

OPERATIONS RESEARCH AND APPLICATIONS

6TH EDITION

Operations Research: Theory and Applications is a comprehensive textbook for courses in quantitative methods, operations research, management science, analytical methods for decision-making, and other related subjects. The 6th edition of the book further enhances the easy-to-understand approach adopted in earlier editions. This edition provides the readers an understanding of the problem-solving methods based on a careful discussion of formulation, solution procedures, and analysis of results.

The chapters have been reorganized and/or rewritten to facilitate better and easier understanding of the theory and text material.

Each chapter begins with a Preview and Learning Objectives to guide the students and help them focus on understanding a specific topic under study.

The chapters contain Management Cases to help students understand various business situations, and provide solutions to managerial issues that are raised while using specific techniques of operations research.

Each chapter contains Concept Quizzes to help students reinforce their understanding of the principles and applications of operations research techniques.

Examples are well illustrated with numerous interesting and varied business-oriented examples.

End-of-chapter Questions, Self-Practice Problems with Hints and Answers have been provided in each chapter to help students to learn at their own pace.

The book conforms to the latest trends of questions appearing in universities and professional examinations.

References included in most of the chapters provide basic theoretical support to the development of specific techniques used in solving decision-making problems appearing in the chapters.

References to questions appearing in the examinations of various Indian universities have been updated.

The book is intended to serve as a core textbook for the students of MBA/PGDBM, MCom, CA and ICWA who need to understand the basic concepts of operations research and apply these directly to real-life business problems. It also caters to the requirements of the students of MA/MSc (Mathematics, Statistics, Operations Research), MCA, MIT, BTech, AMIE, who need both theoretical and practical knowledge related to operations research.

Dr. J. K. Sharma, formerly a Professor at the Faculty of Management Studies, University of Delhi, is currently a Professor at Amity Business School, Amity University, Noida. He has also served as the Director of G L Bajaj Institute of Management and Technology, Greater Noida; Institute of Management Studies, Noida; and Maharishi Institute of Management, Noida. Prof. Sharma has more than 35 years of experience teaching quantitative techniques, operations research, business statistics/mathematics and project management. He is a Gold Medalist in Mathematics and has been a Visiting Professor at Group ESSEC (A Graduate School of Management), France, and Amity University, Dubai.

Dr. Sharma has authored 30 books on quantitative techniques, operations research, business statistics/mathematics, industrial management, management of systems, etc. These books have been widely appreciated by undergraduate and postgraduate students taking courses of the various Indian universities, and management professionals. He has also written over 100 research papers/management cases. Prof. Sharma is actively involved in various projects, and also conducts Management Development Programmes for both public and private sector organizations.



6TH EDITION

OPERATIONS RESEARCH THEORY AND APPLICATIONS

6TH EDITION

OPERATIONS
RESEARCH

658.403 4 SHAO



ISBN 978-93-85935-14-5



PRICE: ₹ 695.00

ROR-3677-895-OPERATION RESEARCH THEO SHA



J K SHARMA

OPERATIONS RESEARCH

THEORY AND APPLICATIONS

SIXTH EDITION

J K SHARMA

*Professor, Amity Business School
Amity University Uttar Pradesh, Noida*



(An Imprint of Laxmi Publications Pvt. Ltd.)

An ISO 9001:2008 Company

BENGALURU • CHENNAI • COCHIN • GUWAHATI • HYDERABAD
JALANDHAR • KOLKATA • LUCKNOW • MUMBAI • RANCHI • NEW DELHI
BOSTON (USA) • NAIROBI (KENYA)

By the Same Author

- *Operations Research: Problems and Solutions (3rd Edn)*
- *Quantitative Techniques for Managerial Decisions (2nd Edn)*
- *Discrete Mathematics (4th Edn)*
- *Management of Systems*
- *Quantitative Methods in Management*
- *Linear Programming: Theory and Applications*

Preface to the First Edition

The primary objective in writing this book is to provide the readers the insight into structures and processes that Operations research can offer and the enormous practical utility of its various techniques.

The aim is to explain the concepts and simultaneously to develop in readers an understanding of problem-solving methods based upon a careful discussion of model formulation, solution procedures and analysis. To this end, numerous solved business-oriented examples have been presented throughout the text. Unsolved *Self Practice Problems with Hints and Answers*, and *Review Questions* have been added in each chapter to strengthen the conceptual as well as practical knowledge of the reader.

