

C93
H1

8363951

Management Science

J. C. Hsiao

Chairman, Department of Economics
Southern Connecticut State College

David S. Cleaver

Coordinator, Management Information Systems
Connecticut State Department of Education



E8363951

Houghton Mifflin Company Boston
Dallas Geneva, Illinois Hopewell, New Jersey Palo Alto London

Copyright © 1982 by Houghton Mifflin Company. All rights reserved. No part of this work may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying and recording, or by any information storage or retrieval system, except as may be expressly permitted by the 1976 Copyright Act or in writing by the publisher. Requests for permission should be addressed in writing to Houghton Mifflin Company, One Beacon Street, Boston, Massachusetts 02108.

Printed in the U.S.A.

Library of Congress Catalog Card Number: 80-80960

ISBN: 0-395-29488-6



To Jean, Eugene, and Huey Hsiao
and William G. Cleaver

PREFACE

Readers of this book—students, faculty, and practitioners—will find it to be a comprehensive introduction to management science. The treatment of the quantitative techniques used in management science begins at ground zero with logical development of elementary terms and concepts. Topics are developed to the point where the reader who is confronted with a practical application will have gained sufficient knowledge to tackle the situation and properly interpret the results. Since courses in operations research techniques for managerial decision making have become a standard part of the business curriculum, we have designed this text for upper-level undergraduate or beginning graduate courses offered in business or public administration and in economics.

A unique feature of our presentation is the way in which we have tried to explain their use of quantitative methods. Insofar as the development of management science has benefited from basic economic theory, we often present underlying economic concepts to fully clarify why a particular method works as it does. This means that we treat basic trade-off concepts, in particular marginal analysis and opportunity costs. This approach, we believe, leads toward a better understanding of the methods involved. It also allows us to offer reasonable explanations of difficult topics, such as integer programming and quadratic programming. Furthermore, our goal is to inspire interest in using management science's tools of analysis. We avoid rigorous mathematical proofs; rather, we stress the application and illustration of techniques. The reader, by using this approach of economic reasoning and motivation, will be able to master the techniques rather than be enslaved by them. Techniques may soon be forgotten, but the concepts behind the techniques should remain with students after they complete their tour of this book.

Organization of the Text

The text is organized in two general divisions. The first of these treats deterministic, programming models including, of course, linear programming and duality concepts, the transportation model, and the assignment problem. Also featured in this first section are comprehensive introductions to integer programming, goal programming, and quadratic programming. The second major division presents probability methods and stochastic decision-making models. Included here are Bayesian models, inventory models, queuing models, simulation techniques, game theory, and Markov processes. Refer to the organization chart for an overview of these topics in the textbook. Notice also that dynamic programming, PERT, and forecasting techniques are presented at appropriate points. Relating to all of these, a short introduction to methods of solving complex quantitative decision problems using computer routines is given.

The introduction of linear programming in Chapter 2 provides a beginning for the subsequent discussion of quantitative optimization methods. Three elementary examples in this chapter are carried through in later chapters as illustrations of linear programming and goal programming models. This approach will enable students, we believe, to apply new ideas and techniques to familiar problems, an approach that will reduce “new material shock.” Underlying assumptions are carefully presented and discussed to help students in mastering the tools of analysis.

In Chapter 3, we incorporate the economic and logical explanations of procedural operations to be used in applying the simplex method. We believe this is pertinent because it enables students to acquire both mechanical orientation and theoretical understanding without being bogged down in sophisticated mathematical details.

We consider duality to be the central underlying concept of linear programming and essential for a complete understanding of linear programming, transportation problems, quadratic programming, and game theory. Presenting the simplex tableau with the objective function in the last row—see Chapters 3 and 4—eases conversion to the study of dual problems by providing a convenient symmetry to the simplex tableaux of the primal and dual problems. Furthermore, this device not only makes the subsequent primal-dual formulation for quadratic programming more straightforward, but also simplifies the presentation of the simplex tableau for goal programming models. We consider this to be a pedagogical innovation.

Transportation problems and the closely related assignment problems are presented in Chapter 5. Heavily influenced by Koopmans' original contribution, the transportation algorithm is fully explained using duality and economic interpretation—considerations that are seldom presented in other management science or operations research textbooks.

