

QUANTITATIVE APPROACHES TO BUSINESS DECISION MAKING

RICHARD M. BURTON

JOHN S. CHANDLER

H. PETER HOLZER

QUANTITATIVE APPROACHES TO BUSINESS DECISION MAKING

RICHARD M. BURTON

Duke University

JOHN S. CHANDLER

University of Illinois, Urbana

H. PETER HOLZER

University of Illinois, Urbana



HARPER & ROW, PUBLISHERS, New York
Cambridge, Philadelphia, San Francisco,
London, Mexico City, São Paulo, Singapore, Sydney

Material from the Certificate in Management Accounting Examinations, Copyright © 1977, 1978, 1979, 1980, and 1981 by the National Association of Accountants, is reprinted with permission.

Material from Uniform CPA Examination Questions and Unofficial Answers, Copyright © 1971, 1973, 1974, 1975, 1976, 1977, and 1978 by the American Institute of Certified Public Accountants, Inc., is reprinted with permission.

Sponsoring Editor: Jayne Maerker

Project Editor: Eleanor Castellano

Cover Design: 20/20 Services, Inc., Mark Berghash

Text Art: Fineline Illustrations, Inc.

Production: Willie Lane

Compositor: The Clarinda Company

Printer and Binder: R. R. Donnelley & Sons Company

Quantitative Approaches to Business Decision Making

Copyright © 1986 **Richard M. Burton, John S. Chandler, and H. Peter Holzer**

All rights reserved. Printed in the United States of America. No part of this book may be used or reproduced in any manner whatsoever without written permission, except in the case of brief quotations embodied in critical articles and reviews. For information address Harper & Row, Publishers, Inc., 10 East 53d Street, New York, NY 10022.

Library of Congress Cataloging in Publication Data

Burton, Richard M.

Quantitative approaches to business decision making.

Includes bibliographies and index.

1. Management science. I. Chandler, John S.

II. Holzer, H. Peter. III. Title.

HD30.25.B872 1986 658.4'03 85-915

ISBN 0-06-041086-8

85 86 87 88 9 8 7 6 5 4 3 2 1

Preface

The increasing use of quantitative methods by business makes it mandatory for today's business students to have a basic understanding of these modern tools of management and decision making. Such basic comprehension enables them to identify situations in which quantitative methods might usefully be applied, as well as to understand the information inputs required in using decision models. With the increasing availability of microcomputers and analytic software, managers have the opportunity to apply quantitative models to their decision situations. Thus, today's business student needs to be prepared for this decision-making environment.

Quantitative Approaches to Business Decision Making is designed to provide the student with an introduction to quantitative methods and the business problems to which they apply in a straightforward and understandable manner. Many of the students may not have extensive mathematical training, so the text presumes only an understanding of college algebra. An introductory statistics course is taken concurrently. Most of the material in this book was designed for and has been class-tested in an undergraduate course in quantitative methods.

The many business problems and examples in this book make the application of the quantitative methods more relevant for the student. Many of the problems and examples in this text are adapted from professional examinations, including those for the Certified Public Accountant (CPA), Certified Management Accountant (CMA), Certified Internal Auditor (CIA), and, in Canada, the Registered Industrial Accountant (RIA). A Solutions Manual is available with the text.

PEDAGOGICAL AIDS

Many different pedagogical techniques are presented here to aid both the instructor and the student. The main ones are:

1. Chapter outlines. Each chapter begins with a short topical outline to help the reader put the forthcoming topics into perspective.

2. Figures and tables. There is liberal use of visual presentation of data and techniques to facilitate learning.
3. Chapter summaries. Each chapter concludes with a brief synopsis of the main points of the chapter.
4. Content review questions. Each chapter has numerous short answer questions relating to the content of the current chapter.
5. Professional examination questions. Each chapter contains several more difficult problems that have been adapted from recent professional examinations, making this book an ideal vehicle for students preparing for the quantitative methods section of CPA, CMA, CIA, and RIA examinations.
6. Short case applications. More involved problems are presented throughout the text to provide the student with opportunities to apply their new knowledge in real-world settings.
7. Glossaries. Each chapter contains a glossary of the new concepts and terms that were introduced in that chapter.
8. Spreadsheet applications. Chapters 11 and 12 on simulation contain several problems that have been designed for solution on an electronic spreadsheet. Templates for these problems are included in the instructors manual.