The book is designed to be self-contained and comprises of 29 chapters divided into four parts and Appendices A and B. Topics providing theoretical support to certain results used for solving business problems in Part II are discussed in Part IV. The book is intended to serve as a core text primarily for students of MBA/PGDBM, MCom, CA, ICWA who need to understand basic concepts of operations research and apply results directly to real-life business problems. The book also suits the requirements of students appearing for MA/MSc (Maths, Statistics, Operations Research), MCA, BE/BTech (Computer Science) and AMIE, who need both theoretical and practical knowledge of operations research techniques, as well as for those preparing for IAS, NET, ISI and other competitive examinations.

I hope that the presentation and sequence of chapters have made the text interesting and lucid. In writing this book I have benefitted immensely by referring to many books and publications. I express my gratitude to all such authors, publishers and institutions; many of them have been listed in the references. If anybody has been left out inadvertently, I seek their pardon.

I express my sincere gratitude to my teachers Prof. Kanti Swarup and Dr S D Sharma for their blessings and inspiration. I wish to acknowledge my sincere thanks to my students, friends and colleagues, particularly to Prof M P Gupta and Prof A S Narag for their valuable suggestions and encouragement during the preparation of this text. I would like to thank the publishers for their efficient and thoroughly professional way in which the whole project was managed. In the end let me thank my wife and children for the unflagging support and encouragement they gave me while I worked on this book.

Any suggestions to improve the book in contents or in style are always welcome and will be appreciated and acknowledged.

J K Sharma

Contents

Preface to the Sixth Edition

v

Preface to the First Edition

vi

Chapter 1 Operations Research: An Introduction

1-24

- 1.1 Operations Research – A Quantitative Approach to Decision-Making 2
- 1.2 The History of Operations Research 2
- 1.3 Definitions of Operations Research 4
- 1.4 Features of Operations Research Approach 5
- 1.5 Operations Research Approach to Problem Solving 6
- Conceptual Questions A 7
- 1.6 Models and Modelling in Operations Research 7
 - Classification Based on Structure 8
 - Classification Based on Function (or Purpose) 10
 - Classification Based on Time Reference 10
 - Classification Based on Degree of Certainty 10
 - Classification Based on Method of Solution or Quantification 11
- 1.7 Advantages of Model Building 11
- 1.8 Methods for Solving Operations Research Models 11
- 1.9 Methodology of Operations Research 12
- 1.10 Advantages of Operations Research Study 14
- 1.11 Opportunities and Shortcomings of the Operations Research Approach 14
- 1.12 Features of Operations Research Solution 15
- 1.13 Applications of Operations Research 15
- 1.14 Operations Research Models in Practice 16
- 1.15 Computer Software for Operations Research 17
- Conceptual Questions B 18
- Chapter Summary 19
- Chapter Concepts Quiz 19
- Case Study 20
- Puzzles in Operations Research 22

Chapter 2 Linear Programming: Applications and Model Formulation

25-67

- 2.1 Introduction 26
- 2.2 Structure of Linear Programming Model 26
 - General Structure of an LP Model 26
 - Assumptions of an LP Model 27
- 2.3 Advantages of Using Linear Programming 27
- 2.4 Limitations of Linear Programming 27
- 2.5 Application Areas of Linear Programming 28
- 2.6 General Mathematical Model of Linear Programming Problem 29
- 2.7 Guidelines on Linear Programming Model Formulation 30
- 2.8 Examples of LP Model Formulation 30
 - Examples on Production 30
 - Examples on Marketing 41
 - Examples on Finance 43
 - Examples on Agriculture 49
 - Example on Transportation 51
 - Examples on Personnel 53
- Conceptual Questions 55
- Self Practice Problems 56
- Hints and Answers 61

Chapter Summary 64
 Chapter Concepts Quiz 65
 Case Study 66

Chapter 3 Linear Programming: The Graphical Method 68–99

3.1 Introduction 69
 3.2 Important Definitions 69
 3.3 Graphical Solution Methods of LP Problems 69
 • *Extreme Point Solution Method* 70 • *Examples on Maximization LP Problem* 70
 • *Examples on Minimization LP Problem* 75 • *Examples on Mixed Constraints LP Problem* 78
 • *Iso-Profit (Cost) Function Line Method* 86 • *Comparison of Two Graphical Solution Methods* 87
 3.4 Special Cases in Linear programming 87
 • *Alternative (or Multiple) Optimal Solutions* 87 • *Unbounded Solution* 88
 • *Infeasible Solution* 90 • *Redundancy* 92
 Conceptual Questions 92
 Self Practice Problems 92
 Hints and Answers 96
 Chapter Summary 97
 Chapter Concepts Quiz 97
 Case Study 98