Following a logical arrangement, with appropriate development from elementary to more complex operations, we introduce the chapters on integer programming, goal programming, quadratic programming and dynamic programming. Naturally, as in other management science or quantitative textbooks, the procedural operations and techniques of these topics require much calculation. Consequently, carefully formulated, step-by-step instructional sequences have been prepared to assist readers in grasping these basics. Here again, the underlying logic using economic reasoning is given. The broad scope of programming methods is completed by covering dynamic programming. This is followed by Chapter 10 where PERT techniques are introduced.

In Chapter 11, Bayesian decision theory and the basic concepts of probability theory lead into the treatment of decision-making models in Chapters 12 through 16. Chapter 11 offers careful treatment of Bayes' Theorem and of differences between the Bayesian and classical approaches. In Chapters 12 and 13, the inventory and queuing models demonstrate fundamental trade-off concepts. By placing these chapters in sequence, the textbook emphasizes the similarity of underlying economic concepts even in seemingly different operational problems. Basic simulation techniques are begun in Chapter 13 on queuing, and are then expanded in Chapter 14, which shifts away from queuing examples and provides a unique business decision-making model involving competing firms and sequential periods of decision making. The model can either be operated by hand calculations or be computerized. It is suitable for teams of students to use in competition with one another. This broad section of the textbook dealing with stochastic models is completed with chapters on game theory and Markov chains.

Among the indispensable tools of management science for business decision making, we feel that one must include forecasting techniques and an appropriate orientation to computer methodology. There is no doubt that realistic business situations require knowledge of these methods as part of the decision-making process, and treatment of these topics therefore has been presented in Chapters 17 and 18, respectively. These chapters, together with the chapters on goal programming and quadratic programming, offer a most comprehensive coverage of quantitative decision-making techniques.

As a final perspective, insights are presented in Chapter 19 into the

future opportunities and potentials in the field of management science for business decision making. Above all, an attempt has been made throughout all chapters to conform to a fundamental goal of this text—that it should be readable and teachable.

With regard to mathematical prerequisites, no calculus or matrix algebra is needed for using this text. Extensive exercises are presented at the end of each chapter. The overall purpose of these exercises is to reinforce the reader's understanding of the basic concepts of quantitative methods and to provide the reader with a *working* knowledge of the application of quantitative techniques. To achieve this purpose, all exercises were selected so that the need to do computations by hand should not intimidate students. Each chapter is also followed by a list of suggested readings.

Many persons have given us help in the preparation of this book. Our chief acknowledgment must go to our colleagues who have reviewed the entire manuscript and made helpful suggestions and comments that have led to substantial improvement. They are: Professor Nesa L. J. Wu of Eastern Michigan University, Professor Donald S. Miller of Emporia State University, Professor Stanley R. Schultz of Cleveland State University, and Professor Whewon Cho of Tennessee Technological University. We also extend our thanks to both Professors Howard A. Plotkin and Andrew J. Thacker, Jr., of the University of Houston, who evaluated several preliminary chapters of our manuscript in its early stages. Others who have provided valuable assistance are Dr. Andrew Hook of the New York Federal Reserve Bank, Professor T. C. Lee of the University of Connecticut, and Professors Yu-Chu Hsu and Frank E. Whelan of Southern Connecticut State College. To them we are indebted.

The unedited version of the manuscript has been used several times in both undergraduate and graduate classes at Southern Connecticut State College. Needless to say, we are extremely grateful to all students who have used these materials and helped improve them by their reactions.

J. C. H.
D. S. C.

8363951

CONTENTS



Preface xiii

Chapter 1 Introduction 1

- 1.1 Economizing Resources and Decision Making 1
- 1.2 Scientific Methodology 3
- 1.3 Management Science and Quantitative Methods 4
*Meaning of Management Science / Decision-Making
Models / Quantitative Methods and Management Science*
- 1.4 The Quantitative Approach and Business Applications:
 Illustrative Examples 8
*Breakeven Analysis / The Effect of Changes in Price and
Cost / Other Applications of Breakeven Analysis / Extensions of the
Breakeven Model*
- 1.5 Overview and Approach of this Book 18
Overview / The Economic Approach
- 1.6 Summary 20

