are the following:

- **Instructor's Manual.** The Instructor's Manual, prepared by the author, contains solutions to all the text problems and cases.
- **Test Bank.** The Test Bank, prepared by Tom Bramorski of the University of Wisconsin-Whitewater, includes multiple-choice, true/false, and short answer problems for each text chapter. It also includes mini-projects that may be assigned as take-home assignments. The Test Bank is included as Microsoft Word files. The Test Bank also comes separately in a computerized ExamView™ format that allows instructors to use or modify the questions and create original questions.
- **PowerPoint Presentation Slides.** Microsoft PowerPoint presentation slides, prepared by the author, provide ready-made lecture material for each chapter in the book.

Instructors who adopt the text for their classes may contact their Cengage Learning Representative to request the Instructor's Resource CD (ISBN 1-111-56841-3).

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Once again, I thank my dear wife, Kathy, for her unending patience, support, encouragement, and love. (You will always be the one.) This book is dedicated to our sons, Thomas, Patrick, and Daniel. I am proud of each one of you and will always be so glad that God let me be your daddy and the leader of the Ragsdale ragamuffin band.

Final Thoughts

I hope you enjoy the spreadsheet approach to teaching OR/MS as much as I do and that you find this book to be very interesting and helpful. If you find creative ways to use the techniques in this book or need help applying them, I would love to hear from you. Also, any comments, questions, suggestions, or constructive criticism you have concerning this text are always welcome.

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Brief Contents

1	Introduction to Modeling and Decision Analysis	1
2	Introduction to Optimization and Linear Programming	17
3	Modeling and Solving LP Problems in a Spreadsheet	46
4	Sensitivity Analysis and the Simplex Method	140
5	Network Modeling	186
6	Integer Linear Programming	242
7	Goal Programming and Multiple Objective Optimization	308
8	Nonlinear Programming and Evolutionary Optimization	351
9	Regression Analysis	424
10	Discriminant Analysis	474
11	Time Series Forecasting	501
12	Introduction to Simulation Using Risk Solver Platform	569
13	Queuing Theory	653
14	Decision Analysis	686
15	Project Management (Online)	15-1
	Index	761

Contents

1. Introduction to Modeling and Decision Analysis 1

Introduction	1
The Modeling Approach to Decision Making	3
Characteristics and Benefits of Modeling	3
Mathematical Models	4
Categories of Mathematical Models	6
The Problem-Solving Process	7
Anchoring and Framing Effects	9
Good Decisions vs. Good Outcomes	11
Summary	12
References	12
The World of Management Science	12
Questions and Problems	14
Case	15

2. Introduction to Optimization and Linear Programming 17

Introduction	17
Applications of Mathematical Optimization	17
Characteristics of Optimization Problems	18
Expressing Optimization Problems Mathematically	19
Decisions 19 Constraints 19 Objective 20	
Mathematical Programming Techniques	20
An Example LP Problem	21
Formulating LP Models	21
Steps in Formulating an LP Model	21
Summary of the LP Model for the Example Problem	23
The General Form of an LP Model	23
Solving LP Problems: An Intuitive Approach	24
Solving LP Problems: A Graphical Approach	25
Plotting the First Constraint 26 Plotting the Second Constraint 26 Plotting the Third Constraint 27 The Feasible Region 28 Plotting the Objective Function 29 Finding the Optimal Solution Using Level Curves 30 Finding the Optimal Solution by Enumerating the Corner Points 32 Summary of Graphical Solution to LP Problems 32	
Understanding How Things Change	33
Special Conditions in LP Models	34
Alternate Optimal Solutions 34 Redundant Constraints 35 Unbounded Solutions 37 Infeasibility 38	
Summary	39

