TABLE OF CONTENTS

PREFACE xviii

CHAPTER 1
Introduction 1
1.1 The Origins of Operations Research 1
1.2 The Nature of Operations Research 3
1.3 A Companion Discipline: Analytics 4
1.4 The Relationship Between Analytics and Operations Research 9
1.5 The Impact of Operations Research 12
1.6 Some Trends that Should Further Increase the Future Impact of Operations Research 15
1.7 Algorithms and or Courseware 16
Selected References 18
Problems 19

CHAPTER 2
Overview of How Operations Research and Analytics Professionals Analyze Problems 20
2.1 A Case Study: First Bank Evaluates Applications for Unsecured Loans 20
2.2 Define the Problem 21
2.3 Performing Descriptive Analytics 25
2.4 Performing Predictive Analytics 45
2.5 Using Operations Research to Perform Prescriptive Analytics 63
2.6 Conclusions 72
Selected References 73
Learning Aids for this Chapter on Our Website 74
Problems 75
Case 2.1 Vacations at Vegas Villas 77

CHAPTER 3
Introduction to Linear Programming 80
3.1 Prototype Example 81
3.2 The Linear Programming Model 88
3.3 Assumptions of Linear Programming 93
3.4 Additional Examples 100
3.5 Formulating and Solving Linear Programming Models on a Spreadsheet 110
3.6 Using Modeling Languages to Formulate Very Large Linear Programming Models 118
3.7 Conclusions 128
Selected References 128
Learning Aids for this Chapter on Our Website 129
Problems 129
Case 3.1 Reclaiming Solid Wastes 140

Previews of Added Cases on Our Website 141
Case 3.2 Cutting Cafeteria Costs 141
Case 3.3 Staffing a Call Center 141
Case 3.4 Promoting a Breakfast Cereal 141
Case 3.5 Auto Assembly 141

CHAPTER 4
Solving Linear Programming Problems: The Simplex Method 142
4.1 The Essence of the Simplex Method 143
4.2 Setting Up the Simplex Method 147
4.3 The Algebra of the Simplex Method 151
4.4 The Simplex Method in Tabular Form 158
4.5 Tie Breaking in the Simplex Method 162
4.6 Reformulating Nonstandard Models to Prepare for Applying the Simplex Method 165
4.7 The Big *M* Method for Helping to Solve Reformulated Models 173
4.8 The Two-Phase Method is an Alternative to the Big *M* Method 181
4.9 Postoptimality Analysis 187
4.10 Computer Implementation 194
4.11 The Interior-Point Approach to Solving Linear Programming Problems 197
4.12 Conclusions 202
Appendix 4.1: Introduction to Using LINGO + Classic LINDO 202
Selected References 206
Learning Aids for this Chapter on Our Website 206
Problems 207
Case 4.1 Fabrics and Fall Fashions 215
Previews of Added Cases on Our Website 218
Case 4.2 New Frontiers 218
Case 4.3 Assigning Students to Schools 218

CHAPTER 5
The Theory of the Simplex Method 219
5.1 Foundations of the Simplex Method 219
5.2 The Simplex Method in Matrix Form 230
5.3 A Fundamental Insight 239
5.4 The Revised Simplex Method 242
5.5 Conclusions 245
Selected References 245
Learning Aids for this Chapter on Our Website 246
Problems 246

CHAPTER 6
Duality Theory 253
6.1 The Essence of Duality Theory 253
6.2 Primal-Dual Relationships 261
6.3 Adapting to Other Primal Forms 266
6.4 The Role of Duality Theory in Sensitivity Analysis 270
6.5 Conclusions 273
Selected References 273
Learning Aids for this Chapter on Our Website 273
Problems 274

CHAPTER 7
Linear Programming under Uncertainty 278
7.1 The Essence of Sensitivity Analysis 279
7.2 Applying Sensitivity Analysis 286
7.3 Performing Sensitivity Analysis on a Spreadsheet 303
7.4 Robust Optimization 312
7.5 Chance Constraints 316
7.6 Stochastic Programming with Recourse 320
7.7 Conclusions 324
Selected References 325
Learning Aids for this Chapter on Our Website 326
Problems 327
Case 7.1 Controlling Air Pollution 336
Previews of Added Cases on Our Website 336
Case 7.2 Farm Management 336
Case 7.3 Assigning Students to Schools, Revisited 337
Case 7.4 Writing a Nontechnical Memo 337

