

TABLE OF CONTENTS

PREFACE xviii

CHAPTER 1

Introduction 1

- 1.1 The Origins of Operations Research 1
- 1.2 The Nature of Operations Research 2
- 1.3 The Impact of Operations Research 3
- 1.4 Algorithms and OR Courseware 5
- Selected References 6
- Problems 7

CHAPTER 2

Overview of the Operations Research Modeling Approach 8

- 2.1 Defining the Problem and Gathering Data 8
- 2.2 Formulating a Mathematical Model 12
- 2.3 Deriving Solutions from the Model 15
- 2.4 Testing the Model 17
- 2.5 Preparing to Apply the Model 19
- 2.6 Implementation 21
- 2.7 Conclusions 22
- Selected References 23
- Problems 23

CHAPTER 3

Introduction to Linear Programming 25

- 3.1 Prototype Example 26
- 3.2 The Linear Programming Model 32
- 3.3 Assumptions of Linear Programming 37
- 3.4 Additional Examples 44
- 3.5 Some Classic Case Studies 60
- 3.6 Formulating and Solving Linear Programming Models on a Spreadsheet 65
- 3.7 Formulating Very Large Linear Programming Models 73
- 3.8 Conclusions 80
- Appendix 3.1 The LINGO Modeling Language 81
- Selected References 90
- Learning Aids for This Chapter on CD-ROM 90
- Problems 91
- Case 3.1 Auto Assembly 100
- Previews of Added Cases on CD-ROM 102
 - Case 3.2 Cutting Cafeteria Costs 102
 - Case 3.3 Staffing a Call Center 102
 - Case 3.4 Promoting a Breakfast Cereal 102

CHAPTER 4

Solving Linear Programming Problems: The Simplex Method 103

- 4.1 The Essence of the Simplex Method 103
- 4.2 Setting Up the Simplex Method 108
- 4.3 The Algebra of the Simplex Method 111
- 4.4 The Simplex Method in Tabular Form 117
- 4.5 Tie Breaking in the Simplex Method 121
- 4.6 Adapting to Other Model Forms 124
- 4.7 Postoptimality Analysis 142
- 4.8 Computer Implementation 150
- 4.9 The Interior-Point Approach to Solving Linear Programming Problems 153
- 4.10 Conclusions 158
- Appendix 4.1 An Introduction to Using LINDO 158
- Selected References 161
- Learning Aids for This Chapter on CD-ROM 161
- Problems 162
- Case 4.1 Fabrics and Fall Fashions 170
- Previews of Added Cases on CD-ROM 172
 - Case 4.2 New Frontiers 172
 - Case 4.3 Assigning Students to Schools 172

CHAPTER 5

The Theory of the Simplex Method 173

- 5.1 Foundations of the Simplex Method 173
- 5.2 The Revised Simplex Method 184
- 5.3 A Fundamental Insight 193
- 5.4 Conclusions 201
- Selected References 201
- Learning Aids for This Chapter on CD-ROM 201
- Problems 202

CHAPTER 6

Duality Theory and Sensitivity Analysis 209

- 6.1 The Essence of Duality Theory 210
- 6.2 Economic Interpretation of Duality 217
- 6.3 Primal-Dual Relationships 220
- 6.4 Adapting to Other Primal Forms 225
- 6.5 The Role of Duality Theory in Sensitivity Analysis 229
- 6.6 The Essence of Sensitivity Analysis 231
- 6.7 Applying Sensitivity Analysis 239
- 6.8 Performing Sensitivity Analysis on a Spreadsheet 259
- 6.9 Conclusions 275
- Selected References 275
- Learning Aids for This Chapter on CD-ROM 276
- Problems 276
- Case 6.1 Controlling Air Pollution 289
- Previews of Added Cases on CD-ROM 290
 - Case 6.2 Farm Management 290
 - Case 6.3 Assigning Students to Schools (Revisited) 291
 - Case 6.4 Writing a Nontechnical Memo 291

CHAPTER 7

Other Algorithms for Linear Programming 292

- 7.1 The Dual Simplex Method 292
- 7.2 Parametric Linear Programming 295
- 7.3 The Upper Bound Technique 300
- 7.4 An Interior-Point Algorithm 303
- 7.5 Conclusions 314
- Selected References 314
- Learning Aids for This Chapter on CD-ROM 315
- Problems 315

CHAPTER 8

The Transportation and Assignment Problems 320

- 8.1 The Transportation Problem 321
- 8.2 A Streamlined Simplex Method for the Transportation Problem 335
- 8.3 The Assignment Problem 350
- 8.4 A Special Algorithm for the Assignment Problem 359
- 8.5 Conclusions 363
- Selected References 363
- Learning Aids for This Chapter on CD-ROM 364
- Problems 364
- Case 8.1 Shipping Wood to Market 372
- Previews of Added Cases on CD-ROM 373
 - Case 8.2 Continuation of the Texago Case Study 373
 - Case 8.3 Project Pickings 373