Chapter 2 Linear Programming and Specific Types of Problems 28

- 2.1 Maximization: A Potato-Tomato Problem 29
*Equality Versus Inequality Relationships / The Feasible Region and
Feasible Solutions / The Optimal Solution / Multiple Optimal
Solutions*
- 2.2 Minimization: A Presidential Election Problem 36
- 2.3 A Transportation Problem 39
- 2.4 The Basic Assumptions and Economic Reasoning of Linear
 Programming 40
*Proportionality / Additivity / Divisibility / A Linear Objective
Function / Nonnegativity*
- 2.5 The General Formulation of Linear Programming
 Models 42

<i>The Sigma Notation / The General Form of Linear Programming Models / Converting an Inequality into an Equality / The Standard Form and the Mixed Form / Algebraic Manipulation of the Objective Function / A Note on Unrestricted Variables</i>	
2.6	Summary 48

Chapter 3 Linear Programming: The Simplex Method 59

3.1	The Simplex Method: A Preview 59
	<i>Corner Points, Slack Variables, and Basic Variables / Pivoting—Formulating a New Basis</i>
3.2	The Simplex Method 65
	<i>Step 1: Finding an Initial Basic Feasible Solution / Step 2: Choosing the Pivot Column / Step 3: Choosing the Pivot Row / Step 4: Forming a New Tableau—Pivoting</i>
3.3	Complications and Their Resolution 71
	<i>Equal Contribution to Profit / Degeneracy / Unbounded Optimal Solutions / Multiple Choice Optimal Solutions</i>
3.4	Minimization and Artificial Variables 77
	<i>The Big M Method—Elimination of Artificial Variables / The Simplex Method Again / The Two-Phase Method / The Generalized Two-Phase Model</i>
3.5	Summary 87

Chapter 4 Duality Theory: Resource Allocation and its Valuation 97

4.1	The Primal and the Dual Problem 97
4.2	Duality Theorems 102
	<i>Duality Theorem 1: The Fundamental Duality Theorem / Duality Theorem 2: The Equilibrium Theorem (Theorem of Complementary Slackness) / Finding the Dual Optimal Solution from the Primal Optimal Tableau / Complementary Slackness</i>
4.3	Economic Interpretation of the Dual 108
	<i>Interpretation of the Dual Constraints / Interpretation of the Dual Objective Function / Interpretation of the Dual Slack Variables / Interpretation of the Primal Slack Variables / Complementary Slackness and Its Economic Significance / Dual Interpretation of a Minimization Problem</i>
4.4	Sensitivity Analysis 113
	<i>A Change in Contribution in the Objective Function / Changes in Technological Coefficients / Changes in RHS Values / The Addition of a New Activity / Additional Considerations</i>
4.5	Summary 120

Chapter 5 The Transportation Problem and its Economic Interpretation 130

- 5.1 The Characteristics of Transportation Problems 131
Fundamental Characteristics / The General Case / Economic Interpretation
- 5.2 Transportation Problem Algorithms 134
The Transportation Table / The Northwest Corner Rule and the Stepping Stone Method / The Minimum Cost Search Method / Creating Balance / Coping with Degeneracy / The Mutually Preferred Method / The Vogel or Penalty Method / The Modified Distribution Method (MODI)
- 5.3 The Assignment Problem 157
The Nature of the Problem / The Hungarian Method of Assignment / A Flowchart
- 5.4 Summary 163

Chapter 6 Integer Programming 172

- 6.1 Integer Programming 172
- 6.2 Formulations of Integer Programming 174
Capital Budgeting: Indivisibility and Interdependence / Transportation Problem with Fixed Charges / Plant Location with Set Up Costs / Other Formulation Devices
- 6.3 Methods of Integer Programming Computation 186
Cutting-Plane Method / Dual Simplex Method / Branch-and-Bound Method
- 6.4 Summary 204

Chapter 7 Goal Programming 216

- 7.1 The Concepts of a Goal Programming Problem 217
The Single-Goal Model / The Simplex Method of Solution / Equally Ranked Goals
- 7.2 Examples of Multiple-Goal Programming Formulation 223
Priority-Ranked Goals / Back to the Potato-Tomato Problem / The General Format
- 7.3 Solving a Goal Programming Model 227
Graphical Analysis of Solution / The Modified Simplex Method of Solution
- 7.4 Summary 238