References	39
Questions and Problems	39
Case	44

3. Modeling and Solving LP Problems in a Spreadsheet 46

Introduction	46
Spreadsheet Solvers	46
Solving LP Problems in a Spreadsheet	47
The Steps in Implementing an LP Model in a Spreadsheet	47
A Spreadsheet Model for the Blue Ridge Hot Tubs Problem	49
Organizing the Data 50 Representing the Decision Variables 50 Representing the Objective Function 50 Representing the Constraints 51 Representing the Bounds on the Decision Variables 51	
How Solver Views the Model	52
Using Risk Solver Platform	54
Defining the Objective Cell 55 Defining the Variable Cells 56 Defining the Constraint Cells 57 Defining the Nonnegativity Conditions 60 Reviewing the Model 61 Other Options 62 Solving the Problem 63	
Using Excel's Built-in Solver	64
Goals and Guidelines for Spreadsheet Design	64
Make vs. Buy Decisions	67
Defining the Decision Variables 68 Defining the Objective Function 68 Defining the Constraints 68 Implementing the Model 69 Solving the Problem 70 Analyzing the Solution 71	
An Investment Problem	72
Defining the Decision Variables 73 Defining the Objective Function 73 Defining the Constraints 73 Implementing the Model 74 Solving the Problem 75 Analyzing the Solution 76	
A Transportation Problem	76
Defining the Decision Variables 77 Defining the Objective Function 78 Defining the Constraints 78 Implementing the Model 79 Heuristic Solution for the Model 80 Solving the Problem 81 Analyzing the Solution 82	
A Blending Problem	83
Defining the Decision Variables 83 Defining the Objective Function 83 Defining the Constraints 84 Some Observations About Constraints, Reporting, and Scaling 84 Re-scaling the Model 85 Implementing the Model 86 Solving the Problem 87 Analyzing the Solution 87	
A Production and Inventory Planning Problem	89
Defining the Decision Variables 90 Defining the Objective Function 90 Defining the Constraints 90 Implementing the Model 91 Solving the Problem 93 Analyzing the Solution 94	
A Multiperiod Cash Flow Problem	95
Defining the Decision Variables 96 Defining the Objective Function 96 Defining the Constraints 96 Implementing the Model 98 Solving the Problem 100 Analyzing the Solution 101 Modifying The Taco-Viva Problem to Account for Risk (Optional) 102 Implementing the Risk Constraints 104 Solving the Problem 105 Analyzing the Solution 105	

Data Envelopment Analysis 106

Defining the Decision Variables 107 Defining the Objective 107 Defining the Constraints 107
 Implementing the Model 108 Solving the Problem 110 Analyzing the Solution 113

Summary 114

References 115

The World of Management Science 116

Questions and Problems 116

Cases 134

4. Sensitivity Analysis and the Simplex Method 140

Introduction 140

The Purpose of Sensitivity Analysis 140

Approaches to Sensitivity Analysis 141

An Example Problem 141

The Answer Report 142

The Sensitivity Report 144

Changes in the Objective Function Coefficients 144 A Note About Constancy 146

Alternate Optimal Solutions 147 Changes in the RHS Values 147 Shadow Prices for
 Nonbinding Constraints 148 A Note About Shadow Prices 148 Shadow Prices and the

Value of Additional Resources 150 Other Uses of Shadow Prices 150 The Meaning of
 the Reduced Costs 151 Analyzing Changes in Constraint Coefficients 153 Simultaneous
 Changes in Objective Function Coefficients 154 A Warning About Degeneracy 155

The Limits Report 155

Ad Hoc Sensitivity Analysis 156

Creating Spider Tables and Plots 156 Creating a Solver Table 160 Comments 163

Robust Optimization 163

The Simplex Method 166

Creating Equality Constraints Using Slack Variables 167 Basic Feasible Solutions 167

Finding the Best Solution 170

Summary 170

References 170

The World of Management Science 171

Questions and Problems 172

Cases 180

5. Network Modeling 186

Introduction 186

The Transshipment Problem 186

Characteristics of Network Flow Problems 186 The Decision Variables for
 Network Flow Problems 188 The Objective Function for Network Flow Problems 188
 The Constraints for Network Flow Problems 189 Implementing the Model in a
 Spreadsheet 190 Analyzing the Solution 191