CHAPTER 8
Other Algorithms for Linear Programming 338
8.1 The Dual Simplex Method 338
8.2 Parametric Linear Programming 342
8.3 The Upper Bound Technique 348
8.4 An Interior-Point Algorithm 350
8.5 Conclusions 361
Selected References 362
Learning Aids for this Chapter on Our Website 362
Problems 362

CHAPTER 9
The Transportation and Assignment Problems 367
9.1 The Transportation Problem 368
9.2 A Streamlined Simplex Method for the Transportation Problem 381
9.3 The Assignment Problem 393
9.4 A Special Algorithm for the Assignment Problem 402
9.5 Conclusions 406
Selected References 407
Learning Aids for this Chapter on Our Website 407
Problems 408
Case 9.1 Shipping Wood to Market 414
Previews of Added Cases on Our Website 415
Case 9.2 Continuation of the Texago Case Study 415
Case 9.3 Project Pickings 415

CHAPTER 10
Network Optimization Models 416
10.1 Prototype Example 417
10.2 The Terminology of Networks 418
10.3 The Shortest-Path Problem 421
10.4 The Minimum Spanning Tree Problem 426

10.5 The Maximum Flow Problem 431
10.6 The Minimum Cost Flow Problem 440
10.7 The Network Simplex Method 448
10.8 A Network Model for Optimizing a Project's Time-Cost Trade-Off 458
10.9 Conclusions 470
Selected References 470
Learning Aids for this Chapter on Our Website 471
Problems 471
Case 10.1 Money in Motion 479
Previews of Added Cases on Our Website 481
Case 10.2 Aiding Allies 481
Case 10.3 Steps to Success 481

CHAPTER 11
Dynamic Programming 482

11.1 A Prototype Example for Dynamic Programming 482
11.2 Characteristics of Dynamic Programming Problems 487
11.3 Deterministic Dynamic Programming 489
11.4 Probabilistic Dynamic Programming 505
11.5 Conclusions 511
Selected References 511
Learning Aids for this Chapter on Our Website 512
Problems 512

CHAPTER 12
Integer Programming 517

12.1 Prototype Example 518
12.2 Some BIP Applications 521
12.3 Using Binary Variables to Deal with Fixed Charges 528
12.4 A Binary Representation of General Integer Variables 530
12.5 Some Perspectives on Solving Integer Programming Problems 531
12.6 The Branch-and-Bound Technique and its Application to Binary Integer Programming 536
12.7 A Branch-and-Bound Algorithm for Mixed Integer Programming 548
12.8 The Branch-and-Cut Approach to Solving Pure BIP Problems 554
12.9 The Incorporation of Constraint Programming 561
12.10 Extensions of Integer Linear Programming 565
12.11 Conclusions 570
Selected References 571
Learning Aids for this Chapter on Our Website 572
Problems 573
Case 12.1 Capacity Concerns 581
Previews of Added Cases on Our Website 583
Case 12.2 Assigning Art 583
Case 12.3 Stocking Sets 583
Case 12.4 Assigning Students to Schools, Revisited Again 583

CHAPTER 13
Nonlinear Programming 584

13.1 Sample Applications 585
13.2 Graphical Illustration of Nonlinear Programming Problems 589

13.3 Types of Nonlinear Programming Problems 594
13.4 One-Variable Unconstrained Optimization 599
13.5 Multivariable Unconstrained Optimization 605
13.6 The Karush-Kuhn-Tucker (KKT) Conditions for Constrained Optimization 611
13.7 Quadratic Programming 615
13.8 Separable Programming 621
13.9 Convex Programming 628
13.10 Nonconvex Programming (with Spreadsheets) 636
13.11 Formulating and Solving Nonlinear Programming Problems with AMPL and Gurobi 641
13.12 Conclusions 648
Selected References 648
Learning Aids for this Chapter on Our Website 649
Problems 650
Case 13.1 Savvy Stock Selection 661
Previews of Added Cases on Our Website 663
Case 13.2 International Investments 663
Case 13.3 Promoting a Breakfast Cereal, Revisited 663