CHAPTER SYNOPSES

The book begins with an introduction to quantitative methods and reviews important probability concepts in Chapters 1 and 2. The question and problem material of this section stresses business-related applications. Chapter 3 presents significant probability distributions and an introduction to decision theory.

Linear programming is first discussed in Chapter 4 with basic concepts being developed through graphical analysis. A unique feature is the early incorporation of shadow prices, sensitivity analysis, and the dual formulation of problems. The next two chapters cover the simplex method and the transportation model.

Chapters 7 and 8 describe inventory models, developing the economic order quantity model and the notions of stockouts, safety stock, and reorder points. Chapter 9 discusses project planning and control, using Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM). Chapter 10 deals with forecasting and cost estimation, employing various averaging techniques, regression analysis, and learning curves.

Simulation techniques are examined in Chapter 11 through a simple pro forma financial accounting model with a step-by-step increase in sophistication. With the presentation of the familiar income statement and balance sheet model, the notions of state and transition variables are introduced, definitional and behavioral relationships

are developed, and probability distributions are incorporated. Applications to inventory management and waiting-line problems conclude this introductory chapter. The following chapter, "Corporate Modeling and Implementation," deals with some planning models that are widely used today.

Chapter 13 introduces dynamic programming concepts by presenting a number of illustrative examples. Chapter 14 discusses queuing theory, giving two simple applications with particular emphasis on the underlying assumptions. Chapter 15 covers Markov processes, using brand-switching and health-care examples as vehicles to present transition and steady-state probabilities and their application to decision making. A review of quantitative method applications in business, which appears in Chapter 16, isolates some of the major problems involved. It synthesizes the topics of previous chapters.

We gratefully acknowledge permission given by the Institute of Management Accounting of the National Association of Accountants, the Society of Management Accountants of Canada, and the American Institute of Certified Public Accountants for the use of their problems throughout the book. These problems are designated parenthetically as (SMA) or (CMA) when they occur in the text.

Richard M. Burton
John S. Chandler
H. Peter Holzer

Acknowledgments

We wish to thank many of our colleagues who have critically reviewed parts of the manuscript. We would like to give special acknowledgment for the assistance given by the reviewers listed below. Professor Song Kim deserves special credit for class testing some of the material. Several students have contributed greatly to the generation of problems and to the editing of textual content. They include Liz Bauer, Amy Kopko, Jody Johnson, and Chuck Westphal. For their invaluable assistance in preparing the manuscript we owe a great deal to Mrs. Kathleen Melton, Mrs. Norma Hubbard, and Mrs. Mary Lou Dunker.

Professor Gordon B. Harwood
Georgia State University
Atlanta, Georgia

Professor John C. Camillus
University of Pittsburgh
Pittsburgh, Pennsylvania

Professor Ted M. Smith
Temple University
Philadelphia, Pennsylvania

Professor Stanley Brooking
University of Southern Mississippi
Hattiesburg, Mississippi

Professor David Ashley
University of Missouri
Kansas City, Missouri

Professor Wayland P. Smith
Western Michigan University
Kalamazoo, Michigan

Mr. Douglas Vaughn
Sarasota, Florida

Professor William Ziemba
University of British Columbia
Vancouver, B.C., Canada

Professor Terry Dielman
Texas Christian University
Fort Worth, Texas

Professor Ed P. Winkofsky
Virginia Polytechnic Institute &
State University
Blacksburg, Virginia

Professor John A. Lawrence
California State University
Fullerton, California

Professor Song K. Kim
University of Illinois at Urbana-Champaign
Urbana, Illinois