The Shortest Path Problem 192

An LP Model for the Example Problem 194 The Spreadsheet Model and Solution 195

Network Flow Models and Integer Solutions 195

The Equipment Replacement Problem 198

The Spreadsheet Model and Solution 198

Transportation/Assignment Problems 201**Generalized Network Flow Problems 202**

Formulating an LP Model for the Recycling Problem 204 Implementing the Model 205
 Analyzing the Solution 206 Generalized Network Flow Problems and Feasibility 207

Maximal Flow Problems 210

An Example of a Maximal Flow Problem 210 The Spreadsheet Model and Solution 212

Special Modeling Considerations 214**Minimal Spanning Tree Problems 217**

An Algorithm for the Minimal Spanning Tree Problem 218 Solving the Example Problem 218

Summary 220**References 220****The World of Management Science 220****Questions and Problems 221****Cases 236****6. Integer Linear Programming 242****Introduction 242****Integrality Conditions 242****Relaxation 243****Solving the Relaxed Problem 243****Bounds 245****Rounding 246****Stopping Rules 249****Solving ILP Problems Using Solver 249****Other ILP Problems 253****An Employee Scheduling Problem 253**

Defining the Decision Variables 254 Defining the Objective Function 254 Defining the Constraints 254 A Note About the Constraints 255 Implementing the Model 255
 Solving the Model 257 Analyzing the Solution 258

Binary Variables 258**A Capital Budgeting Problem 258**

Defining the Decision Variables 259 Defining the Objective Function 259 Defining the Constraints 259 Setting Up the Binary Variables 259 Implementing the Model 260
 Solving the Model 261 Comparing the Optimal Solution to a Heuristic Solution 261

Binary Variables and Logical Conditions 262**The Fixed-Charge Problem 263**

Defining the Decision Variables 264 Defining the Objective Function 264 Defining the Constraints 265 Determining Values for “Big M” 266 Implementing the Model 266
 Solving the Model 267 Analyzing the Solution 268 A Comment on IF() Functions 269

Minimum Order/Purchase Size 270**Quantity Discounts 271**

Formulating the Model 271 The Missing Constraints 272

A Contract Award Problem 272

Formulating the Model: The Objective Function and Transportation Constraints 273
 Implementing the Transportation Constraints 274 Formulating the Model: The Side Constraints 275 Implementing the Side Constraints 276 Solving the Model 278
 Analyzing the Solution 278

The Branch-and-Bound Algorithm (Optional) 278

Branching 280 Bounding 281 Branching Again 282 Bounding Again 284
 Summary of B&B Example 284

Summary 286

References 286

The World of Management Science 286

Questions and Problems 287

Cases 302

7. Goal Programming and Multiple Objective Optimization 308

Introduction 308

Goal Programming 308

A Goal Programming Example 309

Defining the Decision Variables 310 Defining the Goals 310 Defining the Goal Constraints 310 Defining the Hard Constraints 311 GP Objective Functions 312 Defining the Objective 313 Implementing the Model 314 Solving the Model 315 Analyzing the Solution 315 Revising the Model 316 Trade-offs: The Nature of GP 317

Comments about Goal Programming 319

Multiple Objective Optimization 319

An MOLP Example 321

Defining the Decision Variables 321 Defining the Objectives 322 Defining the Constraints 322 Implementing the Model 322 Determining Target Values for the Objectives 323 Summarizing the Target Solutions 325 Determining a GP Objective 326 The MINIMAX Objective 328 Implementing the Revised Model 329 Solving the Model 330

Comments on MOLP 332

Summary 333

References 333

The World of Management Science 333

Questions and Problems 334

Cases 346

8. Nonlinear Programming and Evolutionary Optimization 351

Introduction 351

The Nature of NLP Problems 351

Solution Strategies for NLP Problems 353

Local vs. Global Optimal Solutions 354

Economic Order Quantity Models 356

Implementing the Model 359 Solving the Model 359 Analyzing the Solution 361
 Comments on the EOQ Model 361

Location Problems 362

Defining the Decision Variables 363 Defining the Objective 363 Defining the Constraints 364 Implementing the Model 364 Solving the Model and Analyzing the Solution 365 Another Solution to the Problem 366 Some Comments About the Solution to Location Problems 366