Chapter 8 Quadratic Programming 248

- 8.1 The LP Primal-Dual Model 249
- 8.2 The QP Primal-Dual Model 250
- 8.3 Comparisons Between the LP and QP Simplex Tableaux and an Economic Interpretation 253
Comparisons Between the LP and QP Simplex Tableaux / Economic Interpretation of the QP Tableau
- 8.4 Extension to More Complex Quadratic Problems 255
More Than One Quadratic Decision Variable / General Case
- 8.5 A Numerical Example 256
A Quadratic Problem in the Primal-Dual Model / The Simplex Solution
- 8.6 Summary 260

Chapter 9 Dynamic Programming 264

- 9.1 A Multi-Stage, Shortest Route Problem 265
Solving the Problem by the Backwards Process / The Dynamic Recursive Relationship / Computational Procedures / Principle of Optimality
- 9.2 A Dynamic Programming Approach to an Inventory-Production Problem 275
Dynamic Characterization / The Computational Process
- 9.3 The Dynamic Programming Approach to Other Resource Allocation Problems 283
Allocation of Auditors / A Cargo-Loading Problem / Product-Mix Problem
- 9.4 A Dynamic Programming Model with Two State Variables 296
- 9.5 Summary 298

Chapter 10 Project Planning and Control Using PERT/CPM 308

- 10.1 PERT/CPM: Basic Concepts 308
- 10.2 Project Portrayal—The Gantt Chart 311
- 10.3 The PERT Network 312
- 10.4 PERT-Time Analysis 318
- 10.5 PERT-Cost Extensions 322
- 10.6 Summary 329

Chapter 11 Bayesian Decision Theory and its Applications 336

- 11.1 Bayesian Versus Classical Decision Theory 336

11.2	Decision Criteria and the States of Nature	337
11.3	A Zero Back-Order, Zero Salvage Value Problem	339
	<i>Conditional Profits / Expected Profits</i>	
11.4	Expected Opportunity Loss	346
11.5	Expected Profit Under Certainty and EVPI	349
11.6	Revising Estimates of Prior Probabilities	351
	<i>Bayes Theorem / Applying Bayes Theorem</i>	
11.7	Bayesian Decision Theory and Revised Probabilities	354
11.8	Summary	356

Appendix to Chapter 11 Basic Probability Concepts and Distribution 362

11A.1	Measuring Probability	362
11A.2	Basic Concepts	362
	<i>A Posteriori Probabilities / A Priori Probabilities / Objective Versus Subjective Probabilities / Basic Axioms</i>	
11A.3	Probability Distributions	365
	<i>Random Variable / Uniform Distribution / The Bernoulli Process / Pascal's Triangle / The Binomial Distribution / The Poisson Distribution / The Normal Distribution / Probability Density Function Versus Cumulative Distribution Function</i>	

Chapter 12 Inventory Control Models 375

12.1	Economics of Inventory	375
	<i>Economic Motivations Relating to Inventory / Basic Characteristics of Inventory Situations and Models Notation</i>	
12.2	The Basic Deterministic Model	380
	<i>Determining the Economic Order Quantity / The Marginal Principle / Other Characteristics</i>	
12.3	A Deterministic Model with Periodic Stockouts	388
12.4	A Production-to-Inventory Model	393
12.5	A Model for Probabilistic Demand and Stockouts	401
12.6	Summary	408

Chapter 13 Queuing Models 414

13.1	Basic Queuing Models and Their Classification	415
13.2	The Theoretical-Statistical Approach	418
13.3	Application of the Theoretical-Statistical Model to a Typical Queuing Example	420

13.4	The Simulation Approach	422
13.5	Summary	428

Chapter 14 Simulation 435

14.1	The Applicability of Simulation Techniques	435
	<i>Advantages and Disadvantages / Computer Simulation / Basic System Characteristics</i>	
14.2	Simulation—The Process	438
	<i>Model Building</i>	
14.3	Demonstration of Techniques—Two Competing Firms	439
	<i>Conceptualization / Assumptions, Conditions, and Interrelationships / Inputs, Decisions, and Outcomes / Implementation</i>	
14.4	Summary	450