Chapter 4 Linear Programming: The Simplex Method 100–144

4.1 Introduction 101
 4.2 Standard form of an LP Problem 101
 4.3 Simplex Algorithm (Maximization Case) 103
 4.4 Simplex Algorithm (Minimization Case) 112
 • *Two-Phase Method* 114 • *Big-M Method* 119
 Self Practice Problems A 127
 Hints and Answers 130
 4.5 Some Complications and Their Resolution 131
 • *Unrestricted Variables* 131 • *Tie for Entering Basic Variable (Key Column)* 134
 • *Tie for Leaving Basic Variable (Key Row) – Degeneracy* 134
 4.6 Types of Linear Programming Solutions 135
 • *Alternative (Multiple) Optimal Solutions* 136
 • *Unbounded Solution* 137 • *Infeasible Solution* 138
 Conceptual Questions 139
 Self Practice Problems B 139
 Hints and Answers 141
 Chapter Summary 142
 Chapter Concepts Quiz 142
 Case Study 143

Chapter 5 Duality in Linear Programming 145–168

5.1 Introduction 146
 5.2 Formulation of Dual Linear Programming Problem 146
 • *Symmetrical Form* 146 • *Economic Interpretation of Dual Variables* 147
 • *Economic Interpretation of Dual Constraints* 148
 • *Rules for Constructing the Dual from Primal* 148
 Self Practice Problems A 152
 Hints and Answers 152
 5.3 Standard Results on Duality 153
 • *Principle of Complementary Slackness* 153
 5.4 Managerial Significance of Duality 153

5.5 Advantages of Duality 159
 Conceptual Questions 159
 Self Practice Problems B 159
 Hints and Answers 161
 Chapter Summary 163
 Chapter Concepts Quiz 163
 Case Study 165
 Appendix: Theorems of Duality 166

Chapter 6 Sensitivity Analysis in Linear Programming 169–200

6.1 Introduction 170
 6.2 Sensitivity Analysis 170
 • *Change in Objective Function Coefficient (c_j)* 170
 • *Change in the Availability of Resources (b_j)* 177
 • *Change in the Input-Output Coefficients (a_{ij} 's)* 184
 • *Addition of a New Variable (Column)* 188 • *Addition of a New Constraint (Row)* 189
 Conceptual Questions 196
 Self Practice Problems 196
 Hints and Answers 198
 Chapter Summary 199
 Chapter Concepts Quiz 199
 Case Study 200

Chapter 7 Integer Linear Programming 201–235

7.1 Introduction 202
 7.2 Types of Integer Programming Problems 202
 7.3 Enumeration and Cutting Plane Solution Concept 203
 7.4 Gomory's All Integer Cutting Plane Method 203
 • *Method for Constructing Additional Constraint (Cut)* 204
 • *Steps of Gomory's All Integer Programming Algorithm* 204
 Self Practice Problems A 212
 Hints and Answers 215
 7.5 Gomory's Mixed-Integer Cutting Plane Method 216
 • *Method for Constructing Additional Constraint (Cut)* 216
 • *Steps of Gomory's Mixed-Integer Programming Algorithm* 218
 7.6 Branch and Bound Method 221
 7.7 Applications of Zero-One Integer Programming 228
 • *Capital Budgeting Problem* 228 • *Fixed Cost (or Charge) Problem* 229
 • *Plant Location Problem* 230
 Conceptual Questions 231
 Self Practice Problems B 231
 Hints and Answers 232
 Chapter Summary 232
 Chapter Concepts Quiz 232
 Case Study 234

Chapter 8 Goal Programming 236–255

8.1 Introduction 237
 8.2 Difference Between LP and GP Approach 237
 8.3 Concept of Goal Programming 237
 • *Distinction among Objectives, Goals and Constraints* 238
 8.4 Goal Programming Model Formulation 238
 • *Single Goal with Multiple Subgoals* 238 • *Equally Ranked Multiple Goals* 239
 • *Ranking and Weighting of Unequal Multiple Goals* 240
 • *General GP Model* 241 • *Steps to Formulate GP Model* 241

Contents

- 8.5 Graphical Solution Method for Goal Programming 241
- 8.6 Modified Simplex Method of Goal Programming 245
- 8.7 Alternative Simplex Method for Goal Programming 247
- Conceptual Questions 250
- Self Practice Problems 250
- Chapter Summary 252
- Chapter Concepts Quiz 253
- Case Study 254