Professor Donald R. Williams
North Texas State University
Denton, Texas

Dr. Frank G. Landram
West Texas State University
Canyon, Texas

Contents

Preface xiii

Acknowledgments xvii

I INTRODUCTION TO QUANTITATIVE METHODS I

- 1.1 **Perspective on Quantitative Methods** 2
 - History and Development of Quantitative Methods 2
 - Objectives of Quantitative Methods 3
- 1.2 **Analysis with Models** 4
 - Simulation Models and Heuristic Models 5
 - More About Mathematical Models 6
- 1.3 **Summary** 8
 - Glossary 9
 - Problems 9

2 SURVEY OF PROBABILITY CONCEPTS II

- 2.1 **Basic Foundation of Probability** 12
 - Introduction 12
 - Definition of Probability 13
 - Events 13
 - Objective and Subjective Probabilities 14
 - Probability Notation and Rules 15
 - Addition of Mutually Exclusive Events 15
 - Independent Events 17
 - Dependent Events 18
 - Conditional, Marginal, and Joint Probabilities 20
- 2.2 **Analysis of Probabilistic Situations** 20
 - Probability Tree Diagrams and Joint Probability Tables 20
 - The Revision of Probabilities and Bayes' Theorem 23

- 2.3 **Business Decisions Under Uncertainty** 26
 - Conditional Profits and Opportunity Losses 26
 - Expected Profits 28
 - Expected Profits with Perfect Information 31
 - Expected Profits with Imperfect Information 33
- 2.4 **Summary** 39
 - Glossary 39
 - Problems 40
 - References 55

3 PROBABILITY DISTRIBUTIONS AND DECISION THEORY 57

- 3.1 **Introduction to Probability Distributions** 58
 - Introduction 58
 - Random Variables and Probability Distributions 58
 - Expected Value 59
 - The Variance 60
 - Discrete and Continuous Distributions 61
- 3.2 **Specific Probability Distributions and Their Use** 63
 - The Binomial Distribution 63
 - The Normal Distribution 67
- 3.3 **Decision Theory** 72
 - Different Decision Criteria 73
 - Utility and Decisions 77
 - Measuring Utility 79
- 3.4 **Summary** 85
 - Glossary 85
 - Problems 86
 - References 96

4 LINEAR PROGRAMMING—A GRAPHICAL APPROACH 97

- 4.1 **Perspective** 98
- 4.2 **A Problem To Be Solved** 98
- 4.3 **Setting up the Graphical Approach** 100
 - The Constraints: Feasibility 103
 - The Objective Function: Optimality 105
- 4.4 **The Graphical Solution** 107

4.5	Variations	110
4.6	Marginal Values at the Optimal Solution	114
	Marginal Value of Another Unit of Machining	115
	Marginal Value of Another Unit of Assembling	116
4.7	The Dual Formulation	117
	The Dual Problem	117
	Solution to the Dual	118
4.8	A Comprehensive Problem	121
4.9	Summary	125
	Glossary	125
	Problems	126
	References	145

5 LINEAR PROGRAMMING—THE SIMPLEX METHOD 147

5.1	Introduction	148
5.2	The Simplex Method	149
	Standard Form	149
	The Initial Tableau—Step 0	150
	Can We Do Better?—Is It Profitable to Produce Different Products?—Step 1	153
	Choosing Which Product to Produce—Step 2	154
	How Much Can We Produce?—Step 3	155
	How Much of Other Products to Produce—Step 4	156
	What Are the New Technological Rates of Substitution?—Step 5	157
	Can We Do Better?—Step 6	159
5.3	The Second Iteration	159
5.4	The Third Iteration	161
5.5	The Optimal Solution—Primal and Dual	163
5.6	Variations	164
	Unbounded Solutions	165
	Degenerate Solutions	166
	Multiple Optimal Solutions	168
5.7	Extensions	169
	Artificial Variables	169
	Surplus Variables	169
	Minimization	171
5.8	Sensitivity Analysis and the Limits of the Solution	171
	Changes in Profit Coefficients	172
	Changes in the Availability of Resources	174