Nonlinear Network Flow Problem 367

Defining the Decision Variables 368 Defining the Objective 368 Defining the Constraints 369 Implementing the Model 369 Solving the Model and Analyzing the Solution 372

Project Selection Problems 372

Defining the Decision Variables 373 Defining the Objective Function 373 Defining the Constraints 374 Implementing the Model 374 Solving the Model 376

Optimizing Existing Financial Spreadsheet Models 376

Implementing the Model 378 Optimizing the Spreadsheet Model 379 Analyzing the Solution 380 Comments on Optimizing Existing Spreadsheets 380

The Portfolio Selection Problem 380

Defining the Decision Variables 382 Defining the Objective 382 Defining the Constraints 383 Implementing the Model 383 Analyzing the Solution 385 Handling Conflicting Objectives in Portfolio Problems 387

Sensitivity Analysis 389

Lagrange Multipliers 391 Reduced Gradients 392

Solver Options for Solving NLPs 392**Evolutionary Algorithms 393****Forming Fair Teams 395**

A Spreadsheet Model for the Problem 395 Solving the Model 397 Analyzing the Solution 397

The Traveling Salesperson Problem 398

A Spreadsheet Model for the Problem 399 Solving the Model 401 Analyzing the Solution 401

Summary 402**References 403****The World of Management Science 403****Questions and Problems 404****Cases 419****9. Regression Analysis 424****Introduction 424****An Example 424****Regression Models 426****Simple Linear Regression Analysis 427****Defining “Best Fit” 428****Solving the Problem Using Solver 429****Solving the Problem Using the Regression Tool 431****Evaluating the Fit 433****The R^2 Statistic 435****Making Predictions 437****The Standard Error 437 Prediction Intervals for New Values of Y 438****Confidence Intervals for Mean Values of Y 440 Extrapolation 440****Statistical Tests for Population Parameters 441****Analysis of Variance 441 Assumptions for the Statistical Tests 442**

Introduction to Multiple Regression	444
A Multiple Regression Example	446
Selecting the Model	447
Models with One Independent Variable	447
Models with Two Independent Variables	448
Inflating R^2	451
The Adjusted- R^2 Statistic	451
The Best Model with Two Independent Variables	452
Multicollinearity	452
The Model with Three Independent Variables	452
Making Predictions	454
Binary Independent Variables	454
Statistical Tests for the Population Parameters	455
Polynomial Regression	456
Expressing Nonlinear Relationships Using Linear Models	457
Summary of Nonlinear Regression	460
Summary	461
References	462
The World of Management Science	462
Questions and Problems	463
Cases	470

10. Discriminant Analysis 474

Introduction	474
The Two-Group DA Problem	475
Group Locations and Centroids	475
Calculating Discriminant Scores	477
The Classification Rule	480
Refining the Cut-off Value	481
Classification Accuracy	482
Classifying New Employees	483
The k -Group DA Problem	485
Multiple Discriminant Analysis	486
Distance Measures	488
MDA Classification	489
Summary	492
References	493
The World of Management Science	493
Questions and Problems	494
Cases	497

11. Time Series Forecasting 501

Introduction	501
Time Series Methods	502
Measuring Accuracy	502
Stationary Models	503
Moving Averages	504
Forecasting with the Moving Average Model	506
Weighted Moving Averages	508
Forecasting with the Weighted Moving Average Model	509
Exponential Smoothing	510
Forecasting with the Exponential Smoothing Model	512

