

# 供应链建模

[美] 杰里米·夏皮罗 著 麻省理工学院斯隆管理学院

Modeling the Supply Chain



THOMSON LEARNING  
DUXBURY

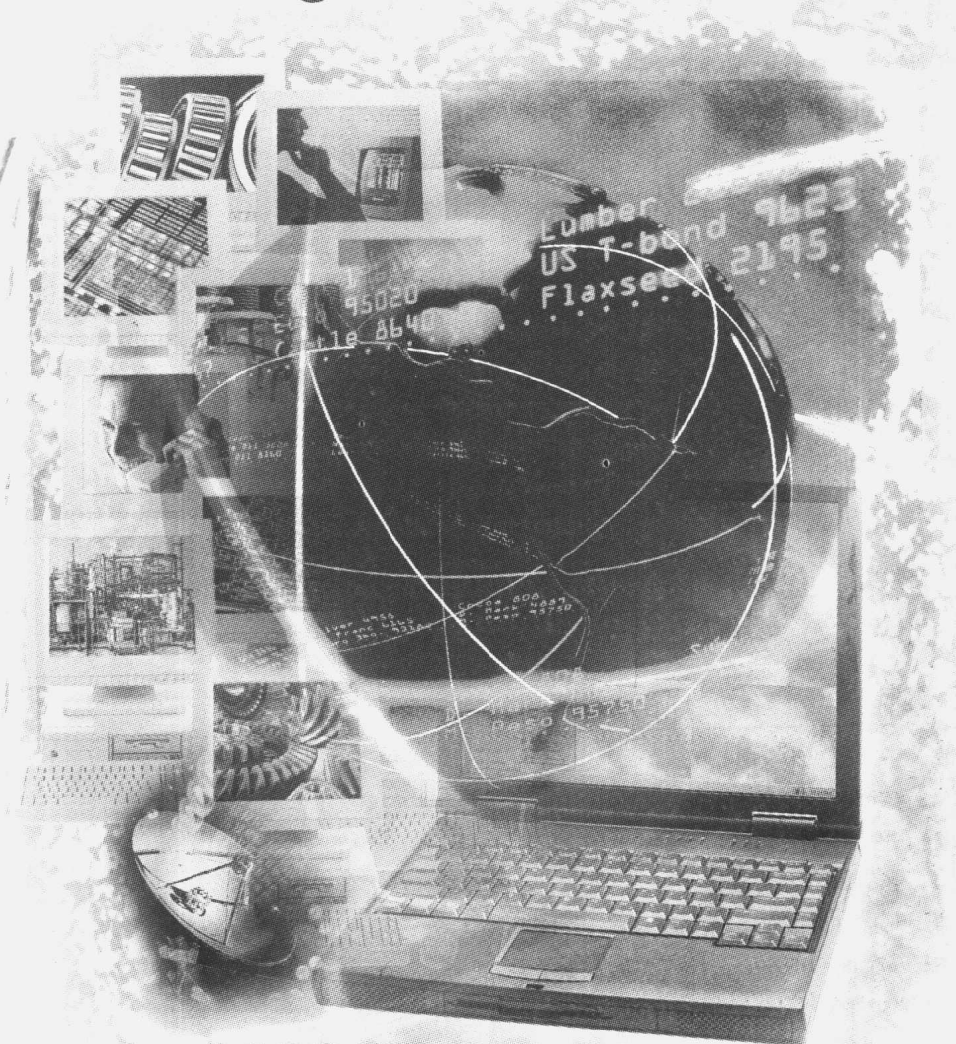


中信出版社  
CITIC PUBLISHING HOUSE

# 供 应 链 建 模

[美] 杰里米·夏皮罗 著 麻省理工学院斯隆管理学院

Modeling the Supply Chain



THOMSON LEARNING  
DUXBURY

中 信 出 版 社  
CITIC PUBLISHING HOUSE

## 图书在版编目 ( CIP ) 数据

供应链建模/ (美) 杰里米·夏皮罗著. —北京: 中信出版社, 2001  
ISBN 7-80073-370-X

I. 供… II. 夏… III. 供销 - 企业管理 - 研究 - 英文 IV. F274

中国版本图书馆CIP数据核字 ( 2001 ) 第070798号

Modeling the Supply Chain ( 0-534-37363-1 )

COPYRIGHT©2001 Wadsworth Group.Duxbury is an imprint of the Wadsworth Group, a division of  
Thomson Learning Inc.Thomson Learning™ is a trademark used herein under license.