5.9 Summary 177

Glossary 177

Problems 178

References 188

6 THE TRANSPORTATION MODEL 189

6.1 Introduction 190

A Transportation Problem 190

A Graphical Basis 192

6.2 A Simplex Approach 193

The Initial Tableau—The Northwest Corner Rule 194

The Initial Tableau—Vogel's Approximation Method 195

Can We Do Better?—The Simplex Criterion (Stepping-stone Method) 199

6.3 Dummy Distributors and Factories 206

6.4 A Special Situation: Degeneracy 207

6.5 Applications 209

6.6 The General Linear Programming Formulation of the Transportation Model 210

6.7 Summary 211

Glossary 211

Problems 212

References 215

7 INVENTORY MODELS WITH DETERMINISTIC DEMAND 217

7.1 Introduction 218

7.2 Cycle Inventories—Economic Order Quantity (EOQ) Model 221

7.3 Data, Errors, and Sensitivity 226

7.4 Economic Production Lot Size Model 229

An Example 231

7.5 Quantity Discounts and the EOQ Model 232

7.6 Inventory Models with Stockouts and Backorders 234

7.7 Summary 238

Glossary 238

Problems 239

References 246

Appendix. Derivation of Optimal Order Size Q and Optimal Shortage V 247

8 INVENTORY MODELS WITH PROBABILISTIC DEMAND 249

- 8.1 Introduction 250**
- 8.2 When to Order: An Example 250**
- 8.3 Reorder Point and Safety Stock 251**
- 8.4 Optimal Levels of Safety Stock 254**
 - Assuming Independence Between Safety Stock and Order Quantity 254
 - Assuming Dependence of ROP and EOQ 258
- 8.5 Note on Normally Distributed Demand During Lead Time 263**
- 8.6 Safety Stock When Stockout Costs Are Unknown 265**
- 8.7 Constant Order Cycle Systems and Periodic Review Systems 267**
- 8.8 Some General Remarks 268**
- 8.9 ABC Inventory Systems 269**
- 8.10 Summary 271**
 - Glossary 271
 - Problems 272
 - References 280
 - Appendix. Derivation of Optimal Q and ROP Under Uncertainty (shortages backordered) 280

9 PROJECT SCHEDULING AND CONTROL USING CPM AND PERT 283

- 9.1 Introduction 284**
- 9.2 The Project Structure 285**
 - An Example: Test Marketing of New Products 285
- 9.3 The Project Network 286**
- 9.4 A Dummy Task 289**
- 9.5 PERT 290**
- 9.6 PERT/Cost 293**
- 9.7 CPM with Limited Resources 297**
 - Limited Resources Approach 297
- 9.8 A Comprehensive Example for CPM with Limited Resources 299**
- 9.9 Summary 302**
 - Glossary 303
 - Problems 303
 - References 314