CHAPTER 9

Network Optimization Models 374

- 9.1 Prototype Example 375
- 9.2 The Terminology of Networks 376
- 9.3 The Shortest-Path Problem 380
- 9.4 The Minimum Spanning Tree Problem 384
- 9.5 The Maximum Flow Problem 388
- 9.6 The Minimum Cost Flow Problem 396
- 9.7 The Network Simplex Method 404
- 9.8 A Network Model for Optimizing a Projects Time-Cost Trade-Off 414
- 9.9 Conclusions 426
- Selected References 427
- Learning Aids for This Chapter on CD-ROM 427
- Problems 428
- Case 9.1 Money in Motion 437
- Previews of Added Cases on CD-ROM 439
 - Case 9.2 Aiding Allies 439
 - Case 9.3 Steps to Success 439

CHAPTER 10

Dynamic Programming 440

- 10.1 A Prototype Example for Dynamic Programming 440
- 10.2 Characteristics of Dynamic Programming Problems 445
- 10.3 Deterministic Dynamic Programming 447

| | |
|--|-----|
| 10.4 Probabilistic Dynamic Programming | 466 |
| 10.5 Conclusions | 471 |
| Selected References | 472 |
| Learning Aids for This Chapter on CD-ROM | 472 |
| Problems | 472 |

CHAPTER 11

Integer Programming 478

| | |
|---|-----|
| 11.1 Prototype Example | 479 |
| 11.2 Some BIP Applications | 482 |
| 11.3 Innovative Uses of Binary Variables in Model Formulation | 487 |
| 11.4 Some Formulation Examples | 493 |
| 11.5 Some Perspectives on Solving Integer Programming Problems | 501 |
| 11.6 The Branch-and-Bound Technique and Its Application to Binary Integer Programming | 505 |
| 11.7 A Branch-and-Bound Algorithm for Mixed Integer Programming | 515 |
| 11.8 The Branch-and-Cut Approach to Solving BIP Problems | 521 |
| 11.9 The Incorporation of Constraint Programming | 527 |
| 11.10 Conclusions | 533 |
| Selected References | 533 |
| Learning Aids for This Chapter on CD-ROM | 534 |
| Problems | 534 |
| Case 11.1 Capacity Concerns | 544 |
| Previews of Added Cases on CD-ROM | 546 |
| Case 11.2 Assigning Art | 546 |
| Case 11.3 Stocking Sets | 546 |
| Case 11.4 Assigning Students to Schools (Revisited Again) | 546 |

CHAPTER 12

Nonlinear Programming 547

| | |
|---|-----|
| 12.1 Sample Applications | 548 |
| 12.2 Graphical Illustration of Nonlinear Programming Problems | 552 |
| 12.3 Types of Nonlinear Programming Problems | 556 |
| 12.4 One-Variable Unconstrained Optimization | 561 |
| 12.5 Multivariable Unconstrained Optimization | 567 |
| 12.6 The Karush-Kuhn-Tucker (KKT) Conditions for Constrained Optimization | 572 |
| 12.7 Quadratic Programming | 576 |
| 12.8 Separable Programming | 583 |
| 12.9 Convex Programming | 589 |
| 12.10 Nonconvex Programming (with Spreadsheets) | 597 |
| 12.11 Conclusions | 602 |
| Selected References | 603 |
| Learning Aids for This Chapter on CD-ROM | 603 |
| Problems | 604 |
| Case 12.1 Savvy Stock Selection | 615 |
| Previews of Added Cases on CD-ROM | 616 |
| Case 12.2 International Investments | 616 |
| Case 12.3 Promoting a Breakfast Cereal (Revisited) | 616 |

CHAPTER 13**Metaheuristics 617**

- 13.1 The Nature of Metaheuristics 618
- 13.2 Tabu Search 625
- 13.3 Simulated Annealing 635
- 13.4 Genetic Algorithms 644
- 13.5 Conclusions 652
- Selected References 654
- Learning Aids for This Chapter on CD-ROM 654
- Problems 655

CHAPTER 14**Game Theory 659**

- 14.1 The Formulation of Two-Person, Zero-Sum Games 659
- 14.2 Solving Simple Games—A Prototype Example 661
- 14.3 Games with Mixed Strategies 666
- 14.4 Graphical Solution Procedure 667
- 14.5 Solving by Linear Programming 670
- 14.6 Extensions 673
- 14.7 Conclusions 674
- Selected References 674
- Learning Aids for This Chapter on CD-ROM 675
- Problems 675

CHAPTER 15**Decision Analysis 680**

- 15.1 A Prototype Example 681
- 15.2 Decision Making without Experimentation 682
- 15.3 Decision Making with Experimentation 687
- 15.4 Decision Trees 693
- 15.5 Using Spreadsheets to Perform Sensitivity Analysis on Decision Trees 698
- 15.6 Utility Theory 708
- 15.7 The Practical Application of Decision Analysis 715
- 15.8 Conclusions 718
- Selected References 718
- Learning Aids for This Chapter on CD-ROM 719
- Problems 719
- Case 15.1 Brainy Business 729
- Preview of an Added Case on CD-ROM 731
 - Case 15.2 Smart Steering Support 731