Seasonality	514
Stationary Data with Additive Seasonal Effects	515
Forecasting with the Model	518
Stationary Data with Multiplicative Seasonal Effects	519
Forecasting with the Model	522
Trend Models	523
An Example	523
Double Moving Average	523
Forecasting with the Model	526
Double Exponential Smoothing (Holt's Method)	527
Forecasting with Holt's Method	530
Holt-Winter's Method for Additive Seasonal Effects	530
Forecasting with Holt-Winter's Additive Method	534
Holt-Winter's Method for Multiplicative Seasonal Effects	534
Forecasting with Holt-Winter's Multiplicative Method	538
Modeling Time Series Trends Using Regression	538
Linear Trend Model	538
Forecasting with the Linear Trend Model	540
Quadratic Trend Model	541
Forecasting with the Quadratic Trend Model	543
Modeling Seasonality with Regression Models	544
Adjusting Trend Predictions with Seasonal Indices	544
Computing Seasonal Indices	544
Forecasting with Seasonal Indices	547
Refining the Seasonal Indices	547
Seasonal Regression Models	550
The Seasonal Model	550
Forecasting with the Seasonal Regression Model	553
Combining Forecasts	553
Summary	554
References	554
The World of Management Science	555
Questions and Problems	555
Cases	564

12. Introduction to Simulation Using Risk Solver Platform 569

Introduction	569
Random Variables and Risk	569
Why Analyze Risk?	570
Methods of Risk Analysis	570
Best-Case/Worst-Case Analysis	571
What-If Analysis	572
Simulation	572
A Corporate Health Insurance Example	573
A Critique of the Base Case Model	575
Spreadsheet Simulation Using Risk Solver Platform	575
Starting Risk Solver Platform	576

Random Number Generators 576

Discrete vs. Continuous Random Variables 578

Preparing the Model for Simulation 579

Alternate RNG Entry 582

Running the Simulation 583

Selecting the Output Cells to Track 583 Selecting the Number of Replications 584

Selecting What Gets Displayed on the Worksheet 586 Running The Simulation 586

Data Analysis 587

The Best Case and the Worst Case 587 Viewing the Distribution of the Output Cells 588

Viewing the Cumulative Distribution of the Output Cells 589 Obtaining Other

Cumulative Probabilities 590 Sensitivity Analysis 591

The Uncertainty of Sampling 591

Constructing a Confidence Interval for the True Population Mean 592 Constructing a

Confidence Interval for a Population Proportion 593 Sample Sizes and Confidence

Interval Widths 594

Interactive Simulation 594**The Benefits of Simulation 596****Additional Uses of Simulation 597****A Reservation Management Example 597**

Implementing the Model 598 Details for Multiple Simulations 599 Running the

Simulations 601 Data Analysis 601

An Inventory Control Example 602

Creating the RNGs 604 Implementing the Model 605 Replicating the Model 607

Optimizing the Model 609 Analyzing the Solution 615 Other Measures of Risk 617

A Project Selection Example 618

A Spreadsheet Model 619 Solving and Analyzing the Problem with Risk

Solver Platform 620 Considering Another Solution 622

A Portfolio Optimization Example 623

A Spreadsheet Model 624 Solving the Problem with Risk Solver Platform 626

Summary 629**References 629****The World of Management Science 630****Questions and Problems 630****Cases 644****13. Queuing Theory 653****Introduction 653****The Purpose of Queuing Models 653****Queuing System Configurations 654****Characteristics of Queuing Systems 655**

Arrival Rate 656 Service Rate 657

Kendall Notation 659**Queuing Models 659****The M/M/s Model 661**

An Example 662 The Current Situation 662 Adding a Server 663

Economic Analysis 664

The M/M/s Model with Finite Queue Length	664
The Current Situation	665
Adding a Server	666
The M/M/s Model with Finite Population	666
An Example	667
The Current Situation	668
Adding Servers	669
The M/G/1 Model	670
The Current Situation	671
Adding the Automated Dispensing Device	672
The M/D/1 Model	674
Simulating Queues and the Steady-state Assumption	674
Summary	675
References	675
The World of Management Science	676
Questions and Problems	677
Cases	683