Chapter 9 Transportation Problem

256–309

- 9.1 Introduction 257
- 9.2 Mathematical Model of Transportation Problem 257
 - *General Mathematical Model of Transportation Problem* 258
- 9.3 The Transportation Algorithm 259
- 9.4 Methods for Finding Initial Solution 259
 - *North-West Corner Method (NWCM)* 259
 - *Least Cost Method (LCM)* 260
 - *Vogel's Approximation Method (VAM)* 262
- Conceptual Questions A 265
- Self Practice Problems A 265
- Hints and Answers 265
- 9.5 Test for Optimality 266
 - *Dual of Transportation Model* 266
 - *Economic Interpretation of u_i 's and v_j 's* 267
 - *Steps of MODI Method (Transportation Algorithm)* 268
 - *Close-Loop in Transportation Table and its Properties* 269
- Conceptual Questions B 278
- Self Practice Problems B 278
- Hints and Answers 280
- 9.6 Variations in Transportation Problem 280
 - *Unbalanced Supply and Demand* 280
 - *Degeneracy and its Resolution* 283
 - *Alternative Optimal Solutions* 287
 - *Prohibited Transportation Routes* 290
- 9.7 Maximization Transportation Problem 294
- 9.8 Trans-shipment Problem 296
- Conceptual Questions C 298
- Self Practice Problems C 298
- Hints and Answers 302
- Chapter Summary 304
- Chapter Concepts Quiz 304
- Case Study 305
- Appendix: Theorems and Results 307

Chapter 10 Assignment Problem

310–338

- 10.1 Introduction 311
- 10.2 Mathematical Models of Assignment Problem 311
- 10.3 Solution Methods of Assignment Problem 312
 - *Hungarian Method for Solving Assignment Problem* 312
- Conceptual Questions A 318
- Self Practice Problems A 318
- Hints and Answers 320
- 10.4 Variations of the Assignment Problem 320
 - *Multiple Optimal Solutions* 320
 - *Maximization Case in Assignment Problem* 320
 - *Unbalanced Assignment Problem* 323
 - *Restrictions on Assignments* 323
- Conceptual Questions B 327
- Self Practice Problems B 327
- Hints and Answers 329

- 10.5 A Typical Assignment Problem 330
- 10.6 Travelling Salesman Problem 331
- Self Practice Problems C 334
- Hints and Answers 335
- Chapter Summary 335
- Chapter Concepts Quiz 335
- Case Study 337
- Appendix: Important Results and Theorems 338

Chapter 11 Decision Theory and Decision Trees

339–381

- 11.1 Introduction 340
- 11.2 Steps of Decision-Making Process 340
- 11.3 Types of Decision-Making Environments 341
- 11.4 Decision-Making Under Uncertainty 342
 - *Optimism (Maximax or Minimin) Criterion* 342
 - *Pessimism (Maximin or Minimax) Criterion* 342
 - *Equal Probabilities (Laplace) Criterion* 342
 - *Coefficient of Optimism (Hurwicz) Criterion* 343
 - *Regret (Savage) Criterion* 343
- Conceptual Questions A 346
- Self Practice Problems A 346
- Hints and Answers 347
- 11.5 Decision-Making Under Risk 347
 - *Expected Monetary Value (EMV)* 347
 - *Expected Opportunity Loss (EOL)* 350
 - *Expected Value of Perfect Information (EVPI)* 351
- 11.6 Posterior Probabilities and Bayesian Analysis 360
- Conceptual Questions B 362
- Self Practice Problems B 362
- Hints and Answers 364
- 11.7 Decision Trees Analysis 365
- 11.8 Decision-Making with Utilities 373
 - *Utility Functions* 374
 - *Utility Curve* 374
 - *Construction of Utility Curves* 375
- Self Practice Problems C 376
- Hints and Answers 378
- Chapter Summary 378
- Chapter Concepts Quiz 379
- Case Study 380

Chapter 12 Theory of Games

382–416

- 12.1 Introduction 383
- 12.2 Two-Person Zero-Sum Games 384
- 12.3 Pure Strategies (Minimax and Maximin Principles): Games with Saddle Point 386
 - *Rules to Determine Saddle Point* 386
- Conceptual Questions A 388
- Self Practice Problems A 389
- Hints and Answers 390
- 12.4 Mixed Strategies: Games without Saddle Point 390
- 12.5 The Rules (Principles) of Dominance 391
- 12.6 Solution Methods Games without Saddle Point 392
 - *Algebraic Method* 392
 - *Arithmetic Method* 400
 - *Matrix Method* 402
 - *Graphical Method* 403
 - *Linear Programming Method* 408
- Conceptual Questions B 411
- Self Practice Problems B 412
- Hints and Answers 414
- Chapter Summary 415
- Chapter Concepts Quiz 415