10 FORECASTING AND COST ESTIMATION 315

10.1 Introduction 316

10.2 Extrapolations of Historical Observations (Time Series) 316

The Simple Average 318

The Moving Average 318

The Weighted Average 319

Exponential Smoothing 320

Estimation of Linear Trends 324

10.3 Prediction Models 326

Regression Analysis 327

Coefficient of Determination 331

Testing the Significance of the Regression Coefficient 334

Confidence Intervals for the Regression Coefficient b 335

Confidence Intervals for the Expected Value of y' 336

10.4 Multiple Regression 337

10.5 Learning Curves and Cost Estimation 339

10.6 Summary 343

Glossary 344

Problems 345

References 358

Appendix. Development of the Normal Equations from Least Squares 359

11 INTRODUCTION TO SIMULATION 361

11.1 Introduction 362

11.2 An Accounting Model: A Deterministic Simulation 363

Concepts and Issues in Simulation 364

Validation of the Model 365

Expanding the Basic Model 366

11.3 Monte Carlo Simulation 370

Using a Random Number Table 371

Sampling and Inference 374

Confidence Intervals 374

Hypothesis Testing 375

The Sample Size: How Many Trials to Perform 375

11.4 Simulation of Analytic Models 377

An Inventory Application 377

Variations on the Inventory Model 378

A Queuing Application 380

11.5 Summary 383

Glossary 384

Problems 385

References 392

12 SIMULATION: CORPORATE MODELING AND IMPLEMENTATION 395**12.1 Introduction 396****12.2 Steps in Corporate Simulation Modeling 397**

Creating the Data Base 397

Constructing the Corporate Model 397

Using the Model for Managerial Reports 399

12.3 An Example of a Corporate Model 399**12.4 Expanding the Corporate Model: Cash Flow 400****12.5 What Are "What If?" Questions? 401****12.6 The "What If?" Response Matrix 403****12.7 Corporate Modeling on Spreadsheets 404****12.8 The Combination of Simulation and Optimization Techniques 405**

Optimization as an Idea Generator for Simulation 405

Optimization as a Submodel in the Larger Simulation Model 406

12.9 Reviewing the Simulation Technique 406**12.10 Summary 409**

Glossary 409

Problems 409

References 418

13 DYNAMIC PROGRAMMING 421**13.1 Introduction 422****13.2 Stages and State Variables 422****13.3 The Shortest-route Problem 423****13.4 An Investment Problem 426****13.5 A Purchasing Problem 432****13.6 A Production Planning Problem 433**

Stage I 435

Stage II 435

13.7 Summary 439

Glossary 439

Problems 440

References 445

14 QUEUING THEORY 447

14.1 Introduction 448

14.2 Waiting-line Systems 449

The Population 450

The Waiting Line 451

The Service Facility 451

Served Units 452

Steady-state Versus Transient-stage Operating Characteristics 453

Definitions and Notations of Operating Characteristics 453

14.3 The Single-channel Model 454

14.4 Multiple-channel Waiting Lines 460

14.5 Other Queuing Models 463

14.6 Summary 463

Glossary 464

Problems 464

References 469

Appendix. The Poisson Process and Distributions; the Exponential Distribution
469

15 MARKOV PROCESSES 473

15.1 Introduction 474

15.2 Two Examples 474

A Brand-switching Model 474

A Health-planning Model 477

15.3 Markov Process Concepts and Terms 478

Calculating Steady-state Probabilities 479

An Intuitive Meaning for Steady-state Probabilities 480

15.4 Decision Making and Markov Processes 482

Brand Switching: An Advertising Decision 482

Health Planning: A Public-sector Decision 483

15.5 Summary 485

Glossary 485

Problems 485

References 490

16 ORGANIZATIONAL IMPLICATIONS FOR THE IMPLEMENTATION OF QUANTITATIVE METHODS 493

16.1 Introduction 494

16.2 Extent of Practical Applications 494

16.3 Problems in Applying Quantitative Methods 497
Interaction Between Model Builder and Managers 497

16.4 Difficulty of Demonstrating a Satisfactory Cost/Benefit Relation 497

16.5 Difficulty in Obtaining Information Needed as Inputs for Quantitative Models 498

16.6 The Bottom Line 499

16.7 Summary 500
References 501

APPENDIX A: A REVIEW OF DIFFERENTIAL CALCULUS 503

APPENDIX B: A REVIEW OF MATRIX ALGEBRA 509

APPENDIX C: TABLES 515

Table 1 Random Numbers 516

Table 2 The Standardized Normal Distribution Function, $F_N(Z)$ 517

Table 3 Student's t-Distribution 518

Table 4 Cumulative Binomial Distribution $P(R \geq r, n, p)$ 519

Table 5 Unit Normal Linear Loss Integral 536

Course Outlines 538

Index 539