14. Decision Analysis 686

Introduction	686
Good Decisions vs. Good Outcomes	686
Characteristics of Decision Problems	687
An Example	687
The Payoff Matrix	688
Decision Alternatives	688
States of Nature	689
The Payoff Values	689
Decision Rules	690
Nonprobabilistic Methods	690
The Maximax Decision Rule	691
The Maximin Decision Rule	692
The Minimax Regret Decision Rule	692
Probabilistic Methods	694
Expected Monetary Value	695
Expected Regret	696
Sensitivity Analysis	697
The Expected Value of Perfect Information	699
Decision Trees	701
Rolling Back a Decision Tree	702
Creating Decision Trees with Risk Solver Platform	703
Adding Event Nodes	704
Determining the Payoffs and EMVs	708
Other Features	708
Multistage Decision Problems	709
A Multistage Decision Tree	710
Developing A Risk Profile	711
Sensitivity Analysis	712
Tornado Charts	713
Strategy Tables	716
Strategy Charts	718
Using Sample Information in Decision Making	720
Conditional Probabilities	721
The Expected Value of Sample Information	722
Computing Conditional Probabilities	723
Bayes's Theorem	725
Utility Theory	726
Utility Functions	726
Constructing Utility Functions	727
Using Utilities to Make Decisions	730
The Exponential Utility Function	730
Incorporating Utilities in Decision Trees	731

Multicriteria Decision Making	732
The Multicriteria Scoring Model	733
The Analytic Hierarchy Process	737
Pairwise Comparisons	737
Normalizing the Comparisons	738
Consistency	739
Obtaining Scores for the Remaining Criteria	741
Obtaining Criterion Weights	742
Implementing the Scoring Model	742
Summary	743
References	743
The World of Management Science	744
Questions and Problems	745
Cases	755

15. Project Management (Online) 15-1

Introduction	15-1
An Example	15-1
Creating the Project Network	15-2
Start and Finish Points	15-4
CPM: An Overview	15-5
The Forward Pass	15-6
The Backward Pass	15-8
Determining the Critical Path	15-10
A Note on Slack	15-11
Project Management Using Spreadsheets	15-12
Important Implementation Issue	15-16
Gantt Charts	15-16
Project Crashing	15-18
An LP Approach to Crashing	15-19
Determining the Earliest Crash Completion Time	15-20
Implementing the Model	15-22
Solving the Model	15-23
Determining a Least Costly Crash Schedule	15-24
Crashing as an MOLP	15-25
PERT: An Overview	15-26
The Problems with PERT	15-27
Implications	15-29
Simulating Project Networks	15-29
An Example	15-30
Generating Random Activity Times	15-30
Implementing the Model	15-31
Running the Simulation	15-32
Analyzing the Results	15-34
Microsoft Project	15-35
Summary	15-37
References	15-37
The World of Management Science	15-38
Questions and Problems	15-38
Cases	15-48

Index 761

Chapter 1

Introduction to Modeling and Decision Analysis

1.0 Introduction

This book is titled *Spreadsheet Modeling and Decision Analysis: A Practical Introduction to Management Science*, so let's begin by discussing exactly what this title means. By the very nature of life, all of us must continually make decisions that we hope will solve problems and lead to increased opportunities for ourselves or the organizations for which we work. But making good decisions is rarely an easy task. The problems faced by decision makers in today's competitive, fast-paced business environment are often extremely complex and can be addressed by numerous possible courses of action. Evaluating these alternatives and choosing the best course of action represents the essence of decision analysis.

During the past decade, millions of business people discovered that one of the most effective ways to analyze and evaluate decision alternatives involves using electronic spreadsheets to build computer models of the decision problems they face. A **computer model** is a set of mathematical relationships and logical assumptions implemented in a computer as a representation of some real-world object, decision problem or phenomenon. Today, electronic spreadsheets provide the most convenient and useful way for business people to implement and analyze computer models. Indeed, most business people would probably rate the electronic spreadsheet as their most important analytical tool apart from their brain! Using a **spreadsheet model** (a computer model implemented via a spreadsheet), a businessperson can analyze decision alternatives before having to choose a specific plan for implementation.

This book introduces you to a variety of techniques from the field of management science that can be applied in spreadsheet models to assist in the decision-analysis process. For our purposes, we will define **management science** as a field of study that uses computers, statistics, and mathematics to solve business problems. It involves applying the methods and tools of science to management and decision making. It is the science of making better decisions. Management science is also sometimes referred to as operations research or decision science. See Figure 1.1 for a summary of how management science has been applied successfully in a number of real-world situations.