Chapter 13 Project Management: PERT and CPM

417-473

- 13.1 Introduction 418
- 13.2 Basic Differences Between PERT and CPM 418
 - *Significance of Using PERT/CPM* 418
- 13.3 Phases of Project Management 419
- 13.4 PERT/CPM Network Components and Precedence Relationships 420
 - *Rules for AOA Network Construction* 422 • *Errors and Dummies in Network* 423
- Conceptual Questions A 426
- Self Practice Problems A 426
- 13.5 Critical Path Analysis 428
 - *Forward Pass Method (For Earliest Event Time)* 428
 - *Backward Pass Method (For Latest Allowable Event Time)* 429
 - *Float (Slack) of an Activity and Event* 429 • *Critical Path* 430
- Conceptual Questions B 434
- Self Practice Problems B 434
- Hints and Answers 437
- 13.6 Project Scheduling with Uncertain Activity Times 437
 - *Estimation of Project Completion Time* 438
- Conceptual Questions C 441
- Self Practice Problems C 441
- Hints and Answers 445
- 13.7 Project Time-Cost Trade-Off 445
 - *Project Crashing* 445 • *Time-Cost Trade-Off Procedure* 445
- Self Practice Problems D 454
- Hints and Answers 457
- 13.8 Updating of the Project Progress 458
- 13.9 Resource Allocation 459
 - *Resource Levelling* 459 • *Resource Smoothing* 459
- Self Practice Problems E 469
- Chapter Summary 470
- Chapter Concepts Quiz 471
- Case Study 472

Chapter 14 Deterministic Inventory Control Models

474-540

- 14.1 Introduction 475
- 14.2 The Meaning of Inventory Control 475
- 14.3 Functional Role of Inventory 475
- 14.4 Reasons for Carrying Inventory 477
- 14.5 Factors Involved in Inventory Problem Analysis 477
 - *Inventory Cost Components* 479 • *Demand for Inventory Items* 480
 - *Replenishment Lead Time* 480
 - *Planning Period* 481
- 14.6 Inventory Model Building 481
 - *Steps of Inventory Model Building* 481
 - *Replenishment Order Size Decisions and Concept of EOQ* 481
 - *Classification of EOQ Models* 481
- 14.7 Single Item Inventory Control Models without Shortages 482
- Conceptual Questions A 491
- Self Practice Problems A 492
- Hints and Answers 493
- 14.8 Single Item Inventory Control Models with Shortages 494
- Conceptual Questions B 501
- Self Practice Problems B 501
- Hints and Answers 501

- 14.9 Multi-Item Inventory Models with Constraints 502
- Self Practice Problems C 507
- 14.10 Single Item Inventory Control Models with Quantity Discounts 507
- Self Practice Problems D 511
- Hints and Answers 512
- 14.11 Inventory Control Models with Uncertain Demand 513
 - *Reorder Level with Constant Demand* 513 • *Service Level* 514 • *Additional Stocks* 515
- 14.12 Information Systems for Inventory Control 518
 - *The Q-System with Uncertain Demand* 518
 - *The Q-system with Uncertain Demand and Lead Time* 524
 - *Application of Q-System: Two-Bin System* 524 • *The P-System with Uncertain Demand* 525
 - *Comparison Between Q-system and P-System* 527
- Conceptual Questions C 529
- Self Practice Problems E 529
- Hints and Answers 530
- 14.13 Selective Inventory Control Techniques 532
- Conceptual Questions D 536
- Self Practice Problems F 536
- Chapter Summary 537
- Chapter Concepts Quiz 537
- Case Study 538

Chapter 15 Probabilistic Inventory Control Models

541-558

- 15.1 Introduction 542
- 15.2 Instantaneous Demand Inventory Control Models without Set-Up Cost 542
- Conceptual Questions A 551
- Self Practice Problems A 551
- Hints and Answers 552
- 15.3 Continuous Demand Inventory Control Models without Set-Up Cost 552
- 15.4 Instantaneous Demand Inventory Control Model with Set-Up Cost 556
- Conceptual Questions B 557
- Self Practice Problems B 557
- Hints and Answers 558
- Chapter Summary 558