CHAPTER 16**Markov Chains 732**

- 16.1 Stochastic Processes 732
- 16.2 Markov Chains 734
- 16.3 Chapman-Kolmogorov Equations 739
- 16.4 Classification of States of a Markov Chain 742
- 16.5 Long-Run Properties of Markov Chains 744
- 16.6 First Passage Times 750

| | |
|--|-----|
| 16.7 Absorbing States | 752 |
| 16.8 Continuous Time Markov Chains | 755 |
| Selected References | 759 |
| Learning Aids for This Chapter on CD-ROM | 760 |
| Problems | 760 |

CHAPTER 17**Queueing Theory 765**

| | |
|---|-----|
| 17.1 Prototype Example | 766 |
| 17.2 Basic Structure of Queueing Models | 766 |
| 17.3 Examples of Real Queueing Systems | 771 |
| 17.4 The Role of the Exponential Distribution | 774 |
| 17.5 The Birth-and-Death Process | 780 |
| 17.6 Queueing Models Based on the Birth-and-Death Process | 784 |
| 17.7 Queueing Models Involving Nonexponential Distributions | 796 |
| 17.8 Priority-Discipline Queueing Models | 804 |
| 17.9 Queueing Networks | 809 |
| 17.10 The Application of Queueing Theory | 813 |
| 17.11 Conclusions | 817 |
| Selected References | 818 |
| Learning Aids for This Chapter on CD-ROM | 818 |
| Problems | 819 |
| Case 17.1 Reducing In-Process Inventory | 831 |
| Preview of an Added Case on CD-ROM | 832 |
| Case 17.2 Queueing Quandary | 832 |

CHAPTER 18**Inventory Theory 833**

| | |
|--|-----|
| 18.1 Examples | 834 |
| 18.2 Components of Inventory Models | 836 |
| 18.3 Deterministic Continuous-Review Models | 838 |
| 18.4 A Deterministic Periodic-Review Model | 848 |
| 18.5 Deterministic Multiechelon Inventory Models for Supply Chain Management | 852 |
| 18.6 A Stochastic Continuous-Review Model | 870 |
| 18.7 A Stochastic Single-Period Model for Perishable Products | 875 |
| 18.8 Larger Inventory Systems in Practice | 886 |
| 18.9 Conclusions | 889 |
| Selected References | 890 |
| Learning Aids for This Chapter on CD-ROM | 891 |
| Problems | 891 |
| Case 18.1 Brushing Up on Inventory Control | 900 |
| Previews of Added Cases on CD-ROM | 902 |
| Case 18.2 TNT: Tackling Newsboy's Teachings | 902 |
| Case 18.3 Jettisoning Surplus Stock | 902 |

CHAPTER 19**Markov Decision Processes 903**

| | |
|--|-----|
| 19.1 A Prototype Example | 903 |
| 19.2 A Model for Markov Decision Processes | 906 |
| 19.3 Linear Programming and Optimal Policies | 908 |

| | |
|--|-----|
| 19.4 Policy Improvement Algorithm for Finding Optimal Policies | 912 |
| 19.5 Discounted Cost Criterion | 917 |
| 19.6 Conclusions | 924 |
| Selected References | 925 |
| Learning Aids for This Chapter on CD-ROM | 925 |
| Problems | 926 |

CHAPTER 20

Simulation 930

| | |
|--|------|
| 20.1 The Essence of Simulation | 930 |
| 20.2 Some Common Types of Applications of Simulation | 942 |
| 20.3 Generation of Random Numbers | 946 |
| 20.4 Generation of Random Observations from a Probability Distribution | 950 |
| 20.5 Outline of a Major Simulation Study | 954 |
| 20.6 Performing Simulations on Spreadsheets | 959 |
| 20.7 Optimizing with OptQuest | 978 |
| 20.8 Conclusions | 991 |
| Selected References | 993 |
| Learning Aids for This Chapter on CD-ROM | 993 |
| Problems | 994 |
| Case 20.1 Reducing In-Process Inventory (Revisited) | 1001 |
| Case 20.2 Action Adventures | 1001 |
| Previews of Added Cases on CD-ROM | 1002 |
| Case 20.3 Planning Planers | 1002 |
| Case 20.4 Pricing under Pressure | 1002 |

APPENDIXES

| | |
|--|------|
| 1. Documentation for the OR Courseware | 1003 |
| 2. Convexity | 1006 |
| 3. Classical Optimization Methods | 1011 |
| 4. Matrices and Matrix Operations | 1014 |
| 5. Table for a Normal Distribution | 1019 |

PARTIAL ANSWERS TO SELECTED PROBLEMS 1021

INDEXES

| | |
|---------------|------|
| Author Index | 1035 |
| Subject Index | 1038 |