In the not-too-distant past, management science was a highly specialized field that generally could be practiced only by those who had access to mainframe computers and who possessed an advanced knowledge of mathematics and computer programming languages. However, the proliferation of powerful PCs and the development of easy-to-use electronic spreadsheets have made the tools of management science far more practical and available to a much larger audience. Virtually everyone who uses a

FIGURE 1.1

Examples of
successful
management
science
applications

Over the past decade, scores of operations research and management science projects saved companies millions of dollars. Each year, the Institute for Operations Research and the Management Sciences (INFORMS) sponsors the Franz Edelman Awards competition to recognize some of the most outstanding OR/MS projects during the past year. Here are some of the “home runs” from the 2008 Edelman Awards (described in *Interfaces*, Vol. 39, No. 1, January-February, 2009).

- **Xerox** has invented, tested, and implemented an innovative group of productivity-improvement solutions, trademarked LDP Lean Document Production[®] solutions, for the \$100 billion printing industry in the United States. These solutions have provided dramatic productivity and cost improvements for both print shops and document-manufacturing facilities. These solutions have extended the use of operations research to small- and medium-sized print shops, while increasing the scope of applications in large document-production facilities. **Benefits:** LDP solutions have generated approximately \$200 million of incremental profit across the Xerox customer value chain since their initial introduction in 2000 and improved productivity by 20–40%.
- The network for transport of natural gas on the Norwegian Continental Shelf is the world’s largest offshore pipeline network. The gas flowing through this network represents approximately 15% of European consumption. In a network of interconnected pipelines, system effects are prevalent, and the network must be analyzed as a whole to determine the optimal operation. The main Norwegian shipper of natural gas, **StatoilHydro**, uses a tool called GassOpt that allows users to graphically model their network and run optimizations to find the best network configuration and routing for transporting gas. **Benefits:** The company estimates that its accumulated savings related to the use of GassOpt were approximately US \$2 billion as of 2008.
- In the United States, the **Federal Aviation Administration** (FAA) is responsible for providing air traffic management services and frequently faces situations where a large-scale weather system reduces airspace capacity. In June 2006, the FAA began using a tool known as Airspace Flow Programs that gave the FAA the ability to control activity in congested airspaces by issuing ground delays customized for each individual flight when large-scale thunderstorms block major flight routes. **Benefits:** During its first two years of use, the system saved aircraft operators an estimated \$190 million.
- In 2006, **Netherlands Railways** introduced a new timetable designed to support the growth of passenger and freight transport on a highly used railway network and to reduce the number of train delays. Constructing a railway timetable from scratch for about 5,500 daily trains is a complex challenge. To meet this challenge, techniques were used to generate several timetables, one of which was finally selected and implemented. Additionally, because rolling stock and crew costs are the most significant expenses for a railway operator, OR (operations research) tools were used to design efficient schedules for these two resources. **Benefits:** The more efficient resource schedules and the increased number of passengers have increased annual profit by 40 million Euros (US \$60 million). Moreover, the trains are transporting more passengers on the same railway infrastructure with more on-time arrivals than ever before.

spreadsheet today for model building and decision making is a practitioner of management science—whether they realize it or not.

1.1 The Modeling Approach to Decision Making

The idea of using models in problem solving and decision analysis is really not new and is certainly not tied to the use of computers. At some point, all of us have used a modeling approach to make a decision. For example, if you have ever moved into a dormitory, apartment, or house, you undoubtedly faced a decision about how to arrange the furniture in your new dwelling. There were probably a number of different arrangements to consider. One arrangement might give you the most open space but require that you build a loft. Another might give you less space but allow you to avoid the hassle and expense of building a loft. To analyze these different arrangements and make a decision, you did not build the loft. You more likely built a **mental model** of the two arrangements, picturing what each looked like in your mind's eye. Thus, a simple mental model is sometimes all that is required to analyze a problem and make a decision.