Chapter 16 Queuing Theory

559-612

- 16.1 Introduction 560
- 16.2 The Structure of a Queuing System 561
 - *Calling Population Characteristics* 561 • *Queuing Process* 563
 - *Queue Discipline* 564 • *Service Process (or Mechanism)* 564
- 16.3 Performance Measures of a Queuing System 566
 - *Transient-State and Steady-State* 566 • *Relationships among Performance Measures* 567
- 16.4 Probability Distributions in Queuing Systems 568
 - *Distribution of Arrivals (Pure Birth Process)* 568
 - *Distribution of Interarrival Times* 569
 - *Distribution of Departures (Pure Death Process)* 569
 - *Distribution of Service Times* 569
- Conceptual Questions A 570
- 16.5 Classification of Queuing Models 570
 - *Solution of Queuing Models* 570
- 16.6 Single-Server Queuing Models 571
- Conceptual Questions B 580
- Self Practice Problems A 580
- Hints and Answers 582

- 16.7 Multi-Server Queuing Models 583
 Conceptual Questions C 590
 Self Practice Problems B 591
 Hints and Answers 591
 16.8 Finite Calling Population Queuing Models 592
 Self Practice Problems C 596
 16.9 Multi-Phase Service Queuing Model 596
 Self Practice Problems D 599
 Hints and Answers 599
 16.10 Special Purpose Queuing Models 600
 Chapter Summary 603
 Chapter Concepts Quiz 603
 Case Study 604
 Appendix 16.A: Probability Distribution of Arrivals and Departures 606
 Appendix 16.B: Erlangian Service Time Distribution with K-Phases 610

Chapter 17 Replacement and Maintenance Models

613-646

- 17.1 Introduction 614
 17.2 Types of Failure 614
 • *Gradual Failure* 614 • *Sudden Failure* 614
 17.3 Replacement of Items whose Efficiency Deteriorates with Time 615
 Conceptual Questions A 628
 Self Practice Problems A 629
 Hints and Answers 630
 17.4 Replacement of Items that Completely Fail 631
 • *Individual Replacement Policy* 633 • *Group Replacement Policy* 633
 Conceptual Questions B 639
 Self Practice Problems B 639
 Hints and Answers 640
 17.5 Other Replacement Problems 640
 • *Staffing Problem* 640 • *Equipment Renewal Problem* 642
 Self Practice Problems C 644
 Hints and Answers 645
 Chapter Summary 645
 Chapter Concepts Quiz 645
 Case Study 646

Chapter 18 Markov Chains

647-672

- 18.1 Introduction 648
 18.2 Characteristics of a Markov Chain 648
 18.3 Applications of Markov Analysis 648
 18.4 State and Transition Probabilities 649
 18.5 Multi-Period Transition Probabilities 650
 • *Procedure to Formulate Matrix of Transition Probabilities* 651
 18.6 Steady-State (Equilibrium) Conditions 660
 • *Procedure for Determining Steady-State Condition* 661
 18.7 Absorbing States and Accounts Receivable Application 665
 Conceptual Questions 667
 Self Practice Problems 668
 Hints and Answers 669
 Chapter Summary 670
 Chapter Concepts Quiz 670
 Case Study 671

673-707

Chapter 19 Simulation

- 19.1 Introduction 674
 19.2 Simulation Defined 674
 19.3 Types of Simulation 675
 19.4 Steps of Simulation Process 676
 19.5 Advantages and Disadvantages of Simulation 677
 19.6 Stochastic Simulation and Random Numbers 678
 • *Monte Carlo Simulation* 678 • *Random Number Generation* 679
 19.7 Simulation of Inventory Problems 680
 19.8 Simulation of Queuing Problems 686
 19.9 Simulation of Investment Problems 691
 19.10 Simulation of Maintenance Problems 693
 19.11 Simulation of PERT Problems 697
 Conceptual Questions 699
 Self Practice Problems 699
 Chapter Summary 702
 Chapter Concepts Quiz 702
 Case Study 704
 Appendix: The Seven Most Frequent Causes of Simulation Analysis Failure and How to Avoid Them 704

