PREFACE

Goals of This Book

The field of supply chain management arose from managers' recognition that buying, selling, manufacturing, assembling, warehousing, transporting, and delivering goods—that is, the activities of a supply chain—are expensive endeavors, and that careful attention to how these activities are carried out may reduce their cost. Supply chains used to be viewed, at least by some managers, as "necessary evils." As a result, the mindset for supply chain managers revolved around reducing costs, by reducing inventory levels, taking advantage of economies of scale in shipping, optimizing network designs, reducing volatility in demands, and so on. By and large, these improvements were invisible to companies' customers, provided that they did not result in longer lead times, more frequent stockouts, or other degraded service.

By the end of the last century, however, the purpose of the supply chain had begun to change as some firms discovered that supply chains could be a source of competitive advantage, rather than simply a cost driver. For example, Dell demonstrated that, through excellent supply chain management, it could deliver computers—fully customized to the buyer's specifications—just a few days after they were ordered. In doing so, it shattered the existing paradigm for computer purchases, in which consumers could choose from only a limited number of pre-configured options. Similarly, Walmart showed that, by operating an extremely high-volume supply chain, it could land products on shelves for less money per item. As a result, Walmart offered its customers a high level of product availability and low prices, and this combination ushered the company to its place as the world's largest retailer. Amazon.com built a supply chain that is not only quick and reliable, but also feature-rich, offering users varied shipping options, convenient tracking tools, and flexible return policies. This expansive supply chain has allowed Amazon to overcome consumers' desire for instant gratification and their preference for seeing and touching products before they buy them.

Just as the *practice* of supply chain management has come into its own, so, we would argue, has the *study* of supply chain management. In the past 30 years or so, a huge number of papers have been published that introduce mathematical models for evaluating, analyzing, and optimizing supply chains. Supply chain management became one of the most popular applications of operations research (OR), and one of its greatest success stories. But recently, the mathematical study of supply chains has begun to be viewed not simply as an application area for OR tools, but rather as a methodological area, capable of standing on its own two feet, with its own tools and theory. These tools are now themselves starting to be applied, not just to supply chains, but to health care, energy, finance, the service sector, and other industries.

We wrote this book to help codify the foundations of this emerging supply chain theory and to demonstrate how recent developments build upon the classical models. Our focus is primarily on the seminal models and algorithms of supply chain theory—the building blocks that underlie much of the supply chain literature. We believe that an understanding of these models provides researchers with a sort of guidebook to the literature, as well as a toolbox to draw from when developing new models. We also discuss some more recent models that demonstrate how the classical models can be extended and applied in richer settings. These models provide graduate students and other new researchers in the field with some examples of the trajectory of research on supply chain theory—how the building blocks can be assembled to create something more complex, interesting, or useful.

Studying supply chain theory as a whole allows us the luxury of gaining some perspective on the field as a whole, a perspective that is not always evident when we immerse ourselves deeply in the literature on a particular topic. To that end, wherever possible, we have attempted to highlight the connections among supply chain models—for example, the conceptual similarities among different supply chain pooling models, the ways that inventory and location models can be combined, or the ways that inventory theory interacts with game theory to produce supply chain coordination models.

Who Should Read This Book

This book was written for anyone who is interested in mathematical approaches for studying supply chains. This includes people from a wide range of disciplines, such as industrial engineering/operations research, mathematics, management, economics, computer science, and finance. This also includes students (primarily graduate students), faculty, researchers, and practitioners of supply chain theory. And it includes scholars who are new to supply chain theory and want a gentle but rigorous introduction to it, or scholars who are well versed in the field and want a refresher or a reference for the seminal models. Finally, since you are holding this book, it most likely includes you.