For more complex decision problems, a mental model might be impossible or insufficient, and other types of models might be required. For example, a set of drawings or blueprints for a house or building provides a **visual model** of the real-world structure. These drawings help illustrate how the various parts of the structure will fit together when it is completed. A road map is another type of visual model because it assists a driver in analyzing the various routes from one location to another.

You have probably also seen car commercials on television showing automotive engineers using **physical**, or **scale, models** to study the aerodynamics of various car designs in order to find the shape that creates the least wind resistance and maximizes fuel economy. Similarly, aeronautical engineers use scale models of airplanes to study the flight characteristics of various fuselage and wing designs. And civil engineers might use scale models of buildings and bridges to study the strengths of different construction techniques.

Another common type of model is a **mathematical model**, which uses mathematical relationships to describe or represent an object or decision problem. Throughout this book, we will study how various mathematical models can be implemented and analyzed on computers using spreadsheet software. But before we move to an in-depth discussion of spreadsheet models, let's look at some of the more general characteristics and benefits of modeling.

1.2 Characteristics and Benefits of Modeling

Although this book focuses on mathematical models implemented in computers via spreadsheets, the examples of nonmathematical models given earlier are worth discussing a bit more because they help illustrate a number of important characteristics and benefits of modeling in general. First, the models mentioned earlier are usually simplified versions of the object or decision problem they represent. To study the aerodynamics of a car design, we do not need to build the entire car complete with engine and stereo. Such components have little or no effect on aerodynamics. So, although a model

is often a simplified representation of reality, the model is useful as long as it is valid. A **valid model** is one that accurately represents the relevant characteristics of the object or decision problem being studied.

Second, it is often less expensive to analyze decision problems using a model. This is especially easy to understand with respect to scale models of big-ticket items such as cars and planes. Besides the lower financial cost of building a model, the analysis of a model can help avoid costly mistakes that might result from poor decision making. For example, it is far less costly to discover a flawed wing design using a scale model of an aircraft than after the crash of a fully loaded jet liner.

Frank Brock, former executive vice president of the Brock Candy Company, related the following story about blueprints his company prepared for a new production facility. After months of careful design work, he proudly showed the plans to several of his production workers. When he asked for their comments, one worker responded, “It’s a fine looking building Mr. Brock, but that sugar valve looks like it’s about twenty feet away from the steam valve.”

“What’s wrong with that?” asked Brock.

“Well, nothing,” said the worker, “except that I have to have my hands on both valves at the same time!”¹ Needless to say, it was far less expensive to discover and correct this “little” problem using a visual model before pouring the concrete and laying the pipes as originally planned.

Third, models often deliver needed information on a more timely basis. Again, it is relatively easy to see that scale models of cars or airplanes can be created and analyzed more quickly than their real-world counterparts. Timeliness is also an issue when vital data will not become available until some later point in time. In these cases, we might create a model to help predict the missing data to assist in current decision making.

Fourth, models are frequently helpful in examining things that would be impossible to do in reality. For example, human models (crash dummies) are used in crash tests to see what might happen to an actual person if a car hits a brick wall at a high speed. Likewise, models of DNA can be used to visualize how molecules fit together. Both of these are difficult, if not impossible, to do without the use of models.

Finally, and probably most importantly, models allow us to gain insight and understanding about the object or decision problem under investigation. The ultimate purpose of using models is to improve decision making. As you will see, the process of building a model can shed important light and understanding on a problem. In some cases, a decision might be made while building the model as a previously misunderstood element of the problem is discovered or eliminated. In other cases, a careful analysis of a completed model might be required to “get a handle” on a problem and gain the insights needed to make a decision. In any event, it is the insight gained from the modeling process that ultimately leads to better decision making.

1.3 Mathematical Models

As mentioned earlier, the modeling techniques in this book differ quite a bit from scale models of cars and planes or visual models of production plants. The models we will build use mathematics to describe a decision problem. We use the term “mathematics” in its broadest sense, encompassing not only the most familiar elements of math, such as algebra, but also the related topic of logic.

¹ Colson, Charles and Jack Eckerd, *Why America Doesn’t Work* (Denver, Colorado: Word Publishing, 1991), 146–147.