All rights reserved.

Reprint ISBN 981-240-759-6

本书由中信出版社与汤姆森学习集团合作出版, 未经出版者书面许可, 本书的任何部分不得以任何形式复制或抄袭。

## 供应链建模

---

著 者: (美) 杰里米·夏皮罗

责任编辑: 李宝琳 责任监制: 朱 磊 王祖力

出 版 者: 中信出版社 ( 北京市朝阳区新源南路6号京城大厦 邮编100004 )

经 销 者: 中信联合发行有限公司

承 印 者: 北京忠信诚印刷厂

开 本: 787mm × 1092mm 1/16 印 张: 38 字 数: 730千字

版 次: 2002年5月第1版 印 次: 2002年5月第1次印刷

京权图字: 01-2001-4074

书 号: ISBN 7-80073-370-X / F · 279

定 价: 65.00元

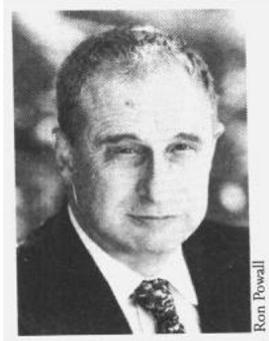
---

## 版权所有·侵权必究

凡购本社图书, 如有缺页、倒页、脱页, 由发行公司负责退换, 服务热线: 010-64648783

*To Martha*

## About the Author

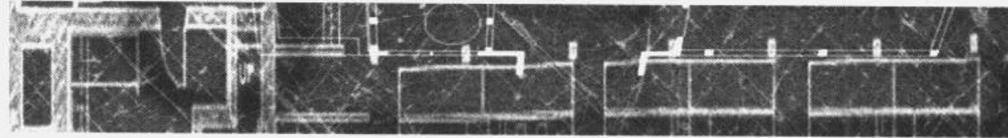


Jeremy Shapiro is professor of operations research and management in the Sloan School of Management at MIT. For 9 years he served as co-director of MIT's Operations Research Center. Previously, he was employed by Procter and Gamble, Hughes Aircraft Company, and the Port of New York Authority. He received B.M.E. and M.I.E. degrees from Cornell and a Ph.D. degree in Operations Research from Stanford. While an undergraduate at Cornell, he studied for 1 year at the University of Paris.

Dr. Shapiro has published over 50 papers in the areas of operations research, mathematical programming, logistics, supply chain management, finance, and marketing and is the author of *Mathematical Programming: Structures and Algorithms*, published by John Wiley in 1979. He is also president of SLIM Technologies, LLC, a Boston-based firm specializing in the implementation and application of modeling systems for supply chain management and other business problems. Outside interests include reading, traveling, biking, and playing tennis. He is married to Martha J. Heigham and has three children, Alexander, Lara, and Nicholas.



## Preface



When I began writing this book 8 years ago, I was motivated by my consulting experiences applying mathematical programming (that is, optimization methods) to business planning problems. These experiences convinced me that data-driven models can and should play a central role in helping managers make decisions. As I waxed and waned in my efforts to articulate arguments supporting this viewpoint, developments in the business world and information technology put the issue in much sharper focus. These include:

- the emergence of supply chain management as a important concept underlying the strategy and operations of virtually all firms that manufacture and/or distribute products
- greater globalization in many companies of their supply chain activities
- the torrid pace of improvements and innovations in information technology, which make supply chain management possible and necessary—including faster computers, more flexible software for implementing interfaces and managing data, and the advent of enterprise resource planning systems and e-commerce
- the realization by managers that they must adapt their organizations to fully exploit information technology

As a result of these developments, many more managers today are actively seeking analytical tools to assist them in making effective supply chain decisions. Thus, the book's goal became to explain how models can be effectively constructed and applied to supply chain planning problems, rather than to argue why models must be considered for such purposes.