Chapter 20 Sequencing Problems

708-725

- 20.1 Introduction 709
 20.2 Notations, Terminology and Assumptions 709
 20.3 Processing n Jobs Through Two Machines 710
 • *Johnson Procedure* 710
 Conceptual Questions A 715
 Self Practice Problems A 715
 Hints and Answers 716
 20.4 Processing n Jobs Through Three Machines 716
 • *The Procedure* 716
 Self Practice Problems B 718
 Hints and Answers 719
 20.5 Processing n Jobs Through m Machines 719
 20.6 Processing Two Jobs Through m Machines 721
 Conceptual Questions B 724
 Self Practice Problems B 724
 Hints and Answers 724
 Chapter Summary 724
 Chapter Concepts Quiz 725

Chapter 21 Information Theory

726-745

- 21.1 Introduction 727
 21.2 Communication Processes 727
 • *Memoryless Channel* 728 • *The Channel Matrix* 728
 • *Probability Relation in a Channel* 728 • *Noiseless Channel* 729
 21.3 A Measure of Information 729
 • *Properties of Entropy Function, H* 730
 21.4 Measures of Other Information Quantities 732
 • *Marginal and Joint Entropies* 732 • *Conditional Entropies* 733
 • *Expected Mutual Information* 735 • *Axiom of an Entropy Function* 736
 • *Basic Requirements of Logarithmic Entropy Functions* 736
 21.5 Channel Capacity, Efficiency and Redundancy 738
 21.6 Encoding 739
 • *Objectives of Encoding* 739

- 21.7 Shannon-Fano Encoding Procedure 740
 21.8 Necessary and Sufficient Condition for Noiseless Encoding 742
 Conceptual Questions 743
 Self Practice Problems 744
 Hints and Answers 744
 Chapter Summary 745
 Chapter Concepts Quiz 745

Chapter 22 Dynamic Programming

746-781

- 22.1 Introduction 747
 22.2 Dynamic Programming Terminology 747
 22.3 Developing Optimal Decision Policy 748
 22.4 Dynamic Programming under Certainty 749
 22.5 Dynamic Programming Approach for Solving Linear Programming Problem 773
 Conceptual Questions 775
 Self Practice Problems 776
 Hints and Answers 779
 Chapter Summary 780
 Chapter Concepts Quiz 781

Chapter 23 Classical Optimization Methods

782-805

- 23.1 Introduction 783
 23.2 Unconstrained Optimization 783
 • *Optimizing Single-Variable Functions* 783
 • *Conditions for Local Minimum and Maximum Value* 784
 • *Optimizing Multivariable Functions* 788
 Self Practice Problems A 791
 Hints and Answers 792
 23.3 Constrained Multivariable Optimization with Equality Constraints 793
 • *Direct Substitution Method* 793 • *Lagrange Multipliers Methods* 794
 Self Practice Problems B 799
 Hints and Answers 800
 23.4 Constrained Multivariable Optimization with Inequality Constraints 800
 • *Kuhn-Tucker Necessary Conditions* 800
 • *Kuhn-Tucker Sufficient Conditions* 801
 Conceptual Questions 804
 Self Practice Problems C 804
 Hints and Answers 805
 Chapter Summary 805
 Chapter Concepts Quiz 805

Chapter 24 Non-Linear Programming Methods

806-847

- 24.1 Introduction 807
 24.2 The General Non-Linear Programming Problem 809
 24.3 Graphical Solution Method 809
 Self Practice Problems A 812
 Hints and Answers 813
 24.4 Quadratic Programming 813
 • *Kuhn-Tucker Conditions* 814 • *Wolfe's Modified Simplex Method* 815
 • *Beale's Method* 820
 24.5 Applications of Quadratic Programming 826
 Conceptual Questions A 829
 Self Practice Problems B 829
 Hints and Answers 830

- 24.6 Separable Programming 830
 • *Separable Functions* 830 • *Definitions* 831
 • *Piece-Wise Linear Approximation of Non-linear Functions* 831
 • *Mixed-Integer Approximation of Separable NLP Problem* 832

Conceptual Questions B 837
 Self Practice Problems C 838
 Hints and Answers 838

24.7 Geometric Programming 838

- *General Mathematical Form of GP* 838
 • *Primal GP Problem with Equality Constraints* 842

24.8 Stochastic Programming 844

- *Sequential Stochastic Programming* 845 • *Non-Sequential Stochastic Programming* 845
 • *Chance-Constrained Programming* 845

Self Practice Problems D 846
 Hints and Answers 847
 Case Study 847
 Chapter Summary 847