Chapter 15 Game Theory: Decision Making Under Conflict 456

15.1	Two Person, Zero-Sum Games	457
	<i>Union–Management Bargaining / Payoff Matrix</i>	
15.2	Pure Strategies: Games with Saddle Points	459
	<i>Maximin and Minimax Strategies / Saddle-Point Solution / Dominance</i>	
15.3	Mixed Strategies: Games Without Saddle Points	463
	<i>Mixed Strategies / Graphical Solution</i>	
15.4	Optimal Mixed Strategies Using Linear Programming	469
	<i>Transforming the Game into a Linear Programming Problem / The Simplex Solution / The Dual Linear Program of a Game and its Economic Interpretation / Conversion of Games into Linear Programming Problems</i>	
15.5	Limitations and Extensions	476
15.6	Summary	477

Chapter 16 Markov Processes 485

16.1	The Use of Markov Processes in Market Share Analysis	485
	<i>Markov Processes Applied to a Hypothetical Airline Situation / Transition Diagram and Probability Trees / Probability</i>	

<i>Calculations / Equilibrium or Steady-State</i>	
16.2	Extending the Example to Three Airlines 494
<i>Transition Matrix and Its Interpretation / Calculation of the Equilibrium or Steady-State Probabilities / Alternative Formulation of the Equilibrium or Steady-State Model</i>	
16.3	Altering Transition Probabilities Through Advertising 500
<i>A Cash Rebate Program / An Alternative Advertising Strategy / First-Order and Higher-Order Markov Processes</i>	
16.4	Summary 503

Chapter 17 Forecasting Techniques 510

17.1	Types of Forecasting 510
<i>Classical Versus Econometric Approaches / The Usefulness and Accuracy of Forecasting</i>	
17.2	Simple Forecasting Techniques 512
<i>Naive Models / Moving Averages / Ordinary Weighted Moving Averages / Exponentially Weighted Moving Averages / Moving Averages Summarized</i>	
17.3	Trend Analysis 530
<i>Typical Characteristics of Trend Data / Trend Lines, Computation, and Projection / Semilogarithmic Trends</i>	
17.4	Summary 542

Chapter 18 Computer Applications of Operations Research Techniques 553

18.1	Linear Programming Solutions by Interactive Computer Processing 554
<i>The Potato-Tomato Problem</i>	
18.2	Various Minimization Routines 559
<i>The Presidential Election Problem / Transportation and Assignment Problems</i>	
18.3	Batch Processing of Quantitative Decision Problems 564
<i>Simulation by Computer Using GPSS / PERT Analysis by Computer</i>	
18.4	Summary 568

Chapter 19 Quantitative Techniques—a Final Perspective 584

19.1	Opportunities in the Field of Quantitative Business Analysis 585
------	--

19.2	Management Science: The People and Their Approach	587
19.3	Management Information Systems	588
19.4	Summary	589

Appendix Selected Tables for Probability Analysis 591

A-1	Table of Random Numbers	592
A-2	Table of Values of the Binomial Distribution	593
A-3	Table of Values of the Poisson Distribution	602
A-4	Areas under the Standard Normal Distribution	604

Index 607

Introduction

Everyone must make decisions. How well these decisions are made affects the success of individuals, the performance of organizations, and ultimately the well-being of society. Many decision problems are deeply rooted in the economic problem of allocating scarce resources.

In recent years, the industrialized world has witnessed the rapid development of quantitative tools for solving increasingly complex management problems. The primary purpose of this book is to present and illustrate these quantitative analyses.

1.1 Economizing Resources and Decision Making

The fundamental problem of economics and business is the need to choose among alternative uses of scarce resources in order to achieve the greatest return from them. The key words are *scarce*, *alternative*, and *greatest*.

Scarcity means that resources are not free; any scarce resource has a price attached to it. If resources were free, there would be no economic problem—everyone would be able to obtain enough of everything to satisfy all wants. Although air may still be a free resource in such places as Alaska and Wyoming, it can no longer be considered free (at least not to society, which must pay for keeping it fit to breathe) in such cities as Pittsburgh and New York. The supply of all resources (including land, labor, capital, and managerial ability) is limited; we must use them efficiently to receive the optimal return from them.