Although my studies and writing are still chasing the developments just cited, it is not premature to posit principles for exploiting data, models and modeling systems. In an era of dynamic change, such principles are needed to help managers identify coherent, long-term plans for acquiring systems and implementing processes that

support data-driven decision making in their companies. Firms that succeed in such efforts will realize significant competitive advantage.

## **Harmonizing Qualitative and Quantitative Analysis**

A story is told in Cambridge, Massachusetts:

A young man, obviously a college student, is unloading his purchases at a supermarket checkout counter. A large sign above the counter indicates that it is for customers with eight items or less, but the young man has at least twenty. The clerk tells him, "You either go to MIT and you can't read, or you go to Harvard and you can't count."

The relevance of this story is: Managers and analysts need both qualitative (verbal) and quantitative (numerate) skills to achieve superior supply chain performance. On one hand, qualitative discussions about the importance of integrating decision making across the supply chain must be realized as new data collection and modeling systems and new decision processes if they are to have an impact. Conversely, despite the potential of modeling systems to reduce costs or increase profits, managers will be reluctant to use them if they have little understanding of how their decision problems are represented as models. Moreover, unless managers and analysts are given a vocabulary for describing insights into the qualitative goals of the company that models provide, modeling activities will be treated as sideshows of little importance.

Harmonization of qualitative and quantitative perspectives is also a central issue when we merge concepts from diverse management disciplines when constructing supply chain models. As we shall see, the following disciplines contribute important elements to such constructions: strategy formation, the theory of industrial organizations, operations management, logistics, transportation science, and managerial accounting. Furthermore, supply chain decisions should be integrated with marketing and financial decisions, especially when evaluating strategic plans. Quantitative models of marketing science and corporate finance, as well as qualitative concepts from these disciplines, can be used in extending supply chain models to the study of strategic planning questions from an enterprise-wide perspective.

Finally, research by organizational behaviorists into how individuals and companies actually make decisions helps managers and modeling practitioners understand the nature of barriers to fact-based decision making. These insights provide a good background for designing and implementing new business processes that overcome such barriers. In so doing, companies will better harness advances in information technology to achieve sustainable competitive advantage from the management of their supply chains.

Thus, an important goal of this book is to furnish students, managers, and analysts with discussions and examples that harmonize qualitative and quantitative thinking about supply chain planning problems and models. In so doing, we also attempt to integrate concepts and constructions from the disciplines discussed in the preceding paragraphs. Our approach relies heavily on optimization models, which provide frames or templates for such integration. Viewed another way, we will

attempt to demonstrate that optimization models and methods provide comprehensive systems analysis approaches to integrated business planning, which is the essence of supply chain management.

## **Intended Audiences**

The intended audiences for the book are as follows:

- managers who seek models and modeling systems to help them make better supply chain decisions
- information technologists who are responsible for developing and maintaining such systems, and for integrating them with enterprise resource planning and e-commerce systems
- consultants who conduct supply chain studies using models
- students who will become supply chain managers, information technologists or consultants

In other words, we intend the book to serve the needs of both initial and continuing education in the use of data and models to support supply chain decision making.

The initial objective of the book was to produce a guide for supply chain managers seeking modeling systems. In developing material supporting the merits of operations research models and methods, I examined papers and books written by academics and practitioners in the fields mentioned earlier that were concerned with issues of data, analysis, the role of information technology, and business process redesign in supporting managerial decision making. It seemed worthwhile to extend the book's scope to incorporate convergent ideas from these diverse disciplines. By adding such discussions, plus numerical examples and exercises, I believe I have created a textbook suitable for management students who wish to be educated about the form and function of practical analytical tools for supply chain management.