Chapter 25 Theory of Simplex Method

848-869

- 25.1 Introduction 849
 25.2 Canonical and Standard Form of LP Problem 849
 25.3 Slack and Surplus Variables 850
 • *Basic Solution* 851 • *Degenerate Solution* 851 • *Cost (or Price) Vector* 852
 Conceptual Questions A 854
 Self Practice Problems A 854
 Hints and Answers 854
 25.4 Reduction of Feasible Solution to a Basic Feasible Solution 855
 25.5 Improving a Basic Feasible Solution 861
 25.6 Alternative Optimal Solutions 864
 25.7 Unbounded Solution 864
 25.8 Optimality Condition 865
 25.9 Some Complications and their Resolution 865
 • *Unrestricted Variables* 866 • *Degeneracy and its Resolution* 866
 Conceptual Questions B 868
 Self Practice Problems B 869
 Hints and Answers 869
 Chapter Summary 869

Chapter 26 Revised Simplex Method

870-885

- 26.1 Introduction 871
 26.2 Standard Forms for Revised Simplex Method 871
 • *Revised Simplex Method in Standard Form I* 871
 26.3 Computational Procedure for Standard Form I 873
 • *Steps of the Procedure* 874
 26.4 Comparison of Simplex Method and Revised Simplex Method 884
 Conceptual Questions 885
 Self Practice Problems 885
 Hints and Answers 885
 Chapter Summary 885

Chapter 27 Dual-Simplex Method

886-895

- 27.1 Introduction 887
 27.2 Dual-Simplex Algorithm 887
 Conceptual Questions 893

Self Practice Problems	893
Hints and Answers	893
Chapter Summary	893
Appendix: Theory of Dual-Simplex Method	894
Chapter 28 Bounded Variables LP Problem	896–905
28.1 Introduction	897
28.2 The Simplex Algorithm	897
Self Practice Problems	905
Hints and Answers	905
Chapter Summary	905
Chapter 29 Parametric Linear Programming	906–917
29.1 Introduction	907
29.2 Variation in the Objective Function Coefficients	907
29.3 Variation in the Availability of Resources (RHS Values)	912
Conceptual Questions	916
Self Practice Problems	917
Hints and Answers	917
Chapter Summary	917
Appendix A: Pre-Study for Operations Research	918–929
A.1 Linear Combination of Vectors	919
A.2 Linear Dependence and Independence	919
A.3 Simultaneous Linear Equations and Nature of Solution	921
A.4 Convex Analysis	922
A.5 Supporting and Separating Hyperplanes	925
A.6 Convex Functions	926
A.7 Quadratic Forms	927
Self Practice Problems	928
Appendix B: Selected Tables	930–937
Table B.1 Values of e^x and e^{-x}	931
Table B.2 Poisson Distribution	932
Table B.3 Normal Distribution	934
Table B.4 Random Numbers	935
Table B.5 Present Values	936
Table B.6 Cumulative Poisson Probabilities	937
Selected References	938–939
Index	940–943

Chapter 1

Operations Research: An Introduction

"The first rule of any technology used in a business is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency."

– Bill Gates

PREVIEW

This chapter presents a framework of a possible structural analysis of problems pertaining to an organization in order to arrive at an optimal solution using operations research approach.

LEARNING OBJECTIVES

After reading this chapter you should be able to

- understand the need of using operations research – a quantitative approach for effective decision-making.
- know the historical perspective of operations research approach.
- know various definitions of operations research, its characteristics and various phases of scientific study.
- recognize, classify and use of various models for solving a problem under consideration.
- be familiar with several computer software available for solving an operations research model.

CHAPTER OUTLINE

- | | |
|--|---|
| 1.1 Operations Research – A Quantitative Approach to Decision-Making | 1.9 Methodology of Operations Research |
| 1.2 The History of Operations Research | 1.10 Advantages of Operations Research Study |
| 1.3 Definitions of Operations Research | 1.11 Opportunities and Shortcomings of the Operations Research Approach |
| 1.4 Features of Operations Research Approach | 1.12 Features of Operations Research Solution |
| 1.5 Operations Research Approach to Problem Solving | 1.13 Applications of Operations Research |
| • Conceptual Questions A | 1.14 Operations Research Models in Practice |
| 1.6 Models and Modelling in Operations Research | 1.15 Computer Software for Operations Research |
| 1.7 Advantages of Model Building | • Conceptual Questions B |
| 1.8 Methods for Solving Operations Research Models | <input type="checkbox"/> Chapter Summary |
| | <input type="checkbox"/> Chapter Concepts Quiz |
| | <input type="checkbox"/> Case Study |
| | <input type="checkbox"/> Puzzles in Operations Research |