CHAPTER 14
Metaheuristics 664

14.1 The Nature of Metaheuristics 665
14.2 Tabu Search 672
14.3 Simulated Annealing 682
14.4 Genetic Algorithms 692
14.5 Conclusions 702
Selected References 703
Learning Aids for this Chapter on Our Website 704
Problems 704

CHAPTER 15
Game Theory 709

15.1 The Formulation of Two-Person, Zero-Sum Games 710
15.2 Solving Simple Games—A Prototype Example 711
15.3 Games with Mixed Strategies 716
15.4 Graphical Solution Procedure 718
15.5 Solving by Linear Programming 721
15.6 Extensions 724
15.7 Conclusions 725
Selected References 725
Learning Aids for this Chapter on Our Website 726
Problems 726

CHAPTER 16
Decision Analysis 731

16.1 A Prototype Example 732
16.2 Decision Making without Experimentation 733
16.3 Decision Making with Experimentation 738
16.4 Decision Trees 744
16.5 Utility Theory 749

16.6 The Practical Application of Decision Analysis 756
16.7 Multiple Criteria Decision Analysis, Including Goal Programming 758
16.8 Conclusions 762
Selected References 763
Learning Aids for this Chapter on Our Website 764
Problems 764
Case 16.1 Brainy Business 774
Preview of Added Cases on Our Website 776
Case 16.2 Smart Steering Support 776
Case 16.3 Who Wants to Be a Millionaire? 776
Case 16.4 University Toys and the Engineering Professor Action Figures 776

CHAPTER 17
Queueing Theory 777

17.1 Prototype Example 778
17.2 Basic Structure of Queueing Models 778
17.3 Some Common Types of Real Queueing Systems 783
17.4 The Role of the Exponential Distribution 785
17.5 The Birth-and-Death Process 791
17.6 Queueing Models Based on the Birth-and-Death Process 795
17.7 Queueing Models Involving Nonexponential Distributions 808
17.8 Priority-Discipline Queueing Models 816
17.9 Queueing Networks 821
17.10 The Application of Queueing Theory 826
17.11 Behavioral Queueing Theory 830
17.12 Conclusions 832
Selected References 833
Learning Aids for this Chapter on Our Website 834
Problems 834
Case 17.1 Reducing In-Process Inventory 847
Preview of an Added Case on Our Website 848
Case 17.2 Queueing Quandary 848

CHAPTER 18 (eBook Only)
Inventory Theory and Revenue Management 849

CHAPTER 19
Markov Decision Processes 850

19.1 A Prototype Example 851
19.2 A Model for Markov Decision Processes 854
19.3 Linear Programming and Optimal Policies 857
19.4 Markov Decision Processes in Practice 861
19.5 Approximate Dynamic Programming 864
19.6 Conclusions 873
Selected References 873
Learning Aids for this Chapter on Our Website 874
Problems 875

CHAPTER 20
Simulation 878

20.1 The Essence of Simulation 878
20.2 Some Common Types of Applications of Simulation 890
20.3 Generation of Random Numbers 894
20.4 Generation of Random Observations from a Probability Distribution 899
20.5 Simulation Optimization 903
20.6 Outline of a Major Simulation Study 912
20.7 Conclusions 917
Selected References 918
Learning Aids for this Chapter on Our Website 919
Problems 919
Case 20.1 Reducing In-Process Inventory, Revisited 925
Previews of Added Cases on Our Website 925
Case 20.2 Planning Planers 925
Case 20.3 Pricing under Pressure 925

APPENDIXES
1. Documentation for the OR Courseware 926
2. Convexity 928
3. Classical Optimization Methods 933
4. Matrices and Matrix Operations 936
5. Table for a Normal Distribution 941
6. Simultaneous Linear Equations 943

PARTIAL ANSWERS TO SELECTED PROBLEMS 945

INDEXES
Author Index 957
Subject Index 961