## **Overview of Content**

The book is divided into four sections as follows:

Part I—Introduction to Supply Chain Management

Part II—Modeling and Solution Methods

Part III—Applications

Part IV—The Future

Part I, which comprises Chapters 1 and 2, discusses motivations for using models to analyze supply chain problems. Particular attention is paid to developments in information technology that have spawned an interest in and a need for integrated supply chain modeling and management. Part I also examines a hierarchy of linked



supply chain modeling systems to support operational, tactical and strategic decision making.

Part II, which comprises Chapters 3, 4, 5, and 6, provides details of linear and mixed integer programming models for optimizing supply chain decisions. The discussion includes small examples of models for production, transportation, and inventory planning problems. Part II also explains algorithmic methods for solving these models and their economic interpretation, and provides illustrations of spreadsheet optimization formulations. Chapter 5 is devoted to the presentation of a unified optimization methodology for combining heuristic methods with mixed integer programming models to analyze operational planning problems. Finally, Chapter 6 examines in detail the supply chain decision database from which optimization models are generated.

Part III, which comprises Chapters 7, 8, 9, 10, and 11, discusses applications of modeling systems to strategic, tactical, and operational supply chain problems. Strategic and tactical planning models are examined in Chapters 7 and 8. The emphasis in Chapter 7 is on state-of-the-art applications in manufacturing and logistics. The chapter includes the presentation of several applications. It also includes a discussion of resource acquisition and allocation planning from the perspective of the resource-based view of the firm, a new paradigm for strategic planning.

The emphasis in Chapter 8 is on innovative applications to strategic and tactical planning of a supply chain. These are applications that may be beyond the current state-of-the-art, but have potential for practical applications in the future. Included are modeling approaches for integrating supply chain and demand management, for evaluating price competition among firms in an industry, and for explicit analysis of decision making under uncertainty using stochastic programming.

Chapter 9 presents modeling approaches for optimizing corporate financial planning decisions and for integrating them with models for optimizing supply chain decisions. This chapter also discusses integrated models for planning in multinational corporations that allow managers to blend decisions involving financial flows with those involving physical flows. The goal is to maximize after-tax profits that are repatriated to the parent company, subject to constraints on the performance of partially or wholly owned foreign subsidiaries.

Modeling systems for operational planning are examined in Chapter 10, including in-depth reviews of a vehicle routing system for an e-commerce company and a production planning and scheduling system for a semi-conductor company. The chapter also contains brief discussions of several other modeling applications to operational problems arising in production scheduling, vehicle routing and human resources planning.

Inventory management applications, which span all levels of planning, are discussed in Chapter 11. The chapter begins with a review of classical inventory theory, which is particularly appropriate for operational inventory decision making. We then examine methods for integrating inventory theory with optimization models for strategic and tactical supply chain planning. The chapter also includes several applications of models to inventory management in high tech and electronics firms.

Finally, Part IV, which consists of Chapter 12, discusses human and organizational issues surrounding a firm's efforts to exploit data and modeling systems when

improving its supply chain management. The chapter discusses at length the conflict between a firm's desire to achieve fact-based supply chain management and the ecology of decision making that conspires to work against it. The chapter contains suggestions about business process re-design to meet the goals of fact-based decision making while overcoming organizational barriers. It also discusses factors that influence the role played by IT in providing the firm with superior supply chain management. The chapter and the book conclude with a forecast of developments in supply chain management over the next 10 years.

## Exercises and Website

Except for Chapter 1, the printed book contains exercises at the end of every chapter. Some are modeling exercises while others are discussion questions. In addition, the book's Web site ([www.scm-models.com](http://www.scm-models.com)) contains modeling exercises involving data files and discussion questions involving white papers. The Web site also contains hotlinks to other Web sites, organized by sections and chapters where they are relevant. The Web site is also accessible through [www.duxbury.com](http://www.duxbury.com).