One of the hallmarks—and, in our opinion, the great pleasures—of supply chain theory is that it makes use of a wide variety of the tools of operations research, mathematics, and computer science. In this book, you will find mathematical programming models (linear, integer, nonlinear, stochastic, robust), duality theory, optimization techniques (Lagrangian relaxation, column generation, dynamic programming, line search, plus optimization by calculus and finite differences), heuristics and approximations, probability, stochastic processes, game theory, simulation, and convexity theory.

To make use of this book, you need not be an expert in all of these. (We are not.) We assume that you are familiar with basic optimization theory—that you know how to formulate a linear program and its dual, that you know how branch and bound works, and that you can perform a simple line search method such as bisection search. We also assume that you understand probability distributions and know how to compute expectations of random variables and functions thereof. We assume that your calculus is in good working order, that you can compute derivatives and integrals, including ones that involve multiple variables or other derivatives or integrals. We assume you have met Markov chains before, but we don't require you to remember much about them. For just about everything else, we will start from the ground up and tell you (or remind you of) what you need to know in order to understand the topic at hand. For some topics, you will find a useful reference in Appendix C, which lists formulas for calculating expectations, loss functions, geometric series, and some tricky derivatives and integrals. Because Lagrangian relaxation plays a role in several chapters of this book, we have included a brief primer on that topic in Appendix D.

Probably the single most important prerequisite for this book is a high level of general mathematical maturity. We discuss a lot of mathematical proofs, and ask you to write your own in the homework problems. If you do not have much experience in this area, you may find the proofs to be the most challenging aspect of this book. To help you out, we have included in Appendix B a short guide to proof-writing. We hope this appendix will familiarize you with some of the basic principles of proof-writing, as well as some of the finer points of proof style and syntax. But, proof-writing is perhaps more art than science, and the appendix will only get you so far. You will learn to be a good proof-writer mainly by practicing the craft.

Organization of This Book

Our intention in writing this book was to cover a broad range of topics in supply chain theory, even if that meant that we could not cover some topics as deeply as we might have liked. Most of the material in this book is derived from earlier papers, and of course we have cited those papers carefully so that readers can delve deeper into any topics they wish. We have also cited important related references, and review articles where possible, so that readers can find more information about topics that interest them.

This book is, loosely speaking, organized into two sections. The first section (Chapters 2–9) covers *centralized* supply chain models, in which all of the decision variables are under the control of a single decision maker. Most classical supply chain models, such as those for optimizing inventories and facility locations, are centralized models. In contrast, the *decentralized* models of the second section (Chapters 10–12) involve multiple parties with independent, conflicting objectives and the autonomy to choose their decision variables to optimize those objectives. The bullwhip effect (Chapter 10) is an example of a result of this decentralization, while the models of Chapter 11 and 12 discuss strategies for mitigating the negative effects of decentralization.

This chapters of this book are as follows:

- Chapter 1 ("Introduction") gives an overview of supply chain management and defines terms that we will use throughout the book.

- Chapter 2 ("Forecasting and Demand Modeling") discusses classical forecasting methods as well as three approaches—the Bass diffusion model, leading indicators, and choice models—that have been used more recently to predict demand. We refer to these latter approaches as "demand modeling" to differentiate them from classical forecasting techniques and to emphasize the fact that they are also applied to problems outside of forecasting.

- We discuss classical single-location inventory models in Chapters 3 ("Deterministic Inventory Models") and 4 ("Stochastic Inventory Models"). For most of these models, we discuss how to formulate the objective function as well as how to optimize it—exactly or heuristically, in closed form or using algorithms—by our choice of inventory parameters. We also prove the optimality of base-stock and (s, S) policies for problems without and with (respectively) fixed costs.

- In Chapter 5 ("Multi-Echelon Inventory Models"), we discuss multi-echelon inventory models, including both stochastic-service models (including the Clark–Scarf model for serial systems and the Shang and Song approximation) and guaranteed-service models (also known as strategic safety stock placement problems).

- Chapter 6 ("Dealing with Uncertainty in Inventory Optimization") builds upon the classical inventory models by considering different types of uncertainty—in particular, supply uncertainty—and different ways to mitigate uncertainty within an inventory system other than simply holding more inventory.