## Acknowledgments

My thinking and writing were influenced by that of many other academics and practitioners in supply chain modeling and related fields. In supply chain management, I would like to thank the following individuals for helpful ideas, models, and case studies: Corey Billington, Gabriel Bitran, Morris Cohen, Bill Copacino, Marshall Fisher, Arthur Geoffrion, Stephen Graves, Paul Kleindorfer, Rob Leachman, Hau Lee, Steve Klimczak, Mike Magazine, Tim Magee, Joyce Mehring, Kevin O'Laughlin, Don Rosenfield, Sridhar Tayur, Harvey Wagner, and Sean Willems. In other fields that I perused for insights into supply chain management and modeling, I would like to thank the following individuals: Jay Barney, Frank Bass, William Carleton, Arnaldo Hax, Robert Kaplan, Peter Keen, Donald Lessard, Gary Lilien, John D. C. Little, James March, Margaret Peteraf, Michael Porter, and Paul Schoemaker. I would also like to thank Linus Schrage and Wayne Winston for their interesting and comprehensive books on operations research modeling, which I found especially helpful in developing modeling examples and exercises.

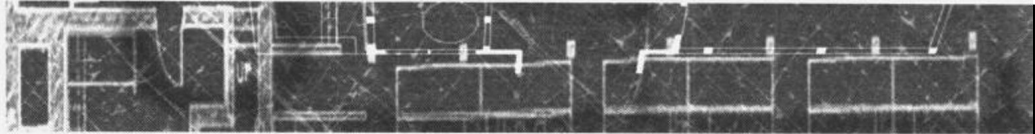
For over 10 years, Vijay Singhal, Steve Wagner, and I have worked on many edifying and sometimes stressful consulting and modeling system development projects. My understanding of supply chain modeling, such as it is, is due in large part to these experiences. More recent experiences of a similar nature working with Kevin Jacobs, Francisco Jauffred, and Dan Sobbott have helped me crawl further up the never ending learning curve associated with putting theory into practice. Interactions with Fred Shepardson contributed significantly to my understanding of the practical aspects of modeling; he also provided valuable feedback on drafts of several chapters. John Bossert's careful reading of the final draft was also very helpful. Finally, Joan and Dexter Wingo displayed great skill and patience over the years in preparing the many drafts of this book.

The following reviewers provided helpful feedback on drafts of the manuscript: Hemant K. Bhargava, Pennsylvania State University; Armann Ingolfsson, University of Alberta; M. Eric Johnson, Vanderbilt University; Jerrold H. May, University of Pittsburgh; Sridhar Seshadri, New York University; Asoo J. Vakharia, University of Florida; and Wayne Winston, Indiana University.

Curt Hinrichs, my editor at Duxbury, provided unwavering enthusiasm for this project and, on several occasions, gently pushed me in valuable directions. Thanks are due to Sue Ewing of Duxbury for negotiating the scores of permissions needed to incorporate materials from other books and journals. Other individuals at Duxbury and in their production network were instrumental in transforming the manuscript to its final form: Tessa Avila and Melanie Field managed the overall production process; Nancy Young edited the manuscript; and Bill Turner created the production pages. Finally, thanks are due to Ankur Rohatgi and his colleagues at Cranomedia for developing the Web site.

*Jeremy Shapiro*

# Contents



## PART ONE Introduction to Supply Chain Management 1

# 1

## Supply Chain Management, Integrated Planning, and Models 3

- 1.1 Fundamentals of Supply Chain Management 5
  - Supply Chain Networks* 6
  - Integrated Supply Chain Planning* 7
  - Objectives of Supply Chain Management* 8
- 1.2 Overview of Supply Chain Models and Modeling Systems 10
- 1.3 Supply Chain Modeling Incorporates Concepts from Several Management Disciplines 12
  - Strategy Formation and the Theory of the Firm* 13
  - Logistics, Production, and Inventory Management* 17
  - Management Accounting* 19
  - Demand Forecasting and Marketing Science* 20
  - Operations Research* 22
- 1.4 Innovations in Information Technology Require and Support Supply Chain Modeling 23
- 1.5 Organizational Adaptation to Integrated Supply Chain Management and Modeling 25
- Notes 26
- References 27

## 2

### Information Technology 29

- 2.1 Developments in Enterprise Resource Planning Systems and E-Commerce 30
  - ERP Systems* 31
  - E-Commerce* 32
- 2.2 Comparison of Transactional IT and Analytical IT 36
  - Time Frame Addressed* 37
  - Purpose* 37
  - Business Scope* 37
  - Nature of Databases* 38
  - Response Time for Queries* 39
  - Implications for Business Process Redesign* 40
- 2.3 Hierarchy of Supply Chain Systems 40
  - Components of the Supply Chain System Hierarchy* 40
  - Frequency of Analysis, Cycle Times, and Run Times of Supply Chain Systems* 46
  - Communication Among Supply Chain Systems of Data and Decisions* 46
  - Balancing Centralized and Decentralized Decision Making* 53
- 2.4 Legacy Systems and Legacy Thinking 53
- 2.5 Final Thoughts 55
- Exercises 56
- Notes 57
- References 59

## PART TWO Modeling and Solution Methods 61

## 3

### Fundamentals of Optimization Models: Linear Programming 63

- 3.1 Linear Programming Modeling Examples 64
  - Resource Allocation Model* 65
  - Infeasible and Unbounded Models* 69

<i>Spreadsheet Optimization</i>	70
<i>Multiperiod Resource Allocation Model</i>	72
<i>Network Models</i>	78
3.2 Properties of Linear Programming Models	84
<i>Linearity</i>	85
<i>Separability and Additivity</i>	89
<i>Indivisibility and Continuity</i>	89
<i>Single Objective Function</i>	90
<i>Data Known with Certainty</i>	90
3.3 Interpreting an Optimal Linear Programming Solution	91
<i>Shadow Prices</i>	92
<i>Reduced Cost Coefficients</i>	94
<i>Dual Linear Programming Model</i>	96
<i>Parametric and Sensitivity Analysis</i>	98
3.4 Multiple Objective Optimization	101
3.5 Stochastic Programming	104
<i>Generalizations</i>	109
3.6 Final Thoughts	109
Exercises	110
Notes	113
References	114
Appendix 3.A The Simplex Method of Linear Programming	115

## 4

### **Fundamentals of Optimization Models: Mixed Integer Programming 125**

4.1 Mixed Integer Programming Modeling Vignettes	126
<i>Fixed Costs</i>	127
<i>Economies of Scale</i>	130
<i>Production Changeovers</i>	131
<i>Multiple Choice and Other Nonnumeric Constraints</i>	132
4.2 Distribution Center Location Models	133
<i>DC Location Model</i>	134
<i>Generalizations</i>	138
4.3 Supply Chain Network Optimization Models	139
<i>Strategic Planning at Ajax</i>	139
<i>Generalizations</i>	151



4.4	Designing and Implementing Optimization Modeling Systems for Strategic and Tactical Planning	151
	<i>System Design</i>	152
	<i>System Implementation</i>	154
4.5	Optimization Software	158
	<i>Optimizers</i>	159
	<i>Algebraic Modeling Language Development Kits</i>	161
	<i>Spreadsheet Optimizers</i>	163
4.6	Final Thoughts	163
	Exercises	164
	Notes	166
	References	167
	Appendix 4.A The Branch-and-Bound Method for Mixed Integer Programming	169