- In Chapter 7 ("Facility Location Models"), we turn our attention to facility location models. We present the classical uncapacitated fixed-charge location problem (UFLP) in some detail, including its formulation as an integer programming problem and its solution by Lagrangian relaxation. We also discuss a multi-echelon location model that more accurately represents the complexity of today's supply chains.

- In Chapter 8 ("Dealing with Uncertainty in Facility Location"), we consider the ways in which uncertainty can be incorporated into facility location models. We discuss a model that incorporates inventory into the location decisions, models for stochastic and robust facility location, and a model for locating facilities under the threat of disruptions. We discuss formulations for these problems as well as solution methods (in most cases, Lagrangian relaxation).

- Chapter 9 ("Process Flexibility") discusses models for evaluating the benefit of manufacturing process flexibility and for optimizing the flexibility within manufacturing processes.

- In Chapter 10 ("The Bullwhip Effect") we discuss a phenomenon of demand variability amplification known as the bullwhip effect. The bullwhip effect can occur because of irrational or suboptimal behavior on the part of supply chain managers, but it can also occur as the result of rational, optimizing behavior. We cover mathematical models for proving that the bullwhip effect occurs as a result of the latter type.

- When supply chain partners each optimize their own objective functions, they typically arrive at solutions that are suboptimal from the point of view of the total supply chain. In Chapter 11 ("Supply Chain Contracts"), we discuss contracts that achieve coordination within a supply chain made up of individual players with differing objectives.

- Chapter 12 ("Auctions") introduces mathematical models for auctions, which are frequently used to set prices within supply chains.

- The book concludes with four appendices. Appendix A contains homework problems whose solutions use material from multiple chapters. Appendix B provides a short primer on how to write mathematical proofs. Appendix C lists helpful formulas that are used throughout the book. Appendix D gives a brief overview of Lagrangian relaxation.

The material in this book can accommodate a good deal of reordering and omission by the instructor. The only real exception is the inventory-theoretic material (Chapters 3–5), which is at the core of much of the subsequent material in the book and therefore should be covered early on, and in the order presented. However, not all of the material in the inventory chapters is used elsewhere, and much of it can be skipped if desired. A bare-bones treatment of the essential inventory topics would include Section 3.2 on the EOQ model, Section 4.3 on (r, Q) policies, and Section 4.4.2 on the newsvendor problem—and even this material could be omitted for students who are already familiar with it. In addition, the material on facility location under uncertainty (Chapter 8) relies on the chapter that precedes it. Other than these, there are no other precedence constraints regarding the sequence of material covered, and the instructor should feel free to rearrange the material according to his or her preferences, interests, and expertise, as well as those of the students.

Each of the chapters (except Chapter 1) is followed by a set of homework problems, and Appendix A presents problems that use material from multiple chapters. The problems challenge readers to understand, interpret, and extend the models and algorithms discussed in the text. Some of them involve simply applying the models and algorithms presented in the book as-is. Most of them, however, ask the reader to prove theorems, develop models, or somehow explore the material more deeply than it is covered in the chapters. Some of the problems require data sets that are too large to include in the text itself. These data sets are posted on the web site for this book at `http://coral.ie.lehigh.edu/~larry/sctheory`.

That web site also contains a list of errata. If you find errors not contained on this list, please e-mail them to `larry.snyder@lehigh.edu`.

An instructor's manual containing full solutions to the homework problems is available to professors. Please send requests for the instructor's manual on department letterhead, by mail, fax, or e-mail, to Jackie Palmieri, Assistant Editor, John Wiley & Sons, Inc., 111 River Street, MS 8-01, Hoboken, NJ 07030, USA, (201) 748-8888 (fax), `jpalmier@wiley.com`.

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Lawrence V. Snyder
Lehigh University

Zuo-Jun Max Shen
University of California, Berkeley

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