## 5

### **Unified Optimization Methodology for Operational Planning Problems 177**

5.1	Heuristic Methods for Combinatorial Optimization Problems	179
	<i>Local Delivery Heuristics</i>	180
5.2	Overview of the Unified Optimization Methodology	188
	<i>Production Scheduling Example of Decomposition</i>	189
	<i>Unified Optimization Methodology</i>	193
5.3	Unified Optimization Methodology Applied to Vehicle Routing	197
	<i>Statements of the Optimization Models</i>	198
	<i>Numerical Solution</i>	202
	<i>Generalizations</i>	205
5.4	Unified Optimization Methodology Applied to Production Scheduling	207
	<i>Company Background and Numerical Data</i>	207
	<i>Unified Optimization Methodology Specialized     to Goodstone's Production Scheduling Problem</i>	209
	<i>Production Scheduling Solution</i>	213
	<i>Generalizations</i>	218
5.5	Final Thoughts	218

Exercises	219
Notes	222
References	223

## 6

### Supply Chain Decision Databases 225

6.1	Data Aggregations	228
	<i>Aggregating Products</i>	229
	<i>Aggregating Customers and Markets</i>	231
	<i>Aggregating Suppliers</i>	232
6.2	Facility Data	232
	<i>Recipes, Processes, Resources, and Costs</i>	232
6.3	Transportation Network Data	237
	<i>Transportation Network Submodels</i>	237
	<i>Transportation Costs and Capacities</i>	240
	<i>Modal Choice and Shipment Sizes</i>	241
	<i>Utilities for Generating Networks</i>	242
6.4	Supplier Data	242
	<i>Vendor Costs and Constraints</i>	243
6.5	Role of Management Accounting	245
	<i>Develop Causal Cost Relationships of Direct and Indirect Costs</i>	247
	<i>Activity-Based Costing</i>	248
	<i>Connection of ABC to Optimization Models and the Taxonomy of Costs</i>	250
	<i>Computation of Transfer Prices, Product and Customer Costs from an Optimal Solution to a Supply Chain Model</i>	250
6.6	Demand Forecasting	257
	<i>Background</i>	257
	<i>Types of Forecasting Models</i>	258
	<i>Demand Data Specifications for Optimization Models</i>	260
	<i>Forecasting Software</i>	261
6.7	Global and Policy Data	261
6.8	Model Output Data	262
	<i>Management Reports of Output Data</i>	263
	<i>Shadow Prices and Reduced Costs</i>	264
	<i>Derived Output</i>	265

6.9	Connections Among Supply Chain Decision Databases	266
	<i>Scenarios</i>	267
	<i>Multiperiod Decision Databases</i>	268
	<i>Hierarchies</i>	269
6.10	Graphical Displays of Data Inputs and Outputs	270
6.11	Final Thoughts	271
	Exercises	273
	Notes	274
	References	275

## PART THREE APPLICATIONS 277

# 7

## **Strategic and Tactical Supply Chain Planning: State-of-the-Art Modeling Applications 279**

7.1	Resources and the Resource-Based View of the Firm	281
	<i>Taxonomy of Resources</i>	281
	<i>Summary of the Resource-Based View of the Firm</i>	282
	<i>Connections with Optimization Models</i>	283
7.2	Strategic Analysis of Logistics Supply Chains	286
	<i>A Framework for Logistics Strategy Formation</i>	286
	<i>Constructing an Optimization Model for Strategic Logistics Planning</i>	289
7.3	Redesigning the Distribution Network of an Electronics Products Company	292
7.4	Strategic Analysis of Manufacturing Supply Chains	294
	<i>A Framework for Manufacturing Strategy Formation</i>	294
	<i>Constructing an Optimization Model for Strategic Manufacturing Planning</i>	298
7.5	Two Manufacturing Strategy Applications	302
	<i>Worldwide Sourcing at Delta Industrial Chemicals</i>	303
	<i>Postmerger Consolidation of Consumer Paper Companies</i>	306
7.6	Tactical Planning	310
7.7	Two Tactical Planning Applications	312
	<i>Monthly Planning at an Industrial Gases Company</i>	312
	<i>Monthly Planning at a Beer